Fertilizer and Plant Growth Regulator Strategies for Improving Consumer Performance of Container-grown Petunia

Jonathan Ebba¹, Ryan W. Dickson², Paul R. Fisher³,
Crysta N. Harris¹, Todd Guerdat¹, and Sofia Flores³

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SUMMARY. The overall goal was to evaluate fertilizer options for greenhouse producers, with or without a plant growth regulator (PGR) application, to improve subsequent performance of container-grown annuals. *Petunia (Petunia × hybrida)* was the model container-grown crop in simulated production and consumer environments. The first experiment at two locations (New Hampshire and Florida) compared strategies using water-soluble fertilizer [WSF (17N-1.8P-14.1K)], controlled-release fertilizers (CRF), and slow-release fertilizers (SRF) that were either applied throughout or at the end of the 8-week production phase [point of shipping (POS)] for petunia rooted cuttings grown in 8-inch azalea containers. In the subsequent simulated “consumer” phase, container plants were irrigated with clear water (no fertilizer) for 6 weeks. Plant performance [number of flowers, SPAD chlorophyll index, dry weight, and tissue nitrogen (N)] at the end of the consumer phase was improved by top-dressing at POS with either CRF or granular organic fertilizer (both at 2.74 g/container N), or preplant incorporation of either a typical CRF at 4.12 g/container N or a CRF with an additional prill coating to delay initial release (DCT) at 2.74 g/container. There was no carry-over benefit from applying a liquid urea-chain product (1.37 or 2.74 g/container N) or top dressing with granular methylene di-urea (2.74 g/container N), or 400 mg·L⁻¹ N (0.2 g/container N) from a liquid organic fertilizer at POS. The consumer benefit of applying 400 mg·L⁻¹ N (0.2 g/container N) from a WSF at POS was increased by supplementing with 235 mg·L⁻¹ magnesium (Mg) and 10 mg·L⁻¹ iron (Fe). A second experiment in 10-inch-diameter pots evaluated the effect on consumer performance from providing 200 or 400 mg·L⁻¹ N of WSF with the PGR paclobutrazol, at the final 1 L/pot irrigation at POS. Application of 3 mg·L⁻¹ paclobutrazol delayed leaf yellowing and reduced plant height, width, and shoot dry weight during the consumer phase, resulting in a more compact growth habit and higher plant quality compared with plants that received no PGR, regardless of WSF treatment. Addition of supplemental 235 mg·L⁻¹ Mg and 10 mg·L⁻¹ Fe to the high rate of WSF and PGR did not improve consumer performance compared with other treatments that included a PGR. Overall, the first experiment demonstrated that the most effective fertilizer strategies require a CRF or SRF that will release nutrients throughout the consumer phase, and that impact of liquid fertilizer options is limited because of lower N supply per container. A single application at POS of a high rate of WSF with supplemental Mg and Fe may have short-term benefits, for example while plants are in a retail environment. Growers should consider combining a residual fertilizer with a PGR application for premium, value-added container annuals.

consumers are unlikely to fertilize plants after sale (Oliveira et al., 2016). These strategies include a) incorporating a slowly soluble fertilizer into the root substrate before planting that continues to release nutrients after the point of sale, or b) applying a slowly or completely soluble fertilizer immediately before the point of sale. For example, Oliveira et al. (2016) showed high rates of controlled-release fertilizer (CRF) incorporated into the substrate or applied as a top-dress to the substrate surface increased plant performance [number of flowers, SPAD chlorophyll index, dry weight, and tissue nitrogen (N)] during a simulated consumer phase compared with plants that received only water-soluble fertilizer (WSF) during production.

Plant growth regulators (PGRs) applied during production also have carry-over effects on plant growth and habit for the consumer (Davis, 1991; Keever and Kessler, 2008; Latimer and Baden, 1994). Foliar applications of PGRs during production of a range of ornamental container crop species has been shown to suppress shoot growth during simulated shipping and retail environments as well as in the landscape (Keever and Kessler, 2008; Latimer, 1991). Chemicals such as paclobutrazol are also effective at controlling plant growth when taken up by roots (Latimer and Whipker, 2012; Ruter, 1996), and these are sometimes applied as a substrate drench or mixed with the applied fertilizer solution (Million et al., 2002).

Oliveira et al. (2016) only evaluated solid fertilizers that were either incorporated or top-dressed, rather than liquid fertilizer applications, and they did not evaluate the combined effects of increased fertilizer plus a PGR on consumer performance. Application

Fertilizer strategies during production of container-grown floriculture crops have carry-over effects on the performance of these plants during postharvest; and for the consumer, these methods have the potential to add value, differentiate product quality, and increase consumer success and repeat sales. Several fertilizer strategies are available to provide residual fertilizer to container-grown ornamental plants because many

Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.5933	lb/yd ³	kg·m ⁻³	1.6856
1	mmho/cm	mS·cm ⁻¹	1
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274 × 10 ⁻⁵
1	ppm	mg·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

immediately before the point of shipping (POS) of a high concentration of liquid forms of mineral or slow-release fertilizers may reduce labor cost compared with top-dressing solid fertilizer. Cost and labor savings are important in a highly competitive market, and a recent national grower survey (Sparks, 2020) found that labor and production cost are among the top four issues for the United States floriculture industry.

The objective of the first experiment was to compare strategies using WSF, CRF, and organic slow-release fertilizers (SRF) to provide adequate nutrition during both production and the consumer phases with container-grown petunia (*Petunia ×hybrida*). The second objective was to evaluate the potential of irrigating with a high rate of WSF plus a PGR as the final irrigation of production and immediately before sale to suppress shoot growth and extend plant quality during a simulated retail consumer phase.

Materials and methods

Expt. 1: Fertilizer strategies designed to provide residual nutrients for consumers

A single-factor greenhouse experiment evaluated 12 fertilizer strategy treatments designed to provide residual nutrients during post-production with container-grown petunia. Fertilizer treatments were applied during a

greenhouse production phase, after which plant growth and root zone nutrients were measured during a simulated consumer retail phase. Treatments differed in nutrient concentration and release pattern, whether nutrients were from inorganic or organic sources, fertilizer application as a liquid or solid, and nutrient incorporation into the growing substrate or application at the end of production. The same experiment was conducted at two locations, including the University of Florida (UF) in Gainesville (lat. 29.6516° N, long. 82.3248° W) and the University of New Hampshire (UNH) in Durham (lat. 35.9940° N, long. 78.8986° W). Each location was considered a separate experimental run—where experimental design, treatments, replicate number, data collection, and statistical analysis were identical between locations unless specified otherwise. Daily light integral and average daily air temperature were (mean ± SD) $15.7 \pm 4.6 \text{ mol} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ and $23.5 \pm 1.9^\circ\text{C}$ for the UF experimental run, and $17.8 \pm 7.8 \text{ mol} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ and $22.8 \pm 3.5^\circ\text{C}$ for the UNH experimental run. Photosynthetic light and temperature data were measured at both locations using a portable data logger (WatchDog 2475 Plant Growth Station; Spectrum Technologies, Aurora, IL).

Table 1 summarizes the applied fertilizer treatments, designed to represent a range of strategies that could be used in commercial operations. Treatment 1 (“Control”) represented a control treatment (500 mL of deionized water), to simulate a grower producing a container plant with WSF and then applying no additional residual fertilizer for the consumer. The WSF was applied at $200 \text{ mg} \cdot \text{L}^{-1}$ N with each fertigation during production, using 17.0N–1.8P–14.1K WSF (Jack’s Professional LX 17–4–17 Pure Water; JR Peters, Allentown, PA).

Treatments 2 through 4 consisted of applying WSF or an organic liquid SRF at the end of the production phase (POS) at $0.2 \text{ g/container N}$. In treatment 2 (“WSF400”), a single application of the WSF was applied at $400 \text{ mg} \cdot \text{L}^{-1}$ N, intended to provide a short-term additional fertilizer application to improve consumer performance immediately after sale. In treatment 3 (“WSF400 + MgFe”), the $400 \text{ mg} \cdot \text{L}^{-1}$ N of WSF included

an additional $235 \text{ mg} \cdot \text{L}^{-1}$ magnesium (Mg) from magnesium sulfate (19.9% Mg, JR Peters) and $10 \text{ mg} \cdot \text{L}^{-1}$ iron (Fe) chelate (Fe-EDDHA, 6.0% Fe; AkzoNobel, Amsterdam, The Netherlands) because earlier experiments by Oliveira et al. (2016) noted symptoms of leaf chlorosis during the consumer phase consistent with Mg and Fe deficiency. In treatment 4 (“LOF”), the WSF was replaced with a complete liquid organic fertilizer using oilseed extract (Organic Plant Food 3N–0.4P–0.8K; Nature’s Source, Sherman, TX) at $400 \text{ mg} \cdot \text{L}^{-1}$ N. All fertilizer solutions were mixed using deionized water. Control and fertilizer treatment solutions were applied at 500 mL per container.

Treatments 5 through 9 represented applications of CRF or SRF as a top dress at the POS. In treatment 5 (“CRF TD”) 18.3 g of CRF (Osmocote Plus 15N–3.9P–10.0K; Everris, Geldermalsen, The Netherlands) was applied per container. The resulting 2.74 g N per container (the high label rate) was used to standardize N application for treatments 6 to 9. For treatment 6 (“LU”), UF used a liquid urea-chain product (N-Sure 28N–0P–0K; Tessenderlo Kerly, Phoenix, AZ); and in Treatment 7 (“LU + MgFe”), additional Mg and Fe were added to the N-Sure because these nutrients were absent in N-Sure. The N concentration for treatments 6 and 7 was decreased by half at UNH because leaf marginal burn was noted with these treatments at UF. Treatment 8 (“MDU TD”) was a solid slow-release product, methylene di-urea, at 6.9 g per container (Nutralene 40N–0P–0K; Agrium Advanced Technologies, Loveland, CO). Treatment 9 (“SUS TD”) was an organic slow-release fertilizer based on composted poultry litter at 34.3 g per container (Sustane 8N–1.8P–3.3K, Sustane Natural Fertilizers, Cannon Falls, MN). Treatments 5 through 9 were applied at the same time, at the final irrigation of production (500 mL of deionized water).

In treatments 10 through 12, CRF was incorporated into the growing substrate before the start of production. Treatment 10 (“CRF high”) incorporated the same type and rate of CRF as top-dressed in Treatment 5 (18.3 g per container, equivalent to 12.3 lb/yard^3 substrate). In treatment 11 (“CRF very high”), the CRF

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¹Department of Agriculture, Nutrition, and Food Systems, University of New Hampshire, Durham, NH 03824

²Department of Horticulture, University of Arkansas, Fayetteville, AR 72701

³Environmental Horticulture Department, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611

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R.W.D. is the corresponding author. E-mail: ryand@uark.edu.

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Table 1. Fertilizer treatments for container-grown petunia in Expt. 1 at the University of Florida (UF) and University of New Hampshire (UNH) including treatment description, treatment code, incorporated preplant fertilizer, whether water-soluble fertilizer (WSF) or controlled-release fertilizer (CRF) was applied during production, whether fertilizer was applied as a liquid or solid [500 mL/container (16.9 fl oz)] at the end of the production phase, fertilizer type [WSF, CRF, organic slow-release fertilizer (SRF)] and weight of nitrogen (N) applied per container at the start of the consumer phase. Treatments 3 and 7 contained additional magnesium (Mg) and iron (Fe) applied at the start of the consumer phase.

Treatment description	Treatment code	Preplant fertilizer incorporated ^a	WSF during production (mg·L ⁻¹ N) ²	Liquid or solid	Fertilizer applied at end of production phase ^a	Nitrogen (g/container) ²
(1) Control	Control	None	200	Liquid	None, clear water	0
(2) WSF	WSF400	None	200	Liquid	WSF 17N-1.8P-14.1K at 400 mg·L ⁻¹ N	0.2
(3) WSF + Mg + Fe	WSF400 + MgFe	None	200	Liquid	WSF at 400 mg·L ⁻¹ N + 235 mg·L ⁻¹ Mg + 10 mg·L ⁻¹ Fe	0.2
(4) Liquid organic SRF	LOF	None	200	Liquid	Oilseed extract 3N-0.4P-0.8K at 400 mg·L ⁻¹ N	0.2
(5) CRF top-dress	CRF TD	None	200	Solid	CRF 15N-3.9P-10.0K at 18.3 g/container	2.74
(6) Liquid urea (LU) SRF	LU	None	200	Liquid	Liquid urea chain (28% N) at 7.6 mL/container (UF) or 3.8 mL/container (UNH)	2.74 (UF) or 1.37 (UNH)
(7) Liquid urea SRF + Mg and Fe	LU + MgFe	None	200	Liquid	Liquid urea chain (28% N) at 7.6 mL/container (UF) or 3.8 mL/container (UNH) + 235 mg·L ⁻¹ (UNH) + 235 mg·L ⁻¹ Mg + 10 mg·L ⁻¹ Fe	2.74 (UF) or 1.37 (UNH)
(8) Solid urea SRF	MDU TD	None	200	Solid	Methylene di-urea (40% N) at 6.9 g/container	2.74
(9) Solid organic SRF	SUS TD	None	200	Solid	Composted poultry litter 8N-1.8P-3.3K at 34.3 g/container	2.74
(10) Incorporated CRF (high)	CRF high	CRF 15N-3.9P-10.0K at 18.3 g/container	None	Solid	None, clear water	2.74
(11) Incorporated CRF (very high)	CRF very high	CRF 15N-3.9P-10.0K at 27.4 g/container	None	Solid	None, clear water	4.12
(12) WSF + Incorporated dual-coated CRF	DCT	Dual-coated fertilizer 14N-3.5P-9.1K at 19.6 g/container	200	Solid	None, clear water	2.74

²1 g = 0.0353 oz; 1 ppm = 1 mg·L⁻¹; 1 mg = 3.5274 × 10⁻⁵ oz.

incorporation rate was increased to 27.4 g per container (equivalent to 18.5 lb/yard³ substrate). In treatment 12 (“DCT”), a dual-coated fertilizer was used, with a waxy coating that covered an inner CRF prill (Protect 14N–3.5P–9.1K, Everris) incorporated at 19.6 g per container (13.1 lb/yard³) of substrate. Incorporated CRF (treatments 10 and 11) were intended to provide nutrients during both production and consumer phases, whereas incorporated DCT (treatment 12) was intended to provide nutrients primarily during the consumer phase. Treatments 10 through 12 received 500 mL of deionized water as the final irrigation of production.

Vegetatively propagated cuttings of ‘Supertunia Vista Bubblegum’ petunia were sourced from a commercial propagator (Pleasant View Gardens, Loudon, NH) and transplanted from 128-cell trays into 8-inch-diameter plastic azalea containers (Poppelmann Plastics US, Claremont, NC) in soilless peat-based substrate (ProMix BX; Premier Tech, Quakertown, PA) at one plant per container. Controlled-release fertilizer and DCT for treatments 10 through 12 were incorporated into the substrate before transplant (Table 1). Each container represented one treatment replicate. Eight replicates per fertilizer treatment were arranged on eight greenhouse benches using a randomized complete block design, where one bench served as one experimental block.

The production phase began at transplant, which occurred on 15 Feb. 2017 and 5 May 2017 for UF and UNH, respectively. Treatments with incorporated CRF (treatments 10 and 11) were irrigated with 500 mL deionized water at transplant and at each subsequent irrigation event during production. Treatments 1 through 9 and treatment 12 were fertilized at transplant and at each subsequent irrigation event with 500 mL of WSF at 200 mg·L⁻¹ N. All treatments were irrigated uniformly once substrate moisture dried to ≈50% maximum water-holding capacity. Plastic saucers placed under each container collected any leachate after irrigation and allowed for reabsorption into the substrate.

The production phase ended on 29 Mar. 2017 and 15 June 2017 for UF and UNH experimental runs (42 or 41 d after transplant, respectively),

at which point residual fertilizers were applied for treatments 1 through 9 (Table 1). After production, plants remained in the same greenhouse an additional 56 and 61 d at UF and UNH, respectively, for a simulated retail consumer phase. During the consumer phase, plants were irrigated only with deionized water (no fertilizer nutrients), following the irrigation methods described for production. Deionized water was used because high alkalinity in tap water can raise substrate pH and induce micronutrient deficiencies with petunia, particularly iron and manganese (Fisher, 2003).

Twelve additional container replicates grown for the control (treatment 1), CRF high (treatment 10), CRF very high (treatment 11), and DCT (treatment 12) fertilizer treatments were destructively sampled at the end of production for initial data collection. Initial data were not collected for treatments 2 through 9, because these fertilizer strategies were applied at the end of production, and plant growth and substrate nutrients would have been like the Control treatment.

Substrate pH and electrical conductivity (EC) were measured for each replicate using a pour-through method with a benchtop pH/EC meter (Orion Dual Star; Thermo Fisher Scientific, Waltham, MA). Leachate samples (20 mL) were analyzed for ammonium-N (NH₄-N) and nitrate-N (NO₃-N) concentrations using automated and semiautomated colorimetry (University of Florida Soil Testing Laboratory, Gainesville, FL; University of Maine Plant and Soil Laboratory, Augusta, ME), and N forms were summed for total N concentration.

Leaf greenness was measured using a portable SPAD chlorophyll index meter (Minolta leaf SPAD meter; Spectrum Technologies, Aurora, IL). Each replicate value was the average of five leaf SPAD chlorophyll measurements taken on recently mature leaves from randomly selected shoots per plant. Flower number was measured as total open flowers per replicate.

Shoot dry weight per replicate was measured by cutting plant stems directly above the substrate surface and oven-drying shoot tissue at 70 °C for 48 h. Shoot tissue was rinsed with dilute hydrochloric acid (HCl)

followed by deionized water before being oven-dried to remove potential residues on leaf surfaces. Dry shoot tissue was ground and passed through a 0.017-inch sieve, and percent N was measured using the Purcell and King (1996) persulfate digestion method (Quality Analytical Laboratories, Panama City, FL).

Final data collection for all treatments occurred at the end of the consumer phase on 24 May 2017 and 15 Aug. 2017 (56 and 61 d after POS) for UF and UNH experimental runs, respectively. Substrate pH and EC, leaf SPAD chlorophyll index, flower number, shoot dry mass, and percent N were measured for each replicate as described for initial data collection at the end of production. Total accumulation of N in shoot tissue was calculated by multiplying the percentage of N in the dry shoot tissue by the total dry shoot tissue weight per replicate at the end of the consumer phase.

Data were analyzed separately for UF and UNH experimental runs. Analysis of variance with PROC GLIMMIX in SAS (version 9.4; SAS Institute, Cary, NC) was used to evaluate fertilizer strategy effects on substrate pH and EC, plant height and width, leaf SPAD chlorophyll index, flower number, substrate N concentration, shoot dry weight, percent N in dry shoot tissue, and total shoot N per plant separately for the end of production and end of consumer phases. Mean separation used Tukey’s honestly significant difference (HSD) at $\alpha = 0.05$.

Expt. 2: Irrigation with water-soluble fertilizer and plant growth regulator at the end of production

A greenhouse experiment evaluated WSF level with and without paclobutrazol at 0 and 3 mg·L⁻¹ as a final 1-L substrate drench application at POS on 7 Apr. 2018. The five treatments consisted of 200 mg·L⁻¹ N without paclobutrazol (“WSF”), 400 mg·L⁻¹ N without paclobutrazol (“WSF400”), 200 mg·L⁻¹ N plus 3 mg·L⁻¹ paclobutrazol (“WSF + PGR”), 400 mg·L⁻¹ N plus 3 mg·L⁻¹ paclobutrazol (“WSF400 + PGR”), and the WSF400 + PGR treatment with supplemental 235 mg·L⁻¹ Mg and 10 mg·L⁻¹ Fe (“WSF400 + Mg + Fe + PGR”). Petunia were grown in 10-inch-diameter hanging baskets at the same UNH greenhouse location in Expt. 1. Hanging baskets were

used in this experiment because petunia are commonly grown commercially in baskets, and hanging baskets are expected to last for relatively long periods by consumers and may therefore benefit from residual fertilizer and PGR strategies. The experiment started at the end of the production period with the application of WSF and PGR treatments, after which the consumer phase started and root zone nutrients and plant performance were monitored. Daily light integral and average daily air temperature during the consumer phase were (mean $\pm$ SD) $23.3 \pm 9.1 \text{ mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ and $21.5 \pm 1.7^\circ\text{C}$, respectively.

Unrooted cuttings of petunia ‘Supertunia Vista Bubblegum’ from Pleasant View Gardens were vegetatively propagated at UNH in 128-cell trays containing the same soilless substrate used in Expt. 1. Rooted transplants were transferred into 10-inch-diameter plastic hanging basket containers (Poppelmann Plastics US) at one plant per container on 25 May 2017. Plants were fertilized at each irrigation using the same water-soluble fertilizer and irrigation methods described in Expt. 1 at $200 \text{ mg}\cdot\text{L}^{-1} \text{ N}$.

Treatments were formulated with the same WSF used during production and commercially available paclobutrazol (Bonzi; Syngenta Crop Protection, Greensboro, NC). Each replicate consisted of one container, with five replicates per treatment. Replicates were placed on top of mesh greenhouse benches following a randomized complete block design immediately after the application of treatments on 1 Aug. 2017, and these were irrigated as previously described for production using only deionized water (no fertilizer nutrients).

Root zone nutrients and plant performance data were measured as substrate pH and EC, substrate N, and leaf SPAD chlorophyll index collected for each replicate at 1, 7, 21, 35, 49, and 63 d after treatment application, as well as flower number, shoot dry weight, percent shoot tissue N, and total accumulated N at 63 d (end of consumer phase). Data collected for these parameters followed methods described in Expt. 1. Plant dimensions were also measured as greatest height (centimeters) from the substrate surface and greatest width (centimeters) of the canopy per

replicate at 1, 7, 21, 35, 49, and 63 d after treatment application.

Analysis of variance with PROC GLM in SAS (version 9.4) was used to evaluate treatment effects on substrate pH and EC, substrate N, shoot dry weight, plant height and width, leaf SPAD chlorophyll index, flower number, and percent and accumulated N in shoot tissue during the consumer phase. Mean separation used Tukey’s HSD at $\alpha = 0.05$.

Results and discussion

Expt. 1: Fertilizer strategies designed to provide residual nutrients for consumers

END OF PRODUCTION. All four fertilizer strategies (which included WSF only, incorporated CRF at high or very high rates, or incorporated DCT with WSF) produced commercially acceptable plants during the production phase. There were no fertilizer effects on petunia shoot dry weight or flower number at UF or UNH (Table 2). Most substrate pH values were within or slightly above the recommended range for petunia [pH 5.4 to 6.2 (Fisher, 2003)], and there were no visual symptoms of iron deficiency or large differences in leaf SPAD chlorophyll index (Table 2). Substrate EC and N concentrations were higher than recommended for petunia and general bedding plants using a pour-through method [EC 1.3 to $2.0 \text{ mS}\cdot\text{cm}^{-1}$ (Gibson et al., 2007), leachate $\text{NO}_3\text{-N}$ between 100 to $199 \text{ mg}\cdot\text{L}^{-1} \text{ N}$ (Nelson, 2011)] for Control and DCT-treated plants at UF and with all treatments at UNH (Table 2). The high EC likely resulted from excess fertilizer supply combined with no leaching, however there were no signs of high soluble salt stress at either location. All fertilizer treatments produced petunia that appeared healthy, with adequate SPAD chlorophyll index values and flower number at the end of production.

END OF CONSUMER PHASE. Substrate pH at the end of the consumer phase was above recommended values for petunia [pH 5.4 to 6.2 (Fisher, 2003)] at both locations—with the exception of CRF very high at UF (Tables 3 and 4), which remained near the upper recommended pH limit. At UF, substrate EC averaged $1.6 \text{ mS}\cdot\text{cm}^{-1}$ and was not influenced by fertilizer treatment (data not shown), which

was within the range suggested for petunia by Gibson et al. (2007). In contrast, EC levels dropped considerably during the consumer phase at UNH with all treatments to below the recommended $1.3 \text{ mS}\cdot\text{cm}^{-1}$, with the exception of CRF TD with a final substrate EC of $1.52 \text{ mS}\cdot\text{cm}^{-1}$ (Table 4).

In contrast to the dark-green foliage and initial SPAD value above 40 at the end of the production phase (Table 2), chlorosis was severe and decreased to below 30 for Control plants at both locations (Tables 3 and 4). Leaf SPAD was affected by fertilizer treatment at both UF and UNH [$P \leq 0.0001$]. The highest SPAD levels occurred in plants receiving the top-dressed CRF TD and SUS TD treatments at UF and UNH, and also for incorporated treatments CRF very high and DCT at UF.

The high rate of WSF plus supplemental Mg and Fe resulted in a moderate effect on plant performance during the consumer phase compared with the Control. Plants receiving the WSF400 + MgFe treatment had higher SPAD and flower number than Control plants at UNH at the end of the consumer phase (Table 4), but there was no effect of the WSF400 treatment alone. At UF, there was no difference in SPAD or flower number between the control plants vs. those receiving WSF400 or WSF400 + MgFe treatments at the end of the consumer phase (Table 3). However, there was a short-term effect at UF whereby at week 2 the plants receiving WSF400 + MgFe had a higher SPAD value (47.8) than the Control [41.8 ($P < 0.01$)].

Other liquid fertilizer treatments (LOF, LU, LU + MgFe) also provided limited improvement to plant performance during the consumer phase. Liquid fertilizer treatments LOF and LU + MgFe had greater SPAD chlorophyll index compared with the Control at UNH (Table 4), but these had no effect on SPAD at UF. Plants receiving the LU or LU + MgFe treatments exhibited phytotoxicity (marginal leaf burn) and stunted plant growth [lower shoot dry mass and flower number (Table 3)] at UF with the $2.74 \text{ g/container N}$ rate of LU, and the LU concentration was therefore reduced by half at UNH.

Table 2. Fertilizer treatment effects on substrate pH and electrical conductivity (EC), leaf SPAD chlorophyll index, shoot dry weight, flower number, substrate, and tissue nitrogen (N) for ‘Supertunia Vista Bubblegum’ petunia in Expt. 1. Data were collected after a 42-d production phase at the University of Florida (UF) and University of New Hampshire (UNH).

	Treatment code ^z	Substrate pH	Substrate EC (mS·cm ⁻¹) ^y	Leaf SPAD chlorophyll index	Shoot dry wt (g/plant) ^y	Flowers (no./plant)	Substrate N (mg·L ⁻¹) ^y
UF	Control	6.25 b ^x	3.37 a	41.2 b	23.6 a	13 a	395.4 ab
	CRF high	6.56 a	0.72 b	43.9 ab	23.3 a	12 a	107.1 b
	CRF very high	6.40 ab	0.85 b	45.9 a	24.9 a	17 a	163.0 b
	DCT	5.72 c	3.64 a	43.0 ab	24.6 a	16 a	623.8 a
		***	***	*	NS	NS	*
UNH	Control	5.95 a	3.82 b	39.1 b	30.6 a	64 b	553.1 b
	CRF high	5.84 ab	3.08 b	45.0 a	31.9 a	62 b	473.6 b
	CRF very high	5.52 bc	4.65 ab	45.6 a	30.2 a	67 b	1038.6 a
	DCT	5.44 c	6.26 a	46.1 a	29.5 a	65 b	836.3 ab
		*	**	*	NS	NS	**

^zSee Table 1 for complete treatment descriptions. CRF = 15.0N-3.9P-10.0K single-coated controlled-release fertilizer; DCT = 14.0N-3.5P-9.1K double-coated CRF; Control = control treatment with water-soluble fertilizer only and no residual fertilizer; high = high fertilization rate; very high = very high fertilization rate.

^y1 mS·cm⁻¹ = 1 mmho/cm; 1 ppm = 1 mg·L⁻¹; 1 g = 0.0353 oz.

^xData represent least square means of 12 replicates, and mean separation used Tukey's honestly significant difference at $\alpha = 0.05$. Means with the same lowercase letter are not significantly different. NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.0001, respectively.

Fertilizer treatments affected shoot dry weight and flower number at the end of the consumer phase [$P \leq 0.0001$ (Tables 3 and 4)]. Shoot dry weight per plant was greatest for treatments CRF TD (treatment 5) and SUS TD (treatment 9) as well as for the incorporated treatment DCT (treatment 12) at both UF and UNH (Tables 3 and 4). Trends in flower number per plant were like those observed for shoot dry weight (Tables 3 and 4), where greater shoot dry weight appeared correlated with greater flower number. The WSF400 + MgFe and CRF very high also increased flowering compared with the Control at UNH only (Table 4).

Substrate N differed among treatments at the end of the consumer phase at UNH [$P \leq 0.0001$ (Table 4)], where N was greatest for CRF TD and lowest for CRF high, CRF very high, and DCT. At UF, substrate N did not differ between treatments (data not shown).

Percent shoot tissue N also differed between treatments at both locations [$P \leq 0.0001$ (Tables 3 and 4)], with shoot tissue N mainly below the sufficiency range recommended for dried petunia leaves [3.85% to 7.60% N (Mills and Jones, 1996)]. Shoot tissue N was within the sufficiency range for plants receiving LU and LU + MgFe at UF, but this result was probably because of less dilution of N concentration in plants that had low shoot dry mass.

Nitrogen accumulation in shoot tissue was greater than the control for CRF TD (treatment 5), MDU TD (treatment 9), SUS TD (treatment 9), and DCT (treatment 12) at UF (Fig. 1A), and for CRF TD (treatment 5), SUS TD (treatment 9), and DCT (treatment 12) at UNH (Fig. 1B). In comparison with the nitrogen uptake of 676 (CRF high) to 2263 (CRF TD) mg/container N (Fig. 1B), fertilizer treatments 2 to 4 only provided 200 mg/container N whereas treatments 5 to 12 contributed at least 1370 mg/container N (Table 1). Water-soluble fertilizers and LOF applied at the POS therefore did not provide sufficient N to maintain plant performance/quality [flower number, shoot dry weight, SPAD chlorophyll index, and shoot tissue N] for the duration of the consumer phase [56 and 61 d at UF and UNH, respectively (Tables

3 and 4)]. However, the additional 117.5 mg/container Mg and 5 mg/container Fe provided by the WSF400 + MgFe treatment did improve leaf SPAD chlorophyll index and flower number compared with WSF400 alone in the UNH experiment (Table 4), emphasizing the roles of Mg and Fe in addition to N in terms of plant quality. Compared with the WSF400, the WSF400 + MgFe treatment resulted in an additional 164.8 mg/plant Mg and 6.8 mg/plant Fe (data not shown), like the extra Mg and Fe supplied by WSF400 + MgFe at the start of the consumer phase.

A top-dress of CRF and SLF treatments (treatments 5 through 9) provided up to 2.7 g additional N per container when applied at the end of production, but only CRF TD and SUS TD consistently produced high-quality petunia for the consumer at both locations (Tables 3 and 4). The controlled-release fertilizer (CRF TD) and composted poultry litter (SUS TD) top-dress fertilizers were marketed as having nutrient release periods of ≈ 120 and 45 d, respectively, and provided a longer-lasting supply of nutrients during the consumer phase as indicated by the high plant uptake of N in Fig. 1. At UF, a top-dress with methylene di-urea (MDU TD) also resulted in relatively high shoot N accumulation during the consumer phase

(Fig. 1A), but plants had SPAD chlorophyll index, shoot weight, and flower number like the control (treatment 1) in Table 3. The methylene di-urea (MDU TD) treatment only supplied N, and the overall poor plant performance may have resulted from the lack of other essential plant nutrients.

Differences in plant performance between CRF and slow-release organic fertilizer treatments may have resulted from differences in nutrient release over time. Nitrogen release for CRF is influenced mainly by the coating technology and temperature (Bro-schat and Moore, 2007; Cabrera, 1997; Carson and Ozores-Hampton, 2012; Oliveira et al., 2016), where a temperature of 21 °C is usually used to rate CRF longevity (Oliveira et al., 2016). Nitrogen release from organic SRFs is influenced by several factors, including soil type, temperature, microbial activity, and type of organic fertilizer material (Burnett et al., 2016; Fan and Li, 2010; Guertal, 2009; Li and Mattson, 2019), and nitrogen release can vary substantially between fertilizer sources and environmental conditions.

Previous research on residual fertilizer strategies by Oliveira et al. (2016) found that container-grown petunia that received CRF were of the highest quality and still growing

vigorously after 42 d in the consumer phase, especially with CRF (incorporated or top-dressed) or DCT applied at a high rate. In this study, CRF and DCT treatments (treatments 5, 10, 11, and 12), as well as top-dressing with composted poultry litter (SUS TD, treatment 6), also resulted in the most actively growing and healthy plants by the end of the consumer phase at both experimental locations. Incorporation or top-dress with a CRF product is a practical and reliable method of supplying residual nutrients for the consumer. Use of organic SRF may also be effective—provided these products provide a favorable nutrient release and do not overly increase substrate pH during nitrogen mineralization.

Expt. 2: Irrigation with water-soluble fertilizer and plant growth regulator at the end of production

During the consumer phase, substrate pH at the start of the consumer phase was within the recommended range for petunia [pH 5.4 to 6.2 (Fisher, 2003)] and increased over time, but it was not influenced by fertilizer or PGR strategy (data not shown). At day 1 of the consumer phase, substrate EC and N were greater with all treatments that included a high rate of WSF at 400 mg·L⁻¹ N (WSF400 and WSF400

Table 3. Residual fertilizer treatment effects on substrate pH, leaf SPAD chlorophyll index, shoot dry weight, flower number, substrate, and tissue nitrogen (N) at the end of consumer phase for ‘Supertunia Vista Bubblegum’ petunia in Expt. 1 at University of Florida.

Treatment code ^z	Substrate pH	Leaf SPAD chlorophyll index	Shoot dry wt (g/plant) ^y	Flowers (no./plant)	Tissue N (%)
Control	6.95 a ^x	28.9 cd	65.0 cd	131 bc	1.71 c
WSF400	6.99 a	29.4 cd	72.9 abc	162 ab	1.72 c
WSF400 + MgFe	7.01 a	30.6 bcd	73.9 abc	140 bc	1.98 bc
LOF	7.04 a	29.3 cd	67.7 bc	140 bc	1.89 c
CRF TD	6.92 a	38.5 ab	79.3 ab	206 a	2.87 bc
LU	7.11 a	30.2 bcd	35.6 f	53 d	4.97 a
LU + MgFe	7.03 a	37.1 abc	37.5 ef	83 cd	4.61 a
MDU TD	6.99 a	27.9 d	68.1 bc	137 bc	3.17 b
SUS TD	7.03 a	38.8 ab	82.8 a	173 ab	2.52 bc
CRF high	6.39 bc	36.2 abcd	51.2 de	153 ab	2.07 bc
CRF very high	6.21 c	38.5 ab	66.6 bc	161 ab	2.58 bc
DCT	6.54 b	41.1 a	82.7 a	212 a	2.71 bc
	***	***	***	***	***

^zSee Table 1 for complete treatment descriptions. CRF = 15.0N–3.9P–10.0K single-coated controlled-release fertilizer; DCT = 14.0N–3.5P–9.1K double-coated CRF; WSF = 17.0N–1.8P–14.1K water-soluble fertilizer; LOF = 3.0N–0.4P–0.8K liquid organic fertilizer; MgFe = supplemental magnesium and iron; LU = 28.0N–0.0P–0.0K liquid urea; MDU = 40.0N–0.0P–0.0K methylene di-urea; SUS = 8.0N–1.8P–3.3K composted poultry litter; DCT = 14.0N–3.5P–0.8K; TD = top-dressed fertilizer; high = high fertilization rate; very high = very high fertilization rate.

^y1 g = 0.0353 oz.

^xData represent least square means of eight replicates, and mean separation used Tukey’s honestly significant difference at $\alpha = 0.05$. Means with the same lowercase letter are not significantly different. ***Significant at $P \leq 0.0001$.

Table 4. Residual fertilizer treatment effects on substrate pH and electrical conductivity (EC), leaf SPAD chlorophyll index, shoot dry weight, flower number, substrate, and tissue nitrogen (N) at the end of consumer phase for 'Supertunia Vista Bubblegum' petunia in Expt. 1 at the University of New Hampshire.

Treatment code ^z	Substrate pH	Substrate EC (mS·cm ⁻¹) ^y	Leaf SPAD chlorophyll index	Shoot dry wt (g/plant) ^y	Flowers (no./plant)	Substrate N (mg·L ⁻¹) ^y	Tissue N (%)
Control	6.58 a ^x	0.50 b	22.5 ef	38.4 def	59 d	57.2 bc	2.94 ab
WSF400	6.75 a	0.58 b	22.0 ef	36.0 ef	53 d	69.6 bc	2.75 ab
WSF400 + MgFe	6.78 a	0.87 ab	29.8 cd	55.5 cde	161 c	13.5 abc	2.23 abc
LOF	6.95 a	0.29 b	30.4 cd	47.9 def	102 cd	35.0 bc	2.54 ab
CRF TD	6.50 a	1.52 a	40.2 a	78.0 ab	237 ab	233.3 a	2.92 ab
LU	6.98 a	0.42 b	23.4 def	30.3 f	58 d	49.2 bc	3.05 a
LU + MgFe	6.80 a	1.06 ab	32.0 bc	50.0 def	115 cd	175.8 ab	2.40 ab
MDU TD	6.83 a	0.55 b	20.3 f	32.3 f	57 d	64.0 bc	2.96 ab
SUS TD	6.78 a	0.72 ab	38.8 ab	72.2 abc	232 ab	55.3 bc	2.57 ab
CRF high	6.90 a	0.66 ab	28.4 cde	43.8 def	120 cd	0.8 c	1.54 c
CRF very high	6.58 a	0.98 ab	31.1 c	58.4 bcd	169 bc	0.7 c	1.51 c
DCT	6.55 a	0.34 b	32.7 bc	79.5 a	247 a	0.9 c	2.18 bc
	NS	**	***	***	***	***	***

^zSee Table 1 for complete treatment descriptions. CRF = 15.0N-3.9P-10.0K single-coated controlled-release fertilizer; DCT = 14.0N-3.5P-9.1K double-coated CRF; WSF = 17.0N-1.8P-14.1K water-soluble fertilizer; LOF = 3.0N-0.4P-0.8K liquid organic fertilizer; MgFe = supplemental magnesium and iron; LU = 28.0N-0.0P-0.0K liquid urea; MDU = 40.0N-0.0P-0.0K methylene di-urea; SUS = 8.0N-1.8P-3.3K composted poultry litter; DCT = 14.0N-3.5P-0.8K; TD = top-dressed fertilizer; high = high fertilization rate; very high = very high fertilization rate.

^y1 mS·cm⁻¹ = 1 mmho/cm; 1 cm = 0.3937 inch; 1 ppm = 1 mg·L⁻¹; 1 g = 0.0353 oz.

^xData represent least square means of eight replicates, and mean separation used Tukey's honestly significant difference at $\alpha = 0.05$. Means with the same lowercase letter are not significantly different. NS, **, ***Nonsignificant or significant at $P \leq 0.01$ or 0.0001, respectively.

+ PGR or WSF400 + Mg + Fe +PGR) compared with the WSF or WSF + PGR treatments [$P < 0.05$ (Figs. 2A and B)]. However, this difference was short term, and there were no differences in substrate EC or N between fertilizer and PGR strategies for the remainder of the experiment. Substrate EC was below the recommended range for petunia [EC of 1.3 to 2.0 mS·cm⁻¹ (Gibson et al., 2007)] at 7 d into the consumer phase, and an EC of near zero by 21 d indicated depletion of root zone nutrients.

Fig. 1. Effect of residual fertilizer strategy on accumulated nitrogen (N) in shoot tissue of 'Supertunia Vista Bubblegum' petunia at the end of the consumer phase for the University of Florida (UF) and University of New Hampshire (UNH). Data represent eight replicates per treatment, and error bars represent 95% confidence intervals based on Tukey's honestly significant difference at $\alpha = 0.05$; CRF = 15.0N-3.9P-10.0K single-coated controlled-release fertilizer; DCT = 14.0N-3.5P-9.1K double-coated CRF; WSF = 17.0N-1.8P-14.1K water-soluble fertilizer; LOF = 3.0N-0.4P-0.8K liquid organic fertilizer; MgFe = supplemental magnesium and iron; liquid urea (LU) = 28.0N-0.0P-0.0K LU; MDU = 40.0N-0.0P-0.0K methylene di-urea; SUS = 8.0N-1.8P-3.3K composted poultry litter; DCT = 14.0N-3.5P-0.8K; TD = top-dressed fertilizer; high = high fertilization rate; very high = very high fertilization rate; 1 mg = 3.5274×10^{-5} oz.

Applying the PGR paclobutrazol, but not a high rate of WSF at 400 mg·L⁻¹ N, at the final irrigation of production affected SPAD, plant canopy height, and canopy width during the consumer phase [$P \leq 0.05$ (Fig. 3)]. Adding additional Mg and Fe did not increase SPAD compared with WSF400 + PGR alone. Leaf SPAD chlorophyll index remained at relatively high levels across fertilizer and PGR strategies until 21 d into the consumer phase (Fig. 3A), after which SPAD index values decreased. Regardless of fertilizer treatment, irrigating with 3 mg·L⁻¹ paclobutrazol at POS resulted in a lower rate of

decreasing SPAD chlorophyll index and delayed symptoms of leaf chlorosis and yellowing by ≈ 7 d (Fig. 3A), which were visually observed when SPAD values dropped below 30.

Plant canopy height was similar across strategies until 35 d into the consumer phase, after which canopy height remained slightly lower for plants receiving PGR compared with

plants not receiving PGR [$P \leq 0.05$ (Fig. 3B)]. Trends were similar for canopy width as shown in Fig. 3C, where canopy width remained lowest for plants supplied with PGR starting at 21 d into the consumer phase. The effect on plant form is very apparent in representative photos of plants within each treatment over time (Fig. 4), whereby lodging (weak, elongated foliage with open spaces between flowers) was very apparent in plants that did not receive PGR, regardless of fertilizer level.

At the end of the consumer phase, plants supplied PGR at the end of production had lower shoot dry weights compared with those supplied without PGR [WSF and WSF400 ($P \leq 0.05$)], with no effects on flower number (Table 5). Shoot tissue N was also lowest for plants irrigated with PGR before the consumer phase (Table 5), and all fertilizer and PGR strategies resulted in shoot tissue N below range recommended for petunia

Fig. 2. Effect of water-soluble fertilizer [WSF (17.0N–1.8P–14.1K)] and plant growth regulator (PGR) treatments applied as the last irrigation during production on substrate electrical conductivity [EC (A)] and nitrogen [N (B)] during the consumer phase for ‘Supertunia Vista Bubblegum’ petunia. Symbols represent the mean of five replicate plants per fertilizer and PGR treatment. Circle and square symbols represent WSF applied at 200 and 400 mg·L⁻¹ N, respectively. Closed and open symbols represent PGR applied at 0 and 3 mg·L⁻¹ paclobutrazol, respectively. Closed triangle symbols represent WSF at 400 mg·L⁻¹ N, 3 mg·L⁻¹ paclobutrazol, and 235 mg·L⁻¹ magnesium and 10 mg·L⁻¹ iron. Error bars represent 95% confidence intervals based on Tukey’s honestly significant difference at $\alpha = 0.05$ analyzed by date; 1 ppm = 1 mg·L⁻¹; 1 mS·cm⁻¹ = 1 mmho/cm.

Fig. 3. Effect of water-soluble fertilizer [WSF (17.0N–1.8P–14.1K)] and plant growth regulator (PGR) treatments applied as the last irrigation during production on leaf SPAD chlorophyll index (A), canopy height (B), and canopy width (C) during the consumer phase for ‘Supertunia Vista Bubblegum’ petunia. Symbols represent the mean of five replicate plants per fertilizer and PGR treatment. Circle and square symbols represent WSF applied at 200 and 400 mg·L⁻¹ nitrogen, respectively. Closed and open symbols represent PGR applied at 0 and 3 mg·L⁻¹ paclobutrazol, respectively. Closed and open symbols represent PGR applied at 0 and 3 mg·L⁻¹ paclobutrazol, respectively. Closed triangle symbols represent WSF at 400 mg·L⁻¹ N, 3 mg·L⁻¹ paclobutrazol, and 235 mg·L⁻¹ magnesium and 10 mg·L⁻¹ iron. Error bars represent 95% confidence intervals based on Tukey’s honestly significant difference at $\alpha = 0.05$ analyzed by date; 1 ppm = 1 mg·L⁻¹, 1 cm = 0.3937 inch.

Fig. 4. Photographs from Expt. 2 for each combination of the one-time application of water-soluble fertilizer at 200 (WSF) or 400 mg·L⁻¹ N (WSF400), with no PGR or a 3 mg·L⁻¹ paclobutrazol (“+ PGR”), and with WSF400 + PGR + magnesium (Mg) + iron (Fe) (including 235 mg·L⁻¹ Mg and 10 mg·L⁻¹ Fe) during the consumer phase for ‘Supertunia Vista Bubblegum’ petunia after increasing duration of irrigating with clear water. Photos within each row (day) are taken at the same distance from containers, but scale changes over time, and plants were randomly selected within each treatment during each date; 1 ppm = 1 mg·L⁻¹.

Table 5. Water-soluble fertilizer (WSF) and plant growth regulator (PGR) treatment effects on shoot dry weight, flower number, shoot tissue nitrogen (N), and N accumulated in shoot tissue at 63 d into the consumer phase for ‘Supertunia Vista Bubblegum’ petunia in Expt. 2.

Treatment code ^z	Shoot dry wt (g/plant) ^y	Flowers (no./plant)	Tissue N (%)	N accumulated in shoot tissue (mg/plant) ^y
WSF	120.6 b ^x	154 a	0.79 b	952.6 a
WSF400	123.7 b	190 a	0.83 b	1022.1 a
WSF + PGR	100.1 a	195 a	1.05 a	1053.2 a
WSF400 + PGR	102.2 a	214 a	1.13 a	1150.7 a
WSF400 + MgFe + PGR	103.2 a ^x	218 a	1.12 a	1155.8 a

^zWSF = 17.0N–1.8P–14.1K water-soluble fertilizer; PGR = plant growth regulator; MgFe = magnesium and iron.

^y1 g = 0.0353 oz; 1 mg = 3.5274 × 10⁻⁵ oz.

^xData represent least square means of eight replicates, and mean separation used Tukey’s honestly significant difference at $\alpha = 0.05$. Means with the same lowercase letter are not significantly different.

[3.85% to 7.60% N (Gibson et al., 2007)]. There were no differences in accumulated shoot tissue N at the end of the consumer phase (Table 5).

Conclusions

Fertilizer and PGR strategies used during production have carry over effects on the performance of container crops, and these methods have potential to add value, differentiate plant products, and increase consumer success. Providing a residual fertilizer charge and plant growth regulator at the point of sale can increase plant performance for long-term and vigorous plants such as petunia in hanging baskets, patio containers, or the landscape.

Container-grown petunia that received CRF (incorporated or top-dressed) or DCT and were top-dressed with composted poultry litter maintained the greatest plant quality compared with the other fertilizer treatments, and they were still vigorously growing after 42 d in the consumer phase. Irrigating with high rates of WSF with supplemental Mg and Fe before sale provided some additional N and consumer benefit, but plants quickly became stunted and nutrient-deficient post-production. Except for composted poultry litter, organic or urea-based SRF applications resulted either in deficiency from slow nutrient release or phytotoxicity, probably from excessive urea-N. These results highlight the importance of providing continual and adequate rates of nutrient release when selecting residual fertilizer strategies for vigorous floriculture crop species.

Irrigating with the PGR paclobutrazol at the end of production extended petunia shelf life performance by maintaining plant form, as well as reducing plant growth rate and corresponding demand for nutrients. Growers have access to a range of PGR options and application methods, and combining effective PGR and residual fertilizer strategies has potential to further increase the duration of plant performance for the consumer. Selection of an appropriate combination of residual fertilizer and PGR strategy would likely depend on grower practicality and cost.

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