Strategies to Provide Fertilizer for Both Production and Consumer Phases of Petunia

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SUMMARY. **The objective of this study was to compare strategies using water-soluble fertilizers (WSF) and controlled-release fertilizers (CRF) to provide adequate nutrition during both production and consumer phases of petunia (*Petunia ×hybrida*). Strategies included a CRF with a second prill coating (DCT) that delayed initial nutrient release, compared with a conventional single-coated CRF (OSM) and WSF. Rooted cuttings of petunia were grown for 42 days in trade 1-gal (2.84-L) containers (the "production phase") with WSF only, a low rate of combined WSF and substrate-incorporated OSM, or low and high label rates of WSF and top-dressed (TD) OSM (WSF + OSM TD), WSF and substrate-incorporated DCT (WSF + DCT), OSM, or a commercial blend of substrate-incorporated OSM and DCT (OSM + DCT). By the end of production phase after 42 days, all fertilizer strategies tested produced horticulturally acceptable plants in terms of chlorophyll index and number of flowers. In a subsequent "consumer phase," plants were maintained in containers or were transplanted into a landscape and irrigated with clear water for 98 days. Plant performance [number of flowers, SPAD chlorophyll index, dry weight, and tissue nitrogen (N) level] was greater during the consumer phase in treatments with high rates of CRF compared with WSF only or lower rates of CRF. On the basis of nutrient release in a sand substrate without plants at 10, 21, or 32 °C, the DCT had delayed nutrient release compared with single-coated CRF. The release rates of all CRF products and the duration of the delay in release from DCT were temperature dependent. A partial budget found that the lowest cost treatment was WSF only at $0.02/container. Comparing at high application rates, using WSF + DCT ($0.085/container) was more expensive than incorporated OSM ($0.05/container) and had a similar cost to WSF + OSM TD ($0.084/container). The greatly improved consumer performance for plants with residual fertilizer compared with WSF provides an opportunity to add value and profitability if a slightly higher sales price could be obtained. Several fertilizer strategies are available depending on material and labor cost and availability and preferred crop management style.**

Providing residual fertilizer to containerized floriculture products to improve postproduction (consumer) performance is a means to add value and differentiate product quality. Water-soluble and controlled-release fertilizers are widely used for production of container crops. Using CRF instead of WSF is recommended to the landscape service industry as a best management practice to provide nutrients for an extended period (Andiru et al., 2013; Chen et al., 2011). CRF include urea, ammonium nitrate, potassium nitrate, or other soluble fertilizer materials coated with a polymer, resin, sulfur, or a hybrid of sulfur-coated urea coated with a polymer or resin. Polymer-coated materials release nutrients primarily based on the temperature and moisture status of the substrate (Sonneveld and Voogt, 2009). Many studies have demonstrated that CRF have potential to reduce N and phosphorus runoff as compared with fertigation (Wilson and Albano, 2011; Wu et al., 2008). The use of CRF alone does not provide a complete solution to the problem of nutrient leaching; however, appropriate fertilizer application methods, CRF types, and irrigation strategies must be calibrated to match crop needs and the local environment (Broschat and Moore, 2007).

Both growth chamber and greenhouse methods have been used to compare how CRF will act in a particular controlled environment (Broschat and Moore, 2007; Carson and Ozores-Hampton, 2012). Field methods are also used to measure N release in commercial vegetable soil conditions (Birrenkott et al., 2005; Simonne and Hutchinson, 2005). The CRF response profile under controlled laboratory conditions can be combined with substrate extraction methods in the field to quantify release characteristics of CRF for different crops and locations (Birrenkott et al., 2005).

A range of fertilizer strategies are available to provide nutrients during production and consumer phases. Containers may be produced with WSF and then top-dressed with CRF before sale. A CRF may alternatively be incorporated into the substrate or top-dressed at planting with a longevity that exceeds the production time, so that residual nutrient reserves remain for the consumer. In a commercially available technology [DCT (Protect™;

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Units

Units To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
0.5933	lb/yard^3	kg·m^{-3}	1.6856
1000	mmho/cm	µS·cm^{-1}	0.0010
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274×10^{-5}
7.4892	oz/gal	g·L^{-1}	0.1335
1	ppm	mg·L^{-1}	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Everris, Geldermalsen, The Netherlands)], a second outer coating is present over a conventional single-coated CRF prill (Osmocote Exact™; Everris), which according to the manufacturer delays the initial nutrient release for 1.5 to 2 months depending on temperature. For the purposes of clarity in this article, we will use OSM to refer to single-coated CRF technology (Osmocote™; Everris), to differentiate from DCT. A blended product of OSM and DCT (Osmocote Hi-End™; Everris) will be referred to as OSM + DCT, and both OSM and DCT will be referred to as types of CRF.

The objective of this study was to compare nutrient release, plant performance, and cost for strategies that potentially provide adequate nutrition during both the production and consumer phases for container-grown floricultural plants. Unless indicated as top-dressed, all CRF treatments were incorporated into the growing substrate before planting. Fertilizer strategies included WSF only, a combination of low rates of WSF during production plus OSM (WSF + OSM), WSF during production with DCT (WSF + DCT), and OSM or OSM + DCT without WSF. These strategies were used to encompass most approaches in use by floriculture producers. A greenhouse experiment was conducted with petunia grown in a peat/perlite substrate in containers for 42 d with WSF or CRF treatments to simulate the production phase. Plant growth and nutrient level were evaluated under simulated consumer conditions in a landscape planting and in containers for an additional 98 d. A simple financial budget for each fertilizer strategy was calculated. An additional experiment was conducted to generate nutrient release curves in growth chambers at 10, 21, and 32 °C with sand-filled columns, using a protocol based on Carson and Ozores-Hampton (2012).

Materials and methods

Greenhouse fertilizer experiment (petunia). A greenhouse fertilizer experiment was conducted at the University of Florida, Environmental Horticulture Research Complex in Gainesville from 16 Sept. 2014 to 5 Feb. 2015. During the production phase from 16 Sept. 2014 to 29 Oct. 2014, greenhouse daily light integral (DLI) averaged (±SD) 15.7 ± 5.1 $mol \cdot m^{-2} \cdot d^{-1}$ and daily air temperature averaged 24.1 ± 2.2 °C. This production period was followed by 98 d from 30 Oct. 2014 to 5 Feb. 2015, as the "consumer period" in either the same greenhouse (DLI of 12.5 ± 5.7 $mol \cdot m^{-2} \cdot d^{-1}$ and 21.3 ± 1.1 °C) or following transplanting into a drip-irrigated landscape bed (DLI of 21.9 ± 8.2 $mol \cdot m^{-2} \cdot d^{-1}$ and 17.0 ± 5.8 °C). In the landscape, plants were spaced at 0.5 m along the bed and were drip irrigated using 500 $L \cdot h^{-1}$ per 100 m of drip tape for 60 min (2.5 L per plant) about every 2 d depending on rainfall. A total of 19.6 cm of rain fell during the consumer phase. Plants in the landscape were covered with spunbound polyethylene cloth on nights when frosts occurred (19 Nov. and 20 Nov. 2014 and 8 Jan. 2015), with a minimum air temperature of 0 °C.

Unrooted cuttings of 'Supertunia Vista Bubblegum' petunia (Innovaplant, Sarchí, Costa Rica) were transplanted into 25-mm-diameter paper-wrapped pots (Ellepot; Blackmore Co., Bellville, MI) with 70% peat/30% perlite mix (Fafard 1P Mix; Sun Gro Horticulture, Agawam, MA) on 28 Aug. 2014. After cuttings were well rooted (16 Sept. 2014), they were transplanted into trade 1-gal container [2.84 L (Growers Solution, Cookeville, TN)] filled with 80% peatmoss, perlite, and vermiculite substrate (Fafard 2 Mix; Sun Gro Horticulture) that contained a low concentration of WSF as a preplant nutrient charge [initial electrical conductivity (EC) 600 $\mu S \cdot cm^{-1}$, pH 6.3 using the saturated medium extract method (Warncke, 1986)]. The bottom of each container was lined with nylon mesh to avoid substrate being lost through drainage holes.

Production phase. The experiment was a randomized complete block design with three benches in the same greenhouse compartment, where each bench represented a block with six replicate containers for each treatment combination. The treatments included 10 fertilizer strategies at a medium and high rate for color crops based on label recommendations and input from the fertilizer manufacturer (F. Hulme, personal communication), adjusted to provide equivalent N rates across CRF fertilizer types (Table 1).

Between 0 and 42 d, plants were irrigated with one of three solutions: clear water (treatments 5, 6, 9, and 10), 100 $mg \cdot L^{-1}$ of N (treatment 2) from 15 N–2.2P–12.5K (Peters® Excel 15-5-15 CalMag Special Fertilizer; Everris), or 200 $mg \cdot L^{-1}$ N from 15N–2.2P–12.5K (treatments 1, 3, 4, 7, and 8). For treatments with incorporated CRF, a measured dose of the fertilizer per container was mixed into the substrate before planting, at 534 and 890 $mg \cdot L^{-1}$ N of substrate for the low or high rate treatments. Controlled-release fertilizers used were DCT 14N–3.5P–9.1K (Protect™; Everris), OSM 15N–3.9P–10.0K (Osmocote Plus™; Everris), and OSM + DCT 15N–3.9P–10.0K (Osmocote Exact Hi-End™; Everris), with longevity between 5 and 6 months for the three products.

Plants were drip irrigated in the greenhouse using both manual and moisture sensor (10HS; Decagon Devices, Pullman, WA)–based control. Clear water quality had an EC of 410 $\mu S \cdot cm^{-1}$, pH 7.61, and 51 $mg \cdot L^{-1}$ calcium carbonate ($CaCO_3$) alkalinity. Plants were grown with near-zero leaching, using collection saucers for reabsorption of any leachate by the plants. At the end of the experiment, total volume of water applied was 5.4 L per plant.

The pour-through method (Whipker et al., 2011) was used for nondestructive pH and EC measurements at days 0, 7, 14, 21, and 28 and then every 15 d from day 28 onward, for two randomly selected replicate pots per treatment on each of the three benches. Nitrate and ammonium of leachate were analyzed by semiautomated and automated colorimetry at the Institute of Food and Agricultural Sciences Analytical Services Laboratories, University of Florida (Gainesville, FL), with two replicate containers per bench combined into a composite sample, resulting in three replicates for leachate analysis per treatment combination per measurement date.

At day 0, 150 rooted liners were destructively sampled to measure initial dry weight and tissue nutrient content. At day 42, six plants per treatment were destructively sampled for N level in tissue and total plant dry weight (shoot and roots combined). For N analysis of combined shoot and root tissue by Quality Analytical Laboratories (Panama City, FL), the two replicate containers per bench were combined into a composite sample, resulting in three replicates per treatment combination. At day 42,

Table 1. Fertilization treatments applied to 'Supertunia Vista Bubblegum' petunia over a 42-d crop cycle for the greenhouse plant growth experiment ("production phase") and over 98 d in the field experiment ("consumer phase").

Treatment code[z]	Preplant fertilizer incorporated (lb/yard^3)[y]	WSF applied during the production phase (mg·L^{-1} nitrogen)[y]	Fertilizer applied during the consumer phase (lb/yard^3)
(1) WSF	None	200	None
(2) WSF + OSM	OSM (4.0)	100	None
(3) WSF + OSM TD Low	None	200	OSM TD (6)
(4) WSF + OSM TD High	None	200	OSM TD (10)
(5) OSM Low	OSM (6.0)	None	None
(6) OSM High	OSM (10.0)	None	None
(7) WSF + DCT Low	DCT (6.4)	200	None
(8) WSF + DCT High	DCT (10.7)	200	None
(9) OSM + DCT Low	OSM + DCT (6)	None	None
(10) OSM + DCT High	OSM + DCT (10)	None	None

[z]OSM = 15N–3.9P–10.0K single-coated controlled-release fertilizer (CRF); DCT = 14N–3.5P–9.1K double-coated CRF; OSM + DCT = blend of 15N–3.9P–10.0K single- and double-coated CRF; WSF = 15N–2.2P–12.5K water-soluble fertilizer; TD = top-dressed application; Low = low fertilization rate; High = high fertilization rate.
[y]1 lb/yard^3 = 0.5933 kg·m^{-3}; 1 mg·L^{-1} = 1 ppm.

the number of flowers (all open or closed buds showing pink petal color) were counted, and chlorophyll index was measured on five fully expanded leaves per plant with a Minolta SPAD meter (Soil Plant Analysis Development, Ramsey, NJ) on all 18 replicates per fertilizer treatment.

To simulate a consumer phase in either containers or the landscape after day 42, six plants per treatment remained in the 2.84-L containers, and six plants were transplanted into the landscape in a sandy soil for an additional 98 d. No additional fertilizer was applied except for CRF in top-dressed treatments 3 and 4. The landscape soil was tested before planting with a Mehlich III soil extraction (Quality Analytical Laboratories) and showed no detected N, high P (487.8 mg·L^{-1}) and K (219 mg·L^{-1}) (Mylavarapu et al., 2014), pH 6.32, and an EC of 200 μS·cm^{-1}. All plants in both locations were irrigated with clear tap water. Every 15 d after transplanting, chlorophyll index was nondestructively measured on all plants. Flowers were counted every 15 d from day 70 onward. During the consumer phase, plants were drip irrigated in the landscape or were manually watered using a hose in the greenhouse (with zero leaching using collection saucers under each container). For the container-grown plants only, pour-through leachate samples were collected from each container every 15 d.

At day 140, the 12 plants in containers or the landscape were destructively sampled for tissue dry weight and nutrient content, chlorophyll analysis, and number of flowers. Nitrogen uptake efficiency was calculated from leaf tissue. Total N content in oven-dried ground plant tissue samples was determined by Quality Analytical Laboratories.

NITROGEN RELEASE FROM CRF IN THE GREENHOUSE FERTILIZER EXPERIMENT (SAND CONTAINERS, NO PLANTS). On the basis of the protocols from Birrenkott et al. (2005), a leachate collection unit (LCU) was assembled by placing a standard nursery container inside a 6-inch-diameter hole cut into the lid of a 2-gal black polyethylene bucket (Plasticas, Dallas, TX). An injection-molded 2.3-L nursery container (Classic 300S; Nursery Supplies, Chambersburg, PA) was inserted into the collection bucket lid and slid into position so that ≈1 inch of the bottom of the nursery container protruded through the lid, with all drain holes beneath the collection bucket lid. The nursery container was plastic welded to the lid of the collection bucket using a 0.4-cm-diameter, high-density polyethylene plastic welding rod and a plastic welding gun. The container was welded on both the top and bottom sides of the lid. A circular disk (6-inch diameter × 1-inch height) cut from porous spun-bound polyester fabric was placed in the bottom of the nursery container to cover the drain holes, filter the leachate solution, and retain the hydrochloric acid (HCl)–washed sand substrate.

Treatments applied to LCUs were arranged on the greenhouse benches alongside the containers filled with petunia in a randomized complete block design with three replicate LCUs per treatment. Fertilizers were applied to each LCU with five treatments, representing a control (no fertilizer), or the high rates as used in the experiment with plants (Table 1) of incorporated OSM, DCT, blended OSM + DCT, and OSM TD. The LCUs received similar volumes of overhead irrigation as the volumes applied to petunia containers, using clear water, via a dripper during the production phase or hand watering during the consumer phase. Each week, leachate containers were emptied and stored with sulfuric acid (1%, v/v) at 4 °C. Every 21 d (days 21, 42, 63, 84, 105, and 126), an additional 2 L water was applied to each container to ensure a complete leaching of released nutrients. This leached sample was combined with the previous 14 d of leachate for each container to represent the combined nutrient release over each 21-d period. Leachate pH, EC, ammonium (NH_4-N), nitrate (NO_3-N), and volume were then measured as described in greenhouse fertilizer experiment.

GROWTH CHAMBER EXPERIMENT. Plastic columns measuring 40 cm in height (filled with substrate to the 25-cm line) and 2 cm in internal diameter were mounted vertically into growth chambers. Columns were filled with 0.5 L HCl-washed sand, fitted with mesh in the end and sealed to retain moisture. The experiment included three fertilizer source treatments, three growth chamber incubation temperatures [10, 21, and 32 °C (50.0, 69.8, and 89.6 °F)], and 14 sampling dates (1, 2, 4, 7, 14, 28, 42, 56, 70, 84, 98, 112, 126, and 147 d), with six replicate columns for each fertilizer treatment randomized within each temperature environment.

For each experimental unit, fertilizer was added at a rate of 5.93 $g \cdot L^{-1}$ of OSM, 5.93 $g \cdot L^{-1}$ of OSM + DCT, or 6.36 $g \cdot L^{-1}$ for DCT to provide 890 $mg \cdot L^{-1}$ N of substrate. Granular fertilizer was weighed and hand mixed into the sand in each column. A beaker containing 40 mL of 0.2 M sulfuric acid was placed in each growth chamber for ammonia gas entrapment to trap ammonia; however, no dissolved N was measured in this solution.

Experimental conditions and leachate sampling from the sand columns were based on published protocols (Cabrera, 1997; Carson and Ozores-Hampton, 2012; Fan and Li, 2010). Columns remained saturated with water up to the upper level of the sand. At each sampling date, all columns were removed from the growth chamber, and 1.25 L of deionized water was added to each column (substrate:extraction solution ratio of 1:2.5). Leachate from each container was captured in polyethylene beakers and filtered through Whatman No. 42 filter paper (Whatman-GE, Maidstone, UK). Each replicate column was measured separately for pH, EC, and leachate volume. Pairs of replicate columns were combined for N analysis and stored with sulfuric acid (1%, v/v) at 4 °C for no more than 15 d before analysis at the University of Florida Institute of Food and Agricultural Sciences Analytical Services Laboratories. Air temperature was measured in the three controlled climate conditions using data loggers.

Statistical analysis. Nutrient and plant growth data from petunia containers were analyzed with analysis of variance (ANOVA) using SAS PROC GLM (version 9.2; SAS Institute, Cary, NC) where the effect of fertilizer on SPAD chlorophyll index, number of flowers, dry weight, and tissue N concentration was tested at day 42. The pH, EC, and N concentration in pour-through samples were averaged for each container over the 42-d period before analyzing fertilizer effects using ANOVA. Because plants receiving treatments 1, 3, and 4 were treated identically during the production phase (200 $mg \cdot L^{-1}$ WSF and no CRF), these plants were combined as one treatment during the production phase. Plants in these three treatments were analyzed separately during the consumer phase, after CRF was top-dressed for treatments 3 and 4 but not for treatment 1. During the consumer phase, SPAD chlorophyll index and number of flowers were analyzed separately by measurement day and location (greenhouse or landscape). For the LCUs, main and interaction effects of fertilizer and measurement day were analyzed for pH, EC, and milligrams N.

In the growth chamber experiment, main and interaction effects of fertilizer, temperature, and measurement day were analyzed for pH, EC, and milligrams N. In all analyses, least square treatment means were compared using Tukey's honestly significant difference at $\alpha = 0.05$. The nutrient release curves in terms of cumulative percent of total N released (R, as a percentage calculated from milligrams N in leachate per total 445 mg N per column applied) over time t (in days) was first fitted with the Richards (1959) function (Eq. [1]). Initial (H_{init}) and final (H_{final}) percent release were set to 1% and 100%, respectively, and PROC NLIN in SAS was used to estimate N (inflection parameter) and K (rate parameter) by fertilizer and temperature.

$$R = \frac{(H_{init} \times H_{final})}{\left(H_{init}{}^{N} + \left(H_{final}{}^{N} - H_{init}{}^{N}\right) \times e^{-kt}\right)^{1/N}} \quad [1]$$

After plotting the rate parameter K in Eq. [1] for each fertilizer, K increased with temperature in an approximately linear manner. Therefore, K was calculated from the column temperature T, K was replaced with a linear function $a + bT$, and PROC NLIN was used to estimate N, a, and b in Eq. [2] separately for each fertilizer.

$$R = \frac{(H_{init} \times H_{final})}{\left(H_{init}{}^{N} + \left(H_{final}{}^{N} - H_{init}{}^{N}\right) \times e^{-1(a+bT)t}\right)^{1/N}} \quad [2]$$

The empirically fitted curves from Eq. [2] could therefore be used to describe the observed nutrient release at t days within the temperature range from 10 to 32 °C for each fertilizer based on the three parameters, N, a and b, and the temperature T.

Economic analysis. A partial budget analyzed the cost of CRF and WSF strategies based on the treatments applied in the greenhouse fertilizer experiment. Fertilizer cost for OSM was assumed to be \$83.70 per 50-lb bag based on the 2014 catalog cost from BWI Companies (BWI, Apopka, FL). The DCT and OSM + DCT products were not currently sold in the United States. However, based on manufacturer information (F. Hulme, personal communication), the costs per 50-lb bag were estimated at 120% (\$100.50) or 110% (\$92.13) of the base CRF cost of OSM, respectively. The labor cost for top-dressing containers with CRF assumed an hourly rate of \$9.66 based on the minimum wage of \$8.05/h for 2015 in Florida (Florida Nursery Growers and Landscape Association, 2015), with an additional 20% (total \$9.66) to allow for administrative and insurance costs. An estimate of 720 containers top-dressed per hour (12 plants/min) was based on discussion with several greenhouse growers using CRF.

The price of WSF was based on the 2014 catalog cost from BWI for 15N–2.2P–12.5K at \$31.20 per 25-lb bag. The amount of N from the WSF applied to the containers was calculated on a pot-by-pot basis (Mattson, 2010). To use this method, it was necessary to consider the cost and weight per bag, percentage of N, the volume of water applied per container (5.4 L), and the applied concentration of fertilizer (0, 100, or 200 $mg \cdot L^{-1}$ N). These assumptions were used to calculate the WSF cost per container from Eqs. [3], [4], and [5].

$$\text{Cost per gram of N(\$)} = \left\{ \left[\frac{\text{cost per bag(\$)}}{\text{weight per bag(grams)}} \right] \times \%\text{N} \right\} \quad [3]$$

$$\text{Grams of N applied per container} = \frac{\text{volume of water applied(liters)} \times \text{concentration of fertilizer(miligrams per liter N)}}{1000} \quad [4]$$

$$\text{Total cost per container WSF (\$)} = \text{grams of N applied} \times \text{cost per gram of N} \quad [5]$$

Results and discussion

Greenhouse fertilizer experiment (petunia)

Growth during the production phase. Fertilizer treatments affected total dry weight ($P \leq 0.01$), SPAD

Table 2. Summary analysis of variance table showing the effects of fertilizer treatments on 'Supertunia Vista Bubblegum' petunia plant growth and nutrition in containers at the end of the production phase (42 d).

Treatment code[z]	Total dry wt (g/plant)[y]	SPAD chlorophyll index	Flowers (no./plant)	pH	EC ($\mu S \cdot cm^{-1}$)[y]	Substrate nitrogen ($mg \cdot L^{-1}$)[y]	Tissue nitrogen (%)
(1, 3, and 4) WSF	11.4 b[x]	37.8 ab	11.3 c	6.62 a	1,668 d	27.4 c	4.6 ab
(2) WSF + OSM	14.3 ab	37.7 ab	14.4 bc	6.34 bc	2,308 c	72.0 b	4.9 ab
(5) OSM Low	14.7 ab	41.8 a	29.5 a	6.32 bc	2,301 c	86.0 b	3.1 c
(6) OSM High	17.5 a	41.3 ab	20.8 ab	6.12 d	3,224 a	142.1 a	4.7 ab
(7) WSF + DCT Low	13.8 ab	37.3 b	9.3 c	6.35 b	2,535 bc	69.3 b	5.2 ab
(8) WSF + DCT High	13.7 ab	39.1 ab	12.8 bc	6.30 bc	2,869 ab	99.1 b	5.3 a
(9) OSM + DCT Low	10.0 b	38.0 ab	9.6 c	6.38 b	2,210 c	83.3 b	3.0 c
(10) OSM + DCT High	15.7 ab	40.4 ab	18.7 b	6.20 cd	3,141 a	144.2 a	3.8 bc

During the production phase, treatments 1, 3, and 4 all received the same water-soluble fertilizer (WSF) treatment [top-dressing of controlled-release fertilizer (CRF) occurred after 42 d for treatments 3 and 4] and were therefore analyzed as a combined treatment. Substrate nutrient values (pH, EC, and nitrogen) were obtained by the average pour-through concentrations from sampling at days 0, 7, 14, 21, 28, and 42.

[z]OSM = 15N–3.9P–10.0K single-coated CRF; DCT = 14N–3.5P–9.1K double-coated CRF; OSM + DCT = blend of 15N–3.9P–10.0K single- and double-coated CRF; WSF = 15N–2.2P–12.5K WSF; Low = low fertilization rate; High = high fertilization rate.

[y]1 g = 0.0353 oz; 1 $mg \cdot L^{-1}$ = 1 ppm; 1 $\mu S \cdot cm^{-1}$ = 0.0010 mmho/cm.

[x]Least-square means were compared using Tukey's honestly significant difference at $\alpha = 0.05$.

chlorophyll index ($P \leq 0.01$), and number of flowers ($P < 0.0001$) at day 42, with least-square treatment means shown in Table 2. The highest dry weight occurred with the high rate of incorporated OSM (treatment 6), which resulted in more growth than with the low rate of OSM + DCT (treatment 9) or the WSF only treatment (combined treatments 1, 3, and 4). SPAD chlorophyll index was higher for plants receiving the low rate of incorporated OSM (treatment 5) compared with the low rate of WSF + DCT (treatment 7). The highest number of flowers occurred with the low and high rates of incorporated OSM (treatments 5 and 6). Overall, OSM incorporated at low or high rates (treatments 5 and 6) resulted in high levels of growth and quality indices across all variables (dry weight, SPAD chlorophyll index, and number of flowers). However, at day 42 all plants appeared horticulturally acceptable as saleable flowering products, in terms of multiple open blooms with dark green foliage covering the container surface, regardless of fertilizer strategy (Fig. 1A).

NUTRIENT LEVELS DURING THE PRODUCTION PHASE. Fertilizer treatments affected substrate-pH ($P < 0.0001$), substrate-EC ($P \leq 0.0001$), substrate-N ($P \leq 0.0001$), and tissue-N ($P < 0.0001$), with least square treatment means shown in Table 2. Substrate-pH level for WSF only (combined treatments 1, 3, and 4) was higher than substrate-pH for all other treatments. The lowest pH levels occurred with the high rate of OSM (treatment 6) and OSM + DCT (treatment 10). Substrate-EC with the WSF only treatment (combined treatments 1, 3, and 4) was also significantly lower than with other treatments. The highest substrate-EC occurred with the high rate of OSM (treatment 6) and OSM + DCT (treatment 10). The observed trend whereby high pH treatments tended to have a low EC is consistent with cation exchange of fertilizer cations with protons on the peat substrate (Fisher et al., 2014). Most pH levels were slightly higher than recommended for petunia [5.4 to 6.2 (Fisher, 2003)] during the production phase, although there were no visual signs of iron deficiency (Fig. 1A) or large differences in SPAD chlorophyll level (Table 2). The recommended range for EC using the pour-through method of 2600 to 4600 $\mu S \cdot cm^{-1}$ for most established plants (Whipker et al., 2003) was above the EC levels observed in treatments except for the high rates of OSM (treatment 6), WSF + DCT (treatment 8), or OSM + DCT (treatment 10). The average substrate-N content during the production phase (Table 2) was highest with the high rate of incorporated OSM (treatment 6) or OSM + DCT (treatment 10), and was lowest with the WSF-only treatments (1, 3, and 4). The low rate of OSM (treatment 5) and OSM + DCT (treatment 9) resulted in 3.1% and 3.0% tissue-N, respectively, which was lower than the range recommended by Mills and Jones (1996) for petunia of 3.9% to 7.6%.

GROWTH AND TISSUE-N DURING THE CONSUMER PHASE. Fertilizer treatments differed in total dry weight by day 140 (Table 3). In the greenhouse ($P < 0.0001$), dry weight was highest with WSF + DCT (treatments 7 and 8) or WSF + OSM TD (treatments 3 and 4) at both the low and high rates. In the landscape ($P = 0.0001$), the highest dry weight occurred with high rates of WSF + DCT (treatment 8) or WSF + OSM TD (treatment 4). Both WSF + DCT and WSF + OSM TD strategies were expected to release the majority of their CRF nutrients during the consumer phase, an assumption that was supported by the higher dry weight during the consumer phase, especially at high CRF rates. Photographs of plants after 42 d in the consumer phase (84 d after planting, Fig. 1B) illustrate reduced growth of WSF only (treatment 1), WSF + OSM (treatment 2), low rate of OSM (treatment 5), and low rate of OSM + DCT (treatment 9) by day 84. At the end of the consumer phase (140 d), all plants exhibited yellow foliage, lower leaf loss, and a decrease in flowering, particularly plants grown with treatments 1, 2, 5, 7, and 9 (Fig. 1C).

At the end of the consumer phase, fertilizer treatments affected the SPAD chlorophyll index (Table 3). In the greenhouse ($P < 0.0001$), treatments with either a high rate of incorporated OSM (treatment 6) or OSM + DCT (treatment 10), or both low and high rates of WSF + DCT (treatments 7 and 8) or WSF + OSM TD (treatments 3 and 4) resulted in the highest SPAD chlorophyll index. In the landscape ($P < 0.01$), the highest SPAD chlorophyll index occurred with incorporated OSM (treatments 5 and 6) and WSF + OSM TD

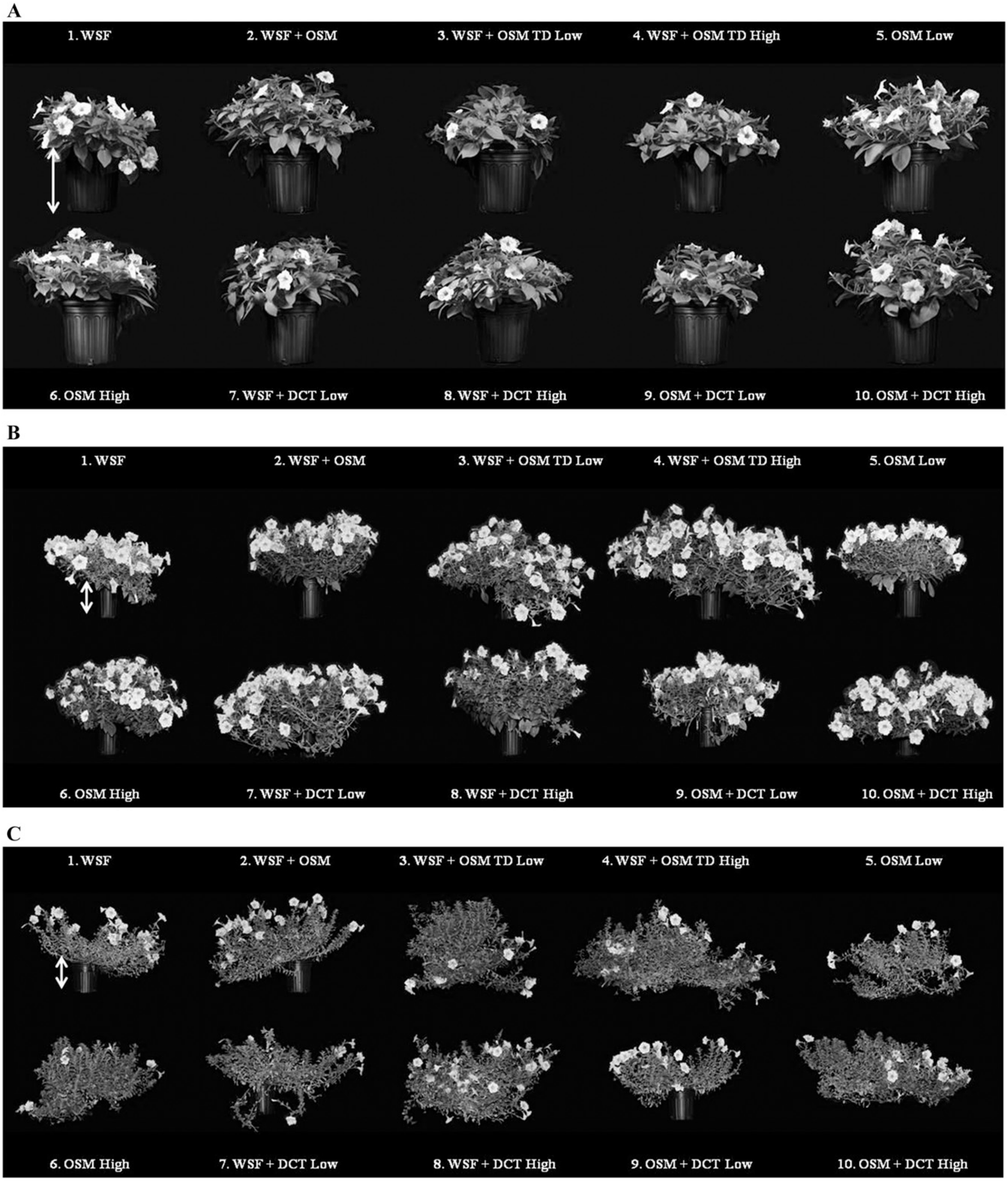

Fig. 1. Photographs of representative 'Supertunia Vista Bubblegum' petunia plants grown with different fertilizer treatments detailed in Table 1. (A) Photograph taken at the end of the production phase (42 d after planting), immediately before the start of the consumer phase. During the production phase, certain treatments (1, 2, 3, 4, 7, and 8) received water-soluble fertilizer (WSF), whereas other treatments (5, 6, 9, and 10) received clear water only. Plants in treatments 3 and 4 had not yet received their top-dressed (TD) fertilizer; (B) 42 d in the consumer phase (84 d after planting); or (C) 98 d in the consumer phase (140 d after planting). During the consumer phase, all plants received clear water only, and WSF labels refer to the nutrient solution applied during the production phase. White arrows on the left of each photo represent the container height of 16.5 cm (6.50 inches) to provide a comparative scale, because photos are taken at increasing distance away from the plants as time progressed. OSM = 15N–3.9P–10.0K single-coated controlled-release fertilizer (CRF); DCT = 14N–3.5P–9.1K double-coated CRF; OSM + DCT = blend of 15N–3.9P–10.0K single- and double-coated CRF; WSF = 15N–2.2P–12.5K WSF; Low = low fertilization rate, High = high fertilization rate.

Table 3. Summary analysis of variance (ANOVA) table showing the effects of fertilizer treatments on 'Supertunia Vista Bubblegum' petunia plant growth and tissue nitrogen (N) after 98 d in the consumer phase (140 d after planting) for the containers continued in the greenhouse or transplanted to the landscape.

	Greenhouse				Landscape			
Treatment code[z]	Total dry wt (g/plant)[y]	SPAD chlorophyll index	Flowers (no./plant)	Tissue N (%)	Total dry wt (g/plant)	SPAD chlorophyll index	Flowers (no./plant)	Tissue N (%)
(1) WSF	43.9 e[x]	18.5 d	45 ab	0.80 b	34.0 e	29.4 bc	0 c	0.96 b
(2) WSF + OSM	75.0 bcd	29.8 bc	33 ab	1.03 ab	54.7 d	29.6 bc	2 bc	1.30 ab
(3) WSF + OSM TD Low	83.2 ab	33.6 abc	44 ab	1.17 ab	73.7 c	31.5 ab	7 abc	1.56 a
(4) WSF + OSM TD High	85.7 ab	37.4 a	56 a	1.57 a	90.7 ab	30.4 abc	15 ab	1.73 a
(5) OSM Low	60.0 cde	29.7 c	14 b	1.30 ab	46.6 d	33.4 a	2 bc	1.40 ab
(6) OSM High	79.1 bc	33.2 abc	19 ab	1.33 ab	78.3 bc	30.4 abc	6 abc	1.76 a
(7) WSF + DCT Low	87.4 ab	32.2 abc	33 ab	1.33 ab	71.1 c	27.2 c	9 abc	1.43 ab
(8) WSF + DCT High	103.0 a	35.8 ab	41 ab	1.70 a	95.8 a	27.8 c	17 a	1.26 ab
(9) OSM + DCT Low	55.7 de	28.6 c	16 b	1.30 ab	47.9 d	29.5 bc	2 bc	1.33 ab
(10) OSM + DCT High	81.0 bc	32.4 abc	27 ab	1.47 ab	74.6 c	28.9 bc	9 abc	1.36 ab

[z] OSM = 15N–3.9P–10.0K single-coated controlled-release fertilizer (CRF); DCT = 14N–3.5P–9.1K double-coated CRF; OSM + DCT = blend of 15N–3.9P–10.0K single- and double-coated CRF; WSF = 15N–2.2P–12.5K water-soluble fertilizer; TD = top-dressed application; Low = low fertilization rate; High = high fertilization rate.

[y] 1 g = 0.0353 oz.

[x] Least-square means were compared using Tukey's honestly significant difference at α = 0.05. The ANOVA for each variable was run separately by environment (greenhouse or landscape).

(treatments 3 and 4) in both low and high rates. In the greenhouse, SPAD chlorophyll index decreased throughout the consumer phase, particularly for the plants with WSF only in treatment 1 that had no CRF (Fig. 2A and B). In the landscape (Fig. 2C and D), SPAD chlorophyll index leveled out or increased during the second half of the consumer phase, during the cool temperatures in Jan. to Feb. 2015.

The number of flowers at the end of the consumer phase [$P < 0.01$ (Table 3)] was higher for WSF + OSM TD high rate (treatment 4) than the low rate of incorporated OSM (treatment 5) or OSM + DCT (treatment 9) in the greenhouse. In the landscape ($P < 0.01$), plants fertilized with the high rate of WSF + DCT (treatment 8) had a higher number of flowers than WSF (treatment 1), WSF + OSM (treatment 2), low rate of incorporated OSM (treatment 5), or OSM + DCT (treatment 9) (Table 3). By the end of the consumer phase, there were no flowers on the WSF-only plants in the field. The number of flowers peaked at 70 d after transplant (28 d in the greenhouse or landscape), and decreased after this period. The number of flowers remained higher for plants in the greenhouse compared with plants in the landscape (Fig. 3).

At the end of the consumer phase (140 d), tissue-N concentration (Table 3) was lower than the recommended range of 3.85% to 7.60% (Mills and Jones, 1996) for all treatments. There were differences between fertilizer treatments in tissue-N in both the greenhouse ($P = 0.01$) and the landscape ($P < 0.01$). Tissue-N was lowest in the WSF only treatment 1 in both environments. Tissue-N in the greenhouse-grown plants was significantly lower in WSF treatment 1 than with high rates of WSF + OSM TD (treatment 4) or WSF + DCT (treatment 8). In the landscape, tissue-N in the WSF treatment 1 was lower than either WSF + OSM TD treatments (3 and 4), or the high rate of incorporated OSM (treatment 6).

NUTRIENT RELEASE IN THE WITHOUT PLANTS. Nutrient release over time differed between CRF treatments in the sand containing LCUs without plants or WSF in the

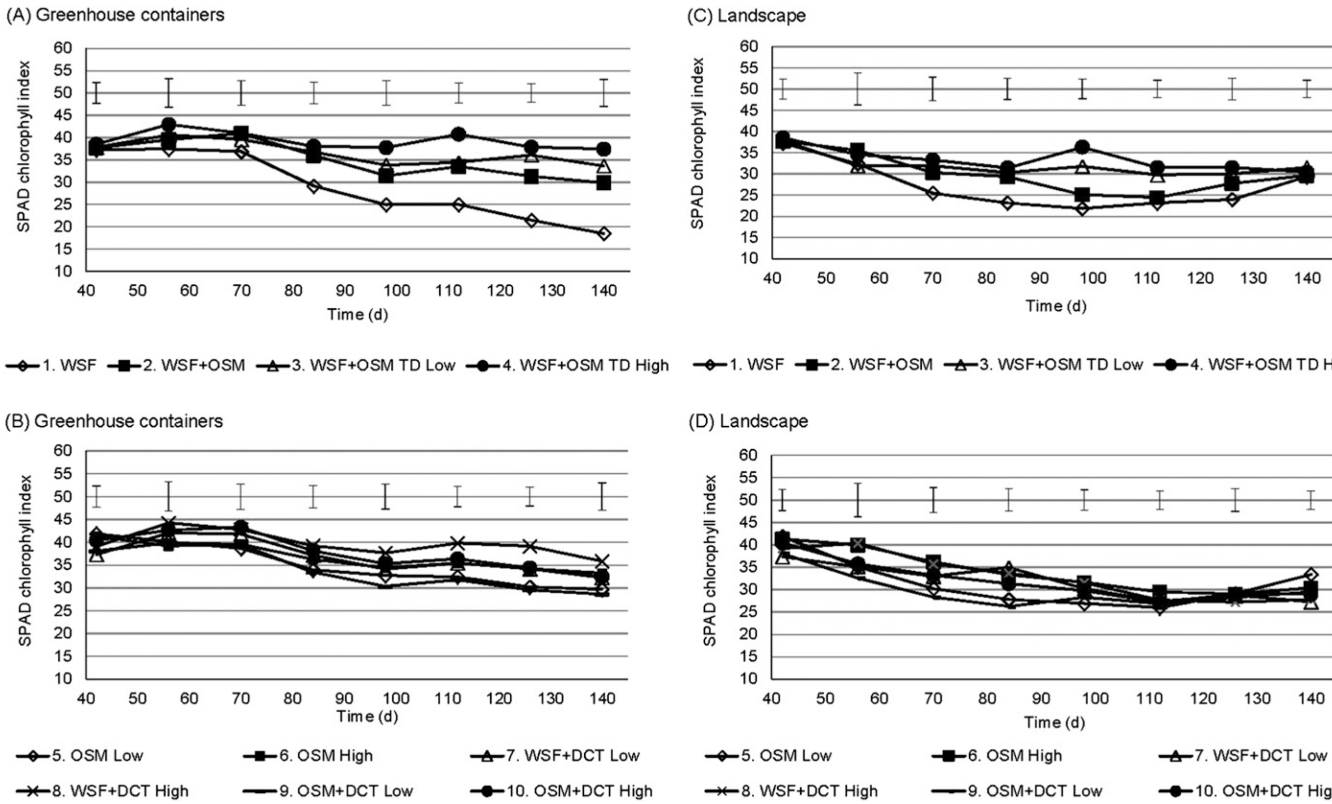

Fig. 2. Effect of controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) treatments on SPAD chlorophyll index on 'Supertunia Vista Bubblegum' petunia plants during the consumer phase in (A, B) greenhouse containers or (C, D) a landscape planting beginning at day 42. Measurements represent the average of five leaves per plant, with six replicate plants per fertilizer treatment. Error bars represent 95% confidence intervals based on Tukey's honestly significant difference at α = 0.05 analyzed by date. Treatments (detailed in Table 1) were separated from (1) to (4) or from (5) to (10) in charts for simplicity of presentation. OSM = 15N–3.9P–10.0K single-coated CRF; DCT = 14N–3.5P–9.1K double-coated CRF; OSM + DCT = blend of 15N–3.9P–10.0K single- and double-coated CRF; WSF = 15N–2.2P–12.5K WSF; TD = top-dressed application; Low = low fertilization rate; High = high fertilization rate.

greenhouse (Fig. 4). Throughout the experiment, as expected, measured N release from the washed sand control was close to zero. During the production phase (up to 42 d), OSM and OSM + DCT had similar release curves. However, initial release from DCT was close to zero for the first 15 d, and then had a similar release rate with other CRF products, as represented by the parallel gradients of curves in Fig. 4. From day 63 onward, the OSM + DCT product had a faster release rate than OSM or OSM TD. Faster release of OSM + DCT than OSM alone was not expected. However, polymers may differ between the OSM products that were formulated in the United States compared with the OSM + DCT product manufactured in Europe. By day 42, at the end of the production phase, OSM and OSM + DCT had released between 42.0% and 44.1% of applied N. In contrast, DCT had released only half this level (21.0%), which would result in greater potential release during the consumer phase. At the end of the consumer phase, 82.1% of OSM, 91.2% of OSM + DCT, and 65.9% of DCT were released. Throughout the LCU experiment, OSM TD had a similar release rate to the incorporated OSM. However, in the petunia experiment, OSM was not top-dressed until 42 d, and the top-dressed LCU data were therefore out of phase with the planted petunia experiment. By the end of the consumer phase at 140 d, lower concentration of nutrients would therefore have been released from OSM TD applied at petunia at 42 d, compared with incorporated OSM applied at day 0.

Temperature effect on nutrient release. In the growth chamber experiment (Fig. 5), CRF products released N more quickly as temperatures increased, and DCT had slower initial nutrient release than either OSM or OSM + DCT (Fig. 5). The parameters N, a, and b from Eq. [2] estimated using PROC NLIN (estimate ± 95% confidence intervals), were N (–0.5095 ± 0.0602), a (–0.00172 ± 0.00036), and b (0.000616 ± 0.000031) for DCT; N (–1.3074 ± 0.0636), a (–0.00081 ± 0.00036), and b (0.000545 ± 0.000030) for OSM + DCT, and N (–1.4151 ± 0.00436), a (–0.00109 ± 0.00027), and b (0.000425 ± 0.000019) for OSM. The temperature parameter b was positive for all fertilizers, which indicates that increased release rate occurred with increased temperature.

Based on the Richards function, the OSM product released 50% N after 88, 47, or 32 d at 10, 21, or 32 °C, respectively. The release rate for OSM + DCT required 111, 49, or 31 d for 50% release at 10, 21, or 32 °C, respectively. The DCT product had a slower initial release rate, with 100 or 62 d required for 50% release of N at 21 or 32 °C. Only 36%

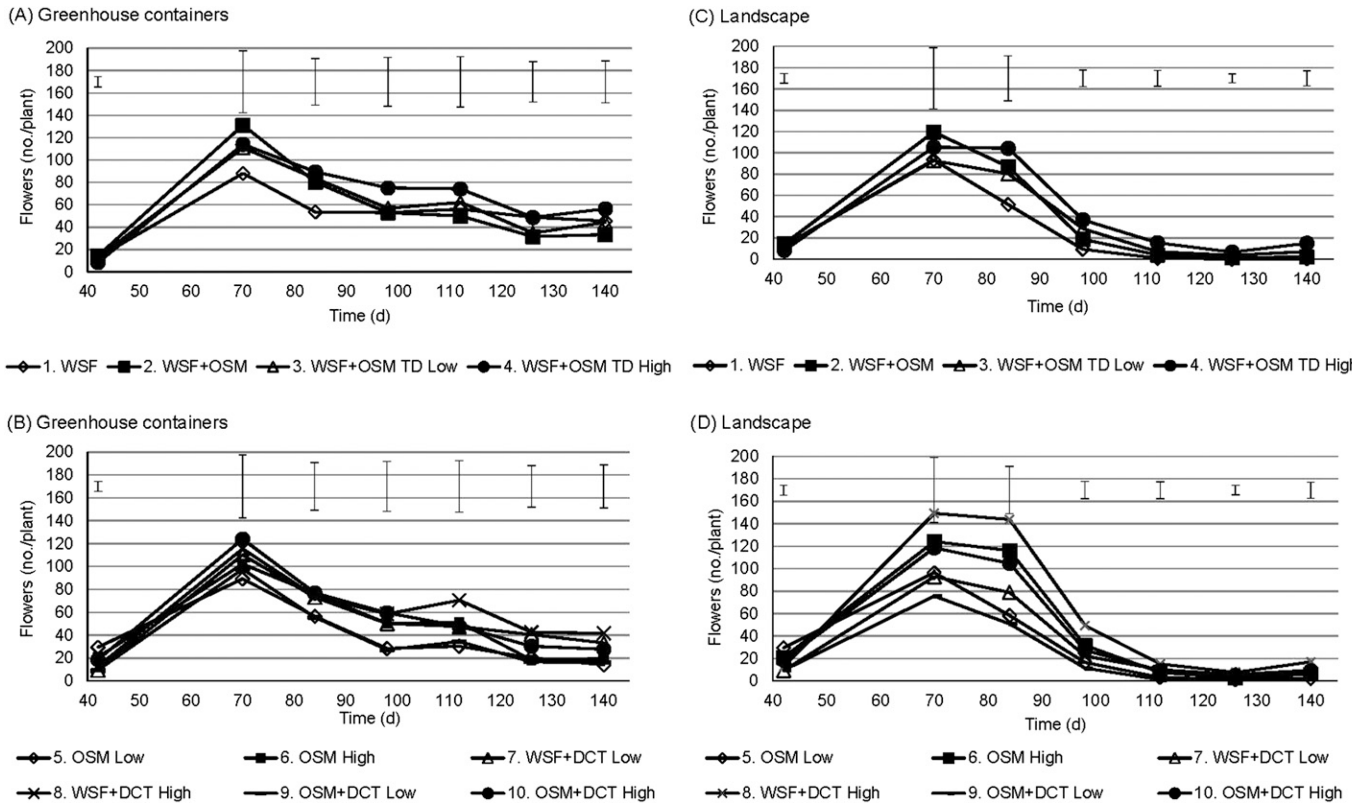

Fig. 3. Effect of controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) treatments on flower count per plant on 'Supertunia Vista Bubblegum' petunia during the consumer phase in (A, B) greenhouse containers or (C, D) a landscape planting beginning at day 42. Symbols represent the mean of six replicate plants per fertilizer treatment. Error bars represent 95% confidence intervals based on Tukey's honestly significant difference at α = 0.05 analyzed by date. Treatments (detailed in Table 1) were separated from (1) to (4) or from (5) to (10) in charts for simplicity of presentation. OSM = 15N–3.9P–10.0K single-coated CRF; DCT = 14N–3.5P–9.1K double-coated CRF; OSM + DCT = blend of 15N–3.9P–10.0K single- and double-coated CRF; WSF = 15N–2.2P–12.5K WSF; TD = top-dressed application; Low = low fertilization rate; High = high fertilization rate.

of N was released from DCT at 10 °C after 182 d. The Richards function estimated 251 d would be required for DCT to release 50% of nutrients at 10 °C (although this was far longer than the tested conditions).

A temperature of 21 °C is typically used to rate CRF longevity, and the manufacturer rating for both the OSM product and the inner coating layer for the DCT product was 5 to 6 months at 21 °C. By 182 d (≈6 months) at 21 °C, the OSM, OSM + DCT, and DCT products had released 89%, 88%, and 78% of N, respectively.

Nutrient release rate in % N/day could be calculated based on the gradient of the Richards function curves shown in Fig. 5. At 10 °C, it took 136 d for the release rate for DCT to equal or exceed that of OSM. In contrast, at 21 and 32 °C, it took 51 and 31 d, respectively, for DCT to have an equal or greater release rate compared with OSM. The lag in release from the second coating in DCT was therefore temperature dependent.

ECONOMIC ANALYSIS. The lowest cost treatment was WSF only (treatment 1) at \$0.02/container (Table 4). This analysis illustrates why many greenhouse growers produce plants using WSF rather than CRF because of lower production cost. Using incorporated OSM (treatments 5 and 6) increased cost by \$0.010 to \$0.031 per container at the low or high experimental rates, respectively, compared with WSF only. However, based on the results from the petunia experiment, improved plant performance with residual fertilizer from CRF has potential to add value for the consumer. A slight increase in sales price could pay for the added cost of CRF compared with WSF only.

The cost of CRF application increased when labor was required to top-dress containers (treatments 3 and 4) by an estimated \$0.013/container compared with incorporating OSM before planting [which had an assumed zero labor cost (treatments 5 and 6)]. In addition, \$0.02/container in WSF cost would be required if top-dressing occurred before shipping (at the production phase, as in this experiment). Where labor is limiting or costly, incorporation of CRF would therefore be preferred to top-dressing. A practical management advantage of top-dressing CRF is that for growers who prefer using fertigation, top-dressing does not require changes in fertilizer during production.

In the petunia experiment, OSM + DCT treatments had similar observed nutrient release rate and plant performance to OSM. The slightly higher cost of OSM + DCT (treatments 9 and 10) than OSM alone (treatments 5 and 6) (by \$0.003 to \$0.005 per container at the low or high rates, respectively) would therefore not be justified.

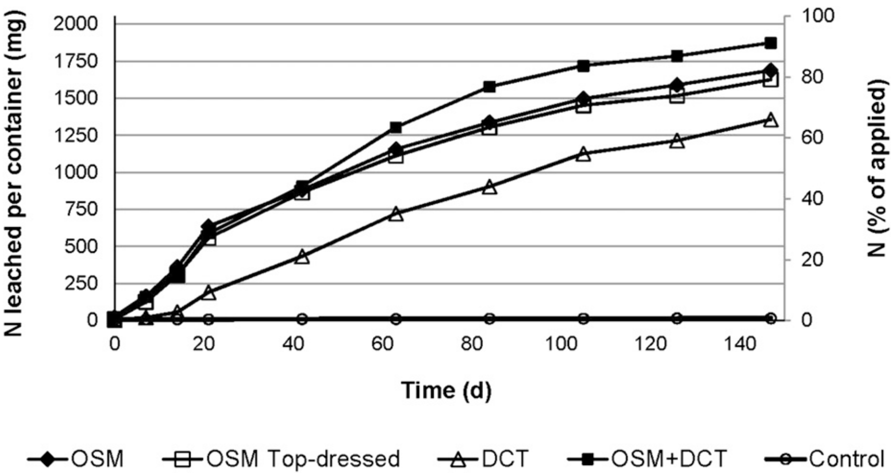

Fig. 4. Effect of fertilizers applied to each leachate collection unit (LCU) (sand container without plants with clear water only) for greenhouse fertilizer experiment without plants with five treatments, representing a control (no fertilizer), or the high rates of incorporated OSM [15N–3.9P–10.0K single-coated controlled-release fertilizer (CRF)], DCT (14N–3.5P–9.1K double-coated CRF), OSM + DCT (a blend of 15N–3.9P–10.0K single- and double-coated CRF), and OSM top-dressed (TD) on total cumulative nitrogen (N) released (milligrams) and the percent nitrogen released out of the cumulative N applied. All fertilizer was applied at day 0. Measurements represent the leachate solution with a volume of 2 L (0.53 gal) of water applied to each container, to ensure a complete leaching of released nutrients, every 3 weeks. Analysis of variance was run across all measurement days on three replicate LCUs per fertilizer treatment, and 95% confidence intervals around least-square means equaled ±33.3 mg N; 1 mg = 3.5274 × 10^{-5} oz.

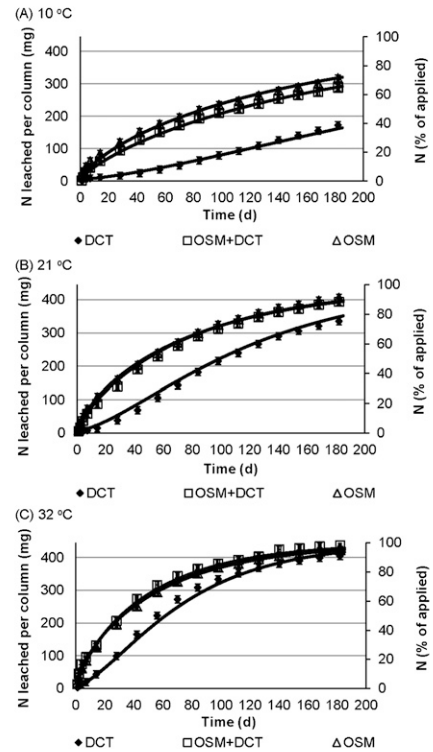

Fig. 5. Effect of controlled-release fertilizers (CRF) on total cumulative nitrogen released (milligrams per column) and the percent of nitrogen (N) released/N applied in three growth chamber incubation temperatures [10, 21 and 32 °C (50.0, 69.8, and 89.6 °F)]. Columns measuring 40 cm (15.7 inches) in height were filled with 0.5 L (0.13 gal) washed sand. Fertilizer was added to each experimental unit at 5.93 g·L^{-1} of OSM (15N–3.9P–10.0K single-coated CRF), 5.93 g·L^{-1} of OSM + DCT (a blend of 15N–3.9P–10.0K single- and double-coated CRF), or 6.36 g·L^{-1} for DCT (14N–3.5P–9.1K double-coated CRF) to provide 890 mg·L^{-1} N. Measurements were taken on the leachate solution after 1.25 L (0.330 gal) of deionized water was added to each column (a substrate volume:applied solution volume ratio of 1:2.5) at each sampling date. Symbols represent least-square means from analysis of variance run across all measurement days on three replicate columns per fertilizer and temperature, and error bars represent 95% confidence intervals of least-square means, equaling ±11.0 mg N. Curves represent the Richards function fitted separately by fertilizer, including the temperature function in Eq. [2]; 1 g·L^{-1} = 0.1335 oz/gal; 1 mg = 3.5274 × 10^{-5} oz.

Treatment 2 with low WSF and CRF rates was $0.01/container more costly than WSF alone, and equal in cost to the low rate of incorporated OSM. The main advantage of combining WSF and CRF in production is where 1) there is a mix of plant species that are fertigated at a low WSF concentration, and CRF is only applied to the subset of vigorous crops that require a higher fertilizer charge, or 2) the grower wants to provide a small amount of residual fertilizer while still being able to regulate fertilizer level during production using WSF.

Using DCT in combination with WSF (treatments 7 and 8) was more expensive than OSM (treatments 5 and 6) and had a similar cost to WSF + OSM TD (treatments 3 and 4). The higher cost of WSF + DCT compared with OSM resulted from both an increased cost of the CRF, and the need to apply WSF during the production phase before nutrient release occurred from the DCT. The most likely situation in which DCT would be preferred by growers is where crops are produced with fertigation, a residual fertilizer is desired for the consumer, but the grower prefers not to top-dress with CRF.

Conclusions

If plant products are delivered to the consumer without some residual fertilizer, the grower is passing the responsibility for subsequent fertilization to the customer. Although many landscapers and consumers fertilize plants in the landscape (Shober et al., 2010), plants are not always adequately fertilized after sale. Without residual fertilizer, no matter how good the plant genetics or quality at point of sale, plant performance is likely to be poor for long-term and vigorous plants such as petunia in hanging baskets, patio containers, or the landscape.

All fertilizer treatments, which included WSF only, a low rate of combined WSF and CRF, WSF and DCT, or CRF produced high-quality plants after 42 d of production (the grower phase). Growers therefore have multiple strategies to produce similar quality plants, and the choice comes down to factors such as cost and practicality.

Plants grown with WSF only during the production phase, without residual fertilizer, were severely nutrient deficient (as quantified by chlorophyll index and flower number) after 42 d in the consumer phase [day 84

Table 4. Production cost per container ($ per plant) of 'Supertunia Vista Bubblegum' petunia fertilizer in 2.84-L (0.750-gal) containers for the tested controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) strategies.

	Treatment code[z]									
Cost factor[y]	(1) WSF	(2) WSF + OSM	(3) WSF + OSM TD Low	(4) WSF + OSM TD High	(5) OSM Low	(6) OSM High	(7) WSF + DCT Low	(8) WSF + DCT High	(9) OSM + DCT Low	(10) OSM + DCT High
CRF costs										
Cost per 50-lb (22.7 kg) bag		$83.75	$83.75	$83.75	$83.75	$83.75	$100.50	$100.50	$92.13	$92.13
Cost per gram		$0.0037	$0.0037	$0.0037	$0.0037	$0.0037	$0.0044	$0.0044	$0.0041	$0.0041
CRF wt (g/container)		5.5	8.2	13.7	8.2	13.7	8.8	14.7	8.2	13.7
Material cost per container		$0.020	$0.030	$0.051	$0.030	$0.051	$0.039	$0.065	$0.033	$0.056
Labor cost per container (TD)[x]			$0.013	$0.013						
Total cost per container of CRF (material, labor)		$0.020	$0.044	$0.064	$0.030	$0.051	$0.039	$0.065	$0.033	$0.056
WSF costs										
Fertilizer concentration ($mg \cdot L^{-1}$ nitrogen)	200	100	200	200			200	200		
Nitrogen applied (g)	1.08	0.54	1.08	1.08			1.08	1.08		
Total cost per container WSF (materials)[w]	$0.020	$0.010	$0.020	$0.020			$0.020	$0.020		
CRF cost per plant	$0.000	$0.020	$0.044	$0.064	$0.030	$0.051	$0.039	$0.065	$0.033	$0.056
WSF cost per plant	$0.020	$0.010	$0.020	$0.020	$0.000	$0.000	$0.020	$0.020	$0.000	$0.000
Total cost per container	$0.020	$0.030	$0.064	$0.084	$0.030	$0.051	$0.059	$0.085	$0.033	$0.056
Additional cost beyond WSF only	$0.000	$0.010	$0.044	$0.064	$0.010	$0.031	$0.039	$0.065	$0.013	$0.036

The labor cost of applying fertilizer was only considered for treatments with top-dressed (TD) CRF, because labor cost to prepare WSF or apply CRF before planting would be minor. Cost estimates only consider the production phase, because during the consumer phase only clear water was applied.

[z]OSM = 15N–3.9P–10.0K single-coated CRF; DCT = 14N–3.5P–9.1K double-coated CRF; OSM + DCT = blend of 15N–3.9P–10.0K single- and double-coated CRF; WSF = 15N–2.2P–12.5K WSF; Low = low fertilization rate; High = high fertilization rate.

[y]$1/50-lb bag = $0.0441/kg; $1/g = $28.3495/oz; 1 g = 0.0353 oz; 1 $mg \cdot L^{-1}$ = 1 ppm.

[x]Top-dressing cost assumes a labor cost of $9.66/h, with 720 containers top-dressed per hour (5 s per plant).

[w]WSF cost assumes $31.20 per 25-lb (11.3 kg) bag with 15% nitrogen, giving a cost per gram of nitrogen equal to $0.018.

(Figs. 2 and 3)]. In contrast, any plants receiving CRF were still growing vigorously after 42 d in the consumer phase, especially when OSM (incorporated or top-dressed) or DCT were applied at a high rate.

None of the fertilizer treatments resulted in substrate-EC levels during the production phase that exceeded the recommended range (Table 2). Low tissue-N levels and poor plant performance were observed by the end of the consumer phase. Therefore, improved plant performance during the consumer phase may have been achievable by increasing applied fertilizer concentrations.

The DCT had delayed nutrient release compared with single-coated CRF, in both the greenhouse LCU and growth chamber studies (Figs. 4 and 5). The release rates of all CRF products, and the duration of the delay in release from DCT were temperature dependent. These results emphasize the importance of considering temperature on the longevity of product.

An economic analysis indicated the cost per trade 1-gal container ranged from $0.020/container with WSF only, to $0.051/container with incorporated OSM, $0.084/container with top-dressed OSM, and $0.085/container with DCT at the high rates. Overall, several options are available to growers to add a residual nutrient charge for the consumer phase, with the choice of fertilizer strategy depending on material and labor cost and availability, and preferred crop management style. Given the improved plant performance in the consumer phase with residual fertilizer observed in the petunia experiment, if this added value could be promoted to consumers, the slight extra cost of CRF compared with WSF would be more than compensated for by an increased sales price.

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