Substrate pH Impacts Efficacy of Ethephon Drenches on Growth of Herbaceous Perennials

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Abstract. Ethephon [(2-chloroethyl) phosphonic acid] is widely used as a growth regulator in floricultural crop production, with foliar sprays as the typical application method. Ethephon efficacy is determined by rate of uptake and subsequent ethylene evolution, which can be influenced by a number of factors, including solution pH. This study examines whether an ethephon substrate drench (100 mg·L⁻¹ at a volume of 296 mL per 2.8-L container) would allow for plant uptake in two herbaceous perennials, *Verbena bonariensis* (L.) ‘Lollipop’ and *Veronica spicata* (L.) ‘Goodness Grows’, as measured by subsequent effects on shoot growth and days to flower. We also investigated substrate pH effects on ethephon drench efficacy by analyzing the shoot responses to ethephon applied at a range of starting substrate pH (4.5 to 7.0) compared with untreated plants grown under the same substrate pH conditions (controls). One or more measurements of shoot growth (height, width, shoot dry weight) were reduced in both taxa treated with ethephon as compared with controls. *Veronica* plant growth was not influenced by substrate pH in either the control or ethephon-drenched plants. For *Verbena* plants receiving the ethephon drench, as substrate pH increased, height and width increased. For example, when ethephon was applied at substrate pH 4.5, finished plant height averaged 32.0 cm, compared with 43.5 cm for those plants that received the drench at a substrate pH of 7.0. Increasing substrate pH conditions also influenced the days to flower in *Verbena* plants. Ethephon-treated plants at a substrate pH of 4.5 required an average of 6.5 days longer to flower than those at a substrate pH of 7.0. In summary, ethephon drench applications can result in significant growth regulation effects, as seen in both *Veronica* and *Verbena*. Furthermore, increasing substrate pH can reduce the efficacy of ethephon drench applications.

Ethephon [(2-chloroethyl) phosphonic acid] has been widely used as a foliar spray in the commercial greenhouse industry for decades to abort flowers, promote branching, and restrict plant growth (Kays and Beaudry, 1987). Growers have reported success with ethephon as a growth regulator (Styer, 2002), resulting in continued research on the product and specific recommendations for ethephon use. For maximum efficacy, growers are advised to spray ethephon to runoff and to ensure the leaves remain wet for 3 to 4 h (Styer, 2002). In addition, temperature must be considered when the spray applications are to be made. At low temperatures, the rate of ethylene generation is very slow, limiting the amount of uptake and reducing the efficacy of the chemical (Lougheed and Franklin, 1972). At temperatures above 33 °C, exogenous ethephon breaks down at a high rate, which limits the amount of ethephon available for plant uptake and can potentially

cause phytotoxicity in the form of leaf senescence because of the rapid increase of ethylene in the air surrounding the plant (Lougheed and Franklin, 1972; Olien and Bukovac, 1978).

Another factor influencing efficacy is pH. Maintaining a solution pH between 4.0 and 4.5 when applying an ethephon spray to plants is critical. As solution pH increases, the rate at which ethephon evolves to ethylene also increases (Warner and Leopold, 1969). Consequently, as the speed at which ethephon evolution increases while in solution, ethephon availability for plant uptake decreases, therein reducing the chemical efficacy (Smith, 2010). Ethephon is a relatively strong acid, which will reduce the solution pH; however, in regions with water sources with high alkalinity, the buffering capacity of the bicarbonates in the water may prevent the solution pH from lowering to the recommended range (Camberato et al., 2014). In these circumstances, it is necessary to reduce the pH of the solution by adding an acidic buffer solution to the tank before adding ethephon to prevent ethephon degradation (Yates et al., 2011). There is no doubt that ethephon’s dependence on environmental and physical factors such as temperature, pH, and leaf wetness duration contribute to the challenges growers face in achieving

optimum efficacy and consistency when applying ethephon as a PGR.

Conflicting research results exist as to the mechanism of ethylene evolution within the plant. According to Warner and Leopold (1969), ethephon is absorbed into the plant tissue and subsequently ethylene generation occurs intercellularly because of the higher pH within the plant cells. However, studies conducted by Mudge and Swanson (1978) suggest that the generation of ethylene from ethephon takes place largely extracellularly. Regardless of how the ethylene evolves, once within the plant tissue, the cells respond with a reduction in cell elongation and a reduction in apical dominance, which in turn, can cause an increase in branching (Burg, 1973; Haver and Schuch, 2001).

The extent to which ethephon or ethylene translocates within the plant is also largely unknown. In studies conducted by Edgerton and Hatch (1972), ethephon was applied to sweet cherry leaves and fruit but more ethephon was recovered in the fruit 48 to 72 h after application than what was recovered immediately after the ethephon application, which led the authors to conclude that the majority of ethephon recovered in the fruit had translocated from the leaves. This suggests that ethephon may not need to be applied to target tissue to elicit a growth response. However, it is unknown if, and to what extent, ethephon can translocate from the roots to the shoots when applied to the substrate as a drench (Miller et al., 2012).

Currently, ethephon is not EPA labeled for commercial floriculture use as a drench application. In fact, it was widely believed in commercial horticulture that ethephon had no root activity and could only be absorbed through the leaf and stem tissue (Styer, 2002; Whipker et al., 2003). However, conflicting research results indicates that this theory is incorrect. Johnson et al. (1982) reported that ethephon drench applications reduced the intercellular spaces in *Ficus benjamina* L., resulting in reduced leaf area. More recently, ethephon substrate drenches reduced stem elongation of *Narcissus pseudonarcissus* L. and reduced plant growth and delayed flowering in a wide variety of bedding plants (Miller et al., 2012). Miller et al. (2012) also found that substrate pH affected the rate and duration of ethylene evolution from drench applications of ethephon in a closed system, in the absence of plants.

Drench applications of PGRs have many benefits to growers including a more uniform growth regulation effect across crops. In addition, generally less total chemical is used as the concentrations tend to be lower for drench applications (Currey and Lopez, 2010). Considering the slow uptake of ethephon as a spray application and the resulting logistical issues with plant irrigation and handling, ethephon drenches could have a practical application in the commercial greenhouse industry should they prove effective.

The objective of this study was 2-fold: 1) to determine if ornamental perennial plant

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species could respond to ethephon substrate drenches and the subsequent effect on growth and development of the shoots; and 2) to determine how differences in substrate pH affect ethephon efficacy by analyzing the shoot responses to the substrate drench application over a range of starting substrate pH.

Materials and Methods

Two perennial plant species were studied. *Verbena bonariensis* L. 'Lollipop' (purple-topvervain) and *Veronica spicata* L. 'Goodness Grows' (spiked speedwell), based on their response to foliar applications of ethephon in previous studies (Grossman et al., 2011). Plants were propagated from unrooted cuttings, which received a 10-second basal dip of 1500 mg·L⁻¹ indole-3-butyric acid (IBA) rooting hormone (Hortus IBA Water Soluble Salts 20% IBA; Hortus USA Corp., New York, NY). Cuttings were rooted in 72 cell trays (cell height 5.7 cm, volume 35.4 mL) in a soilless substrate (Fafard 1P, Sun Gro Horticulture, Agawam, MA) consisting of 80% Canadian sphagnum peatmoss, combined with perlite, dolomitic limestone, and a wetting agent. Cuttings were rooted under a clear water mist and bottom heat at 22 °C. After root initials had formed (9 to 14 d, depending on the species), liners were removed from mist and bottom heat and irrigated with constant liquid feed (CLF) using 150 mg·L⁻¹ nitrogen 15N–2.2P–12.5K 4Ca–2Mg (Jack's Professional LX Peat-Lite fertilizer, J.R. Peters Inc., Allentown, PA). Liners were allowed to grow to a well-rooted, transplantable size (3 and 6 weeks for *Verbena* and *Veronica*, respectively).

To satisfy the vernalization requirement of the *Veronica*, after 6 weeks of growth, *Veronica* liners were vernalized at 5 °C with 3.7 μmol·m⁻²·s⁻¹ of light supplied by light-emitting diodes (LEDs) for 9 h/d in a walk-in cooler for 6 weeks. After vernalization, liners were allowed 5 d to resume active growth before transplanting.

Liners were transplanted into trade gallon pots (volume 2.8 L) in a blended substrate consisting of 85% Canadian sphagnum peatmoss (Sun Gro Horticulture), 15% coarse perlite (PVP Industries, North Bloomfield, OH) with the addition of 0.59 kg·m⁻³ of gypsum and 0.59 kg·m⁻³ of Micromax granular micronutrients (Everris NA Inc., Dublin, OH). We conducted preliminary studies to determine the volume of dolomitic lime needed in the substrate to achieve our target pH values. Substrate pH was adjusted by adding 1.19 to 7.11 kg·m⁻³ dolomitic lime to achieve target pH values of 4.5, 5.0, 5.5, 6.0, 6.5, and 7.0 (Table 1). A wetting agent (Aqua Gro 2000L, Aquatrols®, Paulsboro, NJ) was incorporated in the substrate at a rate of 68 mL·m⁻³ and the substrate was allowed to equilibrate for 1 week before transplanting at which time the pH was sampled for starting pH values using the Saturated Media Extract (SME) method.

Ethephon (Collate; Fine Americas, Inc., Walnut Creek, CA) was applied as a substrate

Table 1. Target and actual substrate pH of *Verbena bonariensis* 'Lollipop' and *Veronica spicata* 'Goodness Grows' grown in a custom blended substrate of peat and perlite amended with dolomitic lime, gypsum and micronutrients. Substrate pH monitored by Saturated Media Extract method at 0, 2, 10, or 28 d after potting plants.

Target pH	Lime added (kg·m ⁻³)	pH Day 0	pH Day 2	pH Day 10	pH Day 28
<i>Verbena</i>					
4.5	1.19	4.6 ^z	4.5	4.3	4.3
5.0	1.63	5.0	5.0	4.9	4.9
5.5	2.22	5.3	5.4	5.4	5.3
6.0	2.84	5.9	6.0	5.8	5.7
6.5	4.15	6.5	6.5	6.4	6.3
7.0	7.11	6.8	6.8	6.7	6.7
<i>Veronica</i>					
4.5	1.19	4.3 ^z	4.3	4.5	4.4
5.0	1.63	4.9	4.5	4.8	4.8
5.5	2.22	5.3	5.2	5.3	5.4
6.0	2.84	5.8	5.7	5.7	5.9
6.5	4.15	6.3	6.2	6.2	6.3
7.0	7.11	6.7	6.6	6.6	6.7

^zMeans of three replicates.

drench 1 week after transplant. Care was taken to ensure that solution applied did not make contact with any foliar tissue. The ethephon drench was applied to moderately moist substrate during cloudy weather conditions. The temperature at the time of chemical application to the *Veronica* was 22.5 °C and the relative humidity was 46%. The temperature at the time of the ethephon application to *Verbena* was 18.9 °C with 40% relative humidity. Ethephon was applied at 100 mg·L⁻¹ at a volume of 296 mL per pot to eight single-plant replicates in each of the six substrate pH groups. The ethephon solution combined with municipal tap water (alkalinity 55 mg·L⁻¹ CaCO₃) measured 4.2 pH (HI9811 pH meter; Hannah Instruments, Ann Arbor, MI) at the time of application for both crops; therefore no additional acidifiers were used. Untreated plants (eight replicates) in each of the six substrate pH levels were drenched with water which had been acidified to a pH of 4.2 using Indicate Phase 5 buffer solution (Brandt Consolidate, Inc., Springfield, IL) to serve as the control groups. Plants were grown in a double polyethylene greenhouse located in Blacksburg, VA (lat. 37.23°N, long. 80.42°W). The *Veronica* crop was grown from 13 Mar. 2014 to 12 May 2014, and temperatures averaged 22.2 °C/19.1 °C day/night. The *Verbena* crop was grown 1 Apr. 2014 to 20 May 2014 and the day/night temperatures averaged 21.8 °C/17.7 °C. Plants were grown under a minimum of 14 h long days using supplemental 600 W high pressure sodium (HPS) lighting for day length extension until 10 May 2014, at which point the natural day length exceeded 14 h. The daily light integral (DLI) in the greenhouse averaged 19.6 mol·m⁻²·d⁻¹ during the growth of the *Veronica* and 18.8 mol·m⁻²·d⁻¹ for the *Verbena*. Each plant species was set up as a separate experiment in a completely randomized design.

Data were collected at 0, 2, and 4 weeks after the drench application and at termination of the study (determined by plant flowering). Data collected included plant height, average plant width (average of width measured at the widest point of the plant and then the perpendicular width) and days to flower.

Shoots were harvested on the termination of the study and dried at 65 °C for 1 week to measure dry weight. The pH of each substrate pH level was measured using the SME method at 0, 2, 10, or 28 d after potting for *Verbena* and *Veronica* (Table 1). Substrate samples for pH analysis were taken from the middle one third of the pot. This method was a destructive harvest and additional plants were built into the study to accommodate these samples.

To determine the significance of the ethephon efficacy within a single substrate pH, data were analyzed by ANOVA ($P \leq 0.05$, Student's *t* test) using JMP®9.0© 2010 (SAS Institute Inc., Cary, NC). To determine the substrate pH response, data were analyzed via regression analyses over substrate pH. To determine the interaction of the ethephon drench and substrate pH, linear fit regressions were further analyzed using a multivariate linear regression model including an interaction term (cross term) in JMP®9.0© 2010. Quadratic regression models were further analyzed in R (R Development Core Team, 2010) using a model comparison via an F test for *Verbena* shoot dry weight. A quadratic regression was necessary as both the untreated plants and the ethephon-treated plants showed a quadratic response, but only the ethephon-treated plants demonstrated a linear response.

Results

Actual substrate pH at the time of the 100 mg·L⁻¹ ethephon drench was within ±0.3 units of the target pH (Table 1). The pH of the substrates remained relatively stable throughout the study for *Verbena* and *Veronica* with a standard error of 0.03.

Verbena bonariensis 'Lollipop'. At 6 weeks after drench application, *Verbena* plants showed a significant response to ethephon at all substrate pH levels when compared with controls (Figs. 1 and 2). Plant height was significantly reduced by ethephon at substrate pH levels 4.5, 5.0, 5.5, 6.0, or 6.5; however, there was no significant reduction of height at substrate pH 7.0 as compared with plants in the control groups (Fig. 1A).

The ethephon drench significantly reduced average plant width (Fig. 1B) and shoot dry weight (Fig. 2A) across all substrate pH levels compared with untreated plants grown under the same substrate pH levels. In addition, the ethephon drench resulted in a significant flower delay in all treated plants, regardless of substrate pH compared with control plants (Fig. 2B).

Furthermore, for *Verbena*, there were significant differences in the multivariate linear regression model comparison of the ethephon-drenched plants to the controls (Figs. 1 and 2). The differing slopes of the lines representing the ethephon-drenched group and the control group shows the interaction of substrate pH and the ethephon drench. Within the ethephon-drenched plants, plant height (Fig. 1A) and width (Fig. 1A) increased significantly with increasing substrate pH while the control plant measurements in these same parameters remained relatively static regardless of changing substrate pH. Substrate pH affected shoot dry weight of both control and ethephon-drenched plants, however the effect of increasing substrate pH on shoot dry weight was different depending on whether ethephon was applied (Fig. 2A). Shoot dry weight increased with increasing substrate pH in plants in the ethephon-drenched group, while plants in the control group exhibited a quadratic response with an increase in shoot dry weight at substrate pH levels 4.5 to 5.5, but declining shoot dry weight as substrate pH continued to rise. The number of days to flower decreased with increasing substrate pH for ethephon-drenched plants, while flowering time of control plants was unaffected by substrate pH (Fig. 2A).

Veronica spicata 'Goodness Grows'. There were no significant differences in the parameters measured across substrate pH levels and therefore data were pooled. Across all substrate pHs, *Veronica* showed a significant response to the ethephon drench when compared with the control group (Table 2). Plant height of ethephon-drenched plants was less than that of control plants at 4 weeks after application, though finished (8 weeks after application) plant height showed no significant difference. Average width and shoot dry weight of the ethephon-drenched plants were significantly reduced in finished plants as compared with the control plants. However, the number of days to plant flowering was unaffected by the ethephon drench.

When examining the effect of substrate pH on growth of the ethylene-drenched plants in comparison with the controls, the regression analysis of the two models showed no significant difference between the slopes of the ethephon drench line compared with the control line at 2, 4, or 8 weeks after application (data not presented), indicating that substrate pH did not significantly influence the efficacy of the ethephon drench application.

Discussion

Ethephon response. Both species studied responded to the ethephon substrate drench application. *Verbena* plants subjected to

Fig. 1. The correlation between the growth response of *Verbena bonariensis* 'Lollipop' to the 100 mg·L⁻¹ ethephon drench applied 1 week after potting and increasing substrate pH at 6 weeks after the drench application along with the regression equations and coefficient of determination (r^2) for the growth parameters of total plant height in centimeters (A) and average plant width in centimeters (B). Changes in slope indicate the linear effect of increasing substrate pH. Points are means of eight replicates. Slope equations within the table are for the individual regressions. Significance of individual regression equations:

Height	0 ppm	L ^{NS}	$r^2 = 0.001$	100 mg·L ⁻¹	L ^{****}	$r^2 = 0.3248$
Width	0 ppm	L ^{NS}	$r^2 = 0.43$	100 mg·L ⁻¹	L ^{***}	$r^2 = 0.2330$

^zNS, *, **, ***, and **** Nonsignificant, significant at 0.05, 0.01, 0.001, and 0.0001, respectively.

ethephon drenches exhibited reduced height and average width persisting through 6 weeks after application, a reduction in finished shoot dry weight and a significant delay in flowering. The significant flower delay in treated plants could be problematic in production when applying ethephon to plant material after transplant. However, all plants had flowered within 6 weeks from the time of the ethephon drench, which is within the predicted crop production schedule of 6 to 8 weeks (Green Leaf Plants®, 2014). In addition, the delay in flowering could prove advantageous when ethephon is used in liner production on crops that are prone to early flowering during propagation.

Veronica's response to the ethephon drench was less pronounced, there was an initial height reduction, but it did not persist in the finished plants. Average width and shoot dry weight were reduced at finish on ethephon-drenched plants. Ethephon caused no significant flower delay in this crop. So, it is possible a higher rate or multiple applications of ethephon could increase growth control without adversely affecting flowering.

pH and ethephon interaction. There was a substrate pH response within the *Verbena* plants drenched with ethephon. As the substrate pH increased, there was less effect on plant growth, for example, values in the

Fig. 2. The correlation between the growth response of *Verbena bonariensis* 'Lollipop' to the 100 mg·L⁻¹ ethephon drench applied 1 week after potting and increasing substrate pH at 6 weeks after the drench application along with the regression equations and coefficient of determination (r^2) for the growth parameters of (A) final shoot dry weight in grams fit quadratically. pH significantly influenced shoot dry weight of both the control group and the ethephon drenched group. Days to flower from transplant (B) was fit as a linear regression. Changes in slope indicate the linear effect of increasing substrate pH. Points are means of eight replicates. Slope equations within the table are for the individual regressions. Significance of individual regression equations:

Shoot dry weight	0 mg·L ⁻¹	Q*	$r^2 = 0.15$	100 mg·L ⁻¹	Q**	$r^2 = 0.23$
Days to flower	0 mg·L ⁻¹	L ^{NS}	$r^2 = 0.003$	100 mg·L ⁻¹	L***	$r^2 = 0.26$

^zNS, *, **, ***, and **** Nonsignificant, significant at 0.05, 0.01, 0.001, and 0.0001, respectively.

Table 2. Plant height, average width, final shoot dry weight (g) and days to flower of *Veronica spicata* 'Goodness Grows' at 4 and 8 weeks after ethephon applications under substrate pH of 4.5, 5.0, 5.5, 6.0, 6.5, or 7.0 (data pooled due to nonsignificance among substrate pH levels).

Plant growth regulator (PGR)	Plant ht (cm)		Plant width (cm)		Shoot wt (g)	Days to flower ^z
	4 wk	8 wk	4 wk	8 wk	8 wk	8 wk
Untreated control 0 mg·L ⁻¹	18.8	34.0	19.0	34.9	18.4	43.0
Ethephon drench 100 mg·L ⁻¹	16.2	33.8	17.8	31.6	13.6	43.5
PGR effect	*y	NS	*	****	****	NS

^zDays to flower calculated from the day of transplant.

^yNS, *, **, ***, and **** Nonsignificant, significant at 0.05, 0.01, 0.001, and 0.0001, respectively.

measured parameters of height, width, and shoot weight all increased significantly with increasing substrate pH. Flowering delay was also less pronounced at higher pH levels. This demonstrates that the additional buffering capacity of the dolomitic lime directly influenced the efficacy of the ethephon drench. As

Camberato et al. (2014) demonstrated when looking at carrier water pH of PGR solutions, with low concentrations of bicarbonates, there is little buffering capacity and therefore ethephon drives the solution pH down. However, under high bicarbonate concentrations, the buffering capacity is high and ethephon has

less effect on final solution pH. This same principle can be applied to substrate drenches. Although the pH of the solution applied was consistent at pH 4.2, that solution was altered when applied as a substrate drench, subsequently combining with the pore water within the substrate. The new combined solution's buffering capacity was influenced by the level of bicarbonates in the substrate. For our studies, within the normal growing range (pH 5.5 to 6.5), changes in the level of growth reduction were all within an acceptable range. However, under lower pH levels, the buffering capacity is also greatly reduced, allowing for the potential for significant increases in ethephon efficacy. At higher pH levels, the buffering capacity could be high enough to limit ethephon efficacy. The significant shoot growth reduction response to ethephon applied through a substrate drench application seems to support the research by Edgerton and Hatch (1972), that ethephon could be taken up through the plant roots and translocated to the shoots where conversion to ethylene occurs intercellularly (Warner and Leopold, 1969).

In addition, it appears that because a stronger growth reduction occurred at lower pH levels, the rate of ethephon degradation in the substrate increased with increasing substrate pH, resulting in rapid dissipation of the ethylene and less subsequent uptake of ethephon at higher substrate pH. This theory is consistent with the description of Miller et al. (2012) of greater and faster ethylene evolution from a peatmoss substrate adjusted (with lime) to pH greater than 5.1 in a closed, non-plant system. Alternatively, the lower substrate pH resulted in less ethephon degradation and consequently some persistence in the substrate, resulting in a prolonged uptake of ethephon by the plants. This is again consistent with the Miller et al. (2012) hypothesis that because the evolution of ethylene occurs over a longer span of time at lower substrate pH, there is somewhat of a slow release effect, where the plant not only takes up the ethephon at the time of application, but continuously over days or even weeks.

The variability in growth responses between the two plant species studies shows that ethephon drench responses seem to be species and possibly cultivar specific, just as in spray applications. The species specific response is further supported in work by Miller et al. (2012), in which ethephon drenches were applied to multiple bedding plant crops, which responded in varying degrees. Whipker (2015) also found varying responses to ethephon in regards to branching between cultivars of petunias. *Petunia ×hybrida* 'Supertunia Vista Bubblegum' responded to the ethephon drench with a significant increase in branching, while 'Supertunia Double Peppermint' showed no significant change in branching.

Although we did not measure the plants' root response to the ethephon drench application, it is worth noting that Miller et al. (2012) reported a reduction in the root dry weight of finished bedding plants treated with ethephon drenches. This is important to note,

as reduced root mass has the potential to influence shoot growth. We observed a reduction in root dry weight on *Veronica* 'Goodness Grows' in a previous study (Latimer, 2014); wherein root dry weight was reduced 23% with an ethephon liner drench of 500 mg·L⁻¹ when compared with the controls (unpublished data). We expected the much lower rate of 100 mg·L⁻¹ used in this study to result in minimal reductions in root mass on the *Veronica*, as the data of Miller et al. (2012) show less effect on root dry weight as ethephon drench rates are reduced. Even in finished *Verbena* plants subjected to the ethephon drench where shoot dry weights were reduced up to 66%, there were no visual differences in the extent of rooting in the container compared with the controls (personal observation).

Our results support ethephon drenches as a promising method of application of the chemical. However, it is currently not EPA labeled for drench applications. Although drench applications of ethephon could help growers overcome the challenge of reduced uptake and efficacy because of reduced leaf wetness duration following spray applications, it does present another challenge in managing pH effectively for not only plant growth, but also to ensure the efficacy of the ethephon drenches. Our research indicates that the influence of substrate pH on the ethephon response can vary dependent on the species. For the two species tested, *Veronica longifolia* 'Goodness Grows' and *Verbena bonariensis* 'Lollipop', *Veronica* growth was not influenced by substrate pH in either the control or ethephon-drenched plants, but there was a significant interaction of substrate pH and the efficacy of the ethephon drench in the *Verbena* crop. Within the recommended substrate pH growing range for greenhouse grown crops (pH 5.8 to 6.4) (Fisher, 2003), ethephon uptake resulted in satisfactory growth control in our studies. However, because the efficacy of the ethephon

drench was directly influenced by substrate pH in *Verbena*, there is the potential for overregulation on some crops under low substrate pH conditions, and conversely high substrate pH conditions could reduce ethephon efficacy.

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