Effects of Controlled-Release Fertilizer Placement on Nutrient Leaching and Growth of Bedding Impatiens[1]

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Abstract

Bedding impatiens plants were grown with a 16N-3.9P-10K controlled-release-fertilizer (CRF) of 5–6 or 8–9 month longevities placed at four positions in the container: top-dressed, incorporated, top-one-third, and bottom. These were compared to plants grown with a 20N-4.4P-16.6 water-soluble fertilizer (WSF) at a rate of 150 $mg \cdot L^{-1}$ nitrogen (N) (150 ppm N). All treatments received the same volume of tap water (CRF treatments) or fertilizer solution (WSF treatment), which was enough to achieve a 20 to 30% leaching fraction. Leachates were collected and measured at each irrigation and the concentrations of N, phosphorous (P), and potassium (K) were measured. Shoot dry weight (SDW) and canopy cover (CC) were also determined. Fertilizing with WSF produced plants of similar size as CRF treatments. CRF applied at the bottom of the substrate leached the highest amount of N among all treatments. Higher concentrations for most nutrients were measured in the leachates from containers treated with 5–6 month CRF during the first 20 d after planting than the next 23 to 34 days. The higher levels of nutrients in the leachates observed within two weeks after planting does not support the use of 5–6 month CRF at the application rates used in this experiment with short-cycle plants such as bedding plants in compared to use of WSF. Except for the bottom placement treatment, the use of 8–9 month CRF resulted in generally less nutrients leached than WSF.

Index words: fertigation, plant nutrition, macronutrients.

Species used in this study: *Impatiens wallerana* Hook. f. Xtreme™ 'Scarlet'.

Significance to the Horticulture Industry

Both the nursery and floriculture industries use controlled-release fertilizer (CRFs), in part because they are thought to be a more sustainable and environmentally responsible way to fertilize. Most growers apply these CRF fertilizers either top-dressed after planting or incorporated in the growing medium prior to planting. In this research, there was little difference in plant growth (dry weight) due to the placement of CRF in the container. Growers need to avoid placing the CRF prills at the bottom of the substrate to reduce nutrient losses. Nutrient losses were further reduced by using 8–9 month CRF as opposed to 5–6 month CRF or WSF without affecting plant size. Usually, growers use leaching fractions larger than those used in our study (20 to 30%). In such case, it would be reasonable to expect larger losses of nutrients, especially from WSF-treated containers. Using an 8–9 month CRF may require higher doses, though, as we have shown in a previous work.

Introduction

The use of controlled release fertilizers (CRF) to produce short-cycle crops in greenhouses has not been widely adopted by growers. This may be attributed to a lack of experience by growers, higher costs compared to water-soluble fertilizers (WSF), or fear of losing control over the crop fertility (Blythe et al. 2002, Klock-Moore and Broschat 1999). The use of CRFs may be effective at reducing nutrient runoff and improving nutrient use efficiency (Andiru et al. 2011, Cabrera 1997, Merhaut et al. 2006), thus improving plant quality in greenhouse floriculture production (Wright 1992), and improving the landscape performance of impatiens (Andiru et al. 2013). Researchers have focused on the slow release of nutrients when using a CRF as a tool for environmental protection in the nursery and turf industries (Blythe et al. 2002). Efficient floricultural crop production requires that adequate levels of nutrients be delivered to plants in a timely manner.

Researchers have measured nitrate (NO_3^-) in the leachate collected from CRF-treated, container-grown plants (Merhaut et al. 2006, Haver and Schuch 1996) and concluded that using this type of fertilizer could reduce NO_3^- losses. Similarly, Richards and Reed (2004) measured electrical conductivity (EC), pH, and potassium (K) from leachates and found that using CRF resulted in high nutrient use efficiency regardless of method of irrigation.

CRF release patterns have been determined in experiments without plants and most of these evaluated N (NO_3^--N and or NH_4^+-N), phosphorous (P) and K (Birrenkott et al. 2005, Broschat 2005, Newman et al. 2006). Broschat and Klock-Moore (2007) measured leaching rates of N (NO_3^--N and NH_4^+-N), P, K, Mg, Fe and Mn from columns containing sand for seven CRF formulations. They observed slower leaching of P than N and K, and small releases of Mg, Mn, and Fe. No publications describing the nutrient concentrations present in leachates from floriculture substrates were found. Adams et al. (2013) studied the nutrient release from three CRF types [Osmocote Plus 15-9-12 (3–4 and 12–14 month), Nutricote Total with Minor Nutrients 18-6-8 (3, 9, and 12 month), and Polyon Coated NPK Plus 16-6-13 (1–2 and 10–12 month)] when placed either in water or chemically-inert sand. There was no difference in release rates between the two substrates but there were large differences among CRF types. Large nutrient releases were detected early. The

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Osmocote Plus 3–4 month product released a large amount in the initial 2 weeks at all temperatures tested (5 to 40 C) (41 to 104 F) while Polyon Coated NPK and Nutricote Total released steady amounts between 5 and 30 C (41 and 86 F). The 12–14 month Osmocote Plus released more than the other brands at all temperatures except 40 C (104 F), but did so over 40 d rather than 14 d. No availability or nutrient use efficiencies were studied in their work because their substrates did not contain plants. The objectives of this research were: 1) to determine the effects of the placement of CRF inside the container on the growth of impatiens; and 2) to measure the concentrations of N, P, and K leached from containers treated with CRF placed at different locations inside the container.

Materials and Methods

The substrate consisted of a 3:1 (v/v) mix of Canadian sphagnum peat moss (Sunshine Peat Moss; SunGro Horticulture, Bellevue, WA) and perlite (Therm-O-Rock East, Inc., New Eagle, PA). Pulverized carbonated lime was added at a rate of to 3 $kg \cdot m^{-3}$ (5.1 $lb \cdot yd^{-3}$) to adjust the pH to the target range of 5.8 to 6.4. The substrate was hydrated by adding a solution of 11.2 ml of surfactant (Aqua-Gro L, Scotts Company, Marysville, OH) per liter of water (1.5 fl oz per gal). This solution was added to the substrate at a rate of 10 $L \cdot m^{-3}$ (2 gal per yd^{-3}). The substrate (0.23 m^3 or 8.1 ft^3 in total) was then placed in a 0.5 m^3 (17.7 ft^3) plastic container and left to stabilize for 24 h. Before incorporating the CRFs, electrical conductivity EC and pH of the substrate were measured using the 1:2 dilution method (Cavins et al. 2001) with a pH and EC meter (Accumet model AP85 pH/conductivity meter, Fisher Scientific, Pittsburgh, PA).

Experiment 1. CRF containing 16:3.9:10 N:P:K of two different longevities: 5 to 6 months (5–6CRF) and 8 to 9 months (8–9CRF) (Osmocote Plus 16-9-12; Everris International, Geldermalsen, The Netherlands) or a 20:4.4:16.6 N:P:K WSF (Peters Professional 20-10-20; Everris International) were used. The CRFs were incorporated before planting at 6.8 $kg \cdot m^{-3}$ (11.5 $lb \cdot yd^{-3}$). This application rate was selected based on previous work because it allows for the production of a quality crop and can enhance landscape performance (Andiru et al. 2013). The CRF prills were placed at one of four possible locations inside the container: layered at the top (topdressed); layered in the top-one-third of the container (top1/3); incorporated throughout the substrate (incorporated); and layered below the substrate (bottom). As a point of reference (control), a subset of plants were grown using WSF at a rate of 150 mg $N \cdot L^{-1}$ N (150 ppm N) of tap water [EC < 1.0 $mS \cdot cm^{-1}$, alkalinity < 90 $mg \cdot L^{-1}$ (90 ppm)] at each irrigation.

Plugs of *Impatiens wallerana* Hook XTREME™ 'Scarlet' grown in 288-cell flats were obtained from a commercial grower (Green Circle Growers, Oberlin, OH). A single plug was transplanted into each 12.7 cm-diam (5 in) by 9 cm-high (3.5 in) (770 ml) plastic container. Plants were grown in a double-layer, acrylic-glazed greenhouse in Columbus, OH, for 55 d (November to December). Greenhouse temperatures and outside radiation levels were recorded using a greenhouse computer weather station (Argus Control Systems, White Rock, BC, Canada). Greenhouse low and high temperature set points were 18 and 21 C (64 and 70 F), respectively, and the average daily light integral was 5.1 $mol \cdot m^{-2} \cdot d^{-1}$.

For leachate collections, each container was placed on a 13 by 14 cm (5.1 by 5.5 in) plastic mesh on top of a 12 cm (4.7 in) diam bowl. CRF-treated plants were hand-irrigated with 200 to 450 mL (6.9 to 153 fl oz) of tap water in order to achieve a 20 to 30% leaching fraction (the range in applied water was the consequence of different plant sizes over time and different environmental conditions during the growing period), while WSF-treated plants were irrigated with the same volume of a 150 $mg \cdot L^{-1}$ N (150 ppm N) WSF solution. Plants were monitored daily, and irrigation was supplied as needed. Leachate was collected each time plants were irrigated and its volume measured. In Experiment 1, irrigation events occurred 5, 9, 14, 20, 24, 29, 35, 40, 43, 50, and 54 d after planting (DAP).

EC and pH of the leachate were measured after collection, and up to 50 mL (1.69 ounces) was stored at 2 C for future measurements of N using an ion selective electrode (ISE) (Scotts Testing Laboratory, Lincoln, NE). Phosphorous and K were analyzed by the USDA Greenhouse Production Research Group in Toledo, OH, using inductively coupled plasma-optimal emission spectroscopy (ICP-OES; Iris Intrepid II, Thermo Electron, Waltham, MA).

At the end of the experiment, following a technique similar to the one used by Bumgarner et al. (2012), pictures of the plant canopies without the flowers were taken from above with a digital camera (EX-Z250A; Casio Higashine, Japan). A tripod was placed at a fixed position holding the camera 1 m above ground with the objective lens looking down. A mark was made on the ground and each plant was placed on the mark to ensure uniformity under the focus of the camera.

Pictures were then analyzed with digital analysis software (Assess Image Analysis; APS Press, St. Paul, MN) to measure the exposed leaf area (green), which we refer to as the 'leaf canopy cover' (CC) expressed in square cm. CC was used as an estimate of plant spread (e.g., plant diameter). Plants were cut-off at the substrate surface, placed in paper bags and dried in a forced-air oven at 55 C. After drying for 48 h, the above-ground SDW of each plant was measured.

The experiment was performed using a randomized complete block design with one pot per treatment per block. The nine treatments in each block consisted of the eight combinations of the two CRF formulations and the four placements and one control (WSF). Statistical analysis for SDW and CC consisted of performing a mixed model analysis of variance with formulation, placement, and their interaction as fixed effects and a random block effect.

Leachate P and K were summed over all collection periods, and statistical analyses consisted of multivariate ANOVA (MANOVA) with fixed effects for formulation, placement, and their interaction and a random block effect. For leachate N, which was collected in only four blocks, statistical analysis consisted of a mixed model ANOVA. Means for SDW, CC, and each leachate component were compared across treatments using Tukey's multiple comparisons. All analyses were performed using SAS PROC GLM (SAS Institute, Cary, NC) using $p \leq 0.05$.

Experiment 2. This experiment was a repetition of Experiment 1 with the exception that plants were grown for 43 d between March and May. These plants reached a marketable size 12 d earlier than those in Experiment 1. The greenhouse low and high temperature set points were 18 and 21 C, respectively, and the average daily light integral was 28.1 $mol \cdot m^{-}$

^{2}·d^{-1}. In this experiment, irrigation and leachate collection occurred on 2, 7, 14, 20, 25, 29, 33, 39, and 43 DAP.

Results and Discussion

Initial substrate pH was 6.2, which was within the acceptable range (Argo and Biernbaum, 1996), while initial EC was 0.77 dS·m^{-1}. Leachate pH for both experiments was always within the acceptable range for plant cultivation (results not shown), while the response of leachate EC over time matched the observed response of nutrients leached (Figs. 1, 2 and 3).

Plant growth: Experiment 1. Although the ANOVA results indicated significant differences in CC of plants between the two CRF formulations and among the four fertilizer placements (but not their interaction), Tukey's multiple comparisons of the treatments showed no significant differences in CC among the nine treatment combinations (Table 1). For SDW, both the main effects formulation and placement and their interaction were significant. In general, plants treated with 5–6CRF had smaller SDWs than plants treated with 8–9CRF. Using a multiple comparison test among all nine treatments, plants treated with the 5–6CRF topdressed had significantly smaller SDWs than plants treated with 8–9CR topdressed and 8–9CRF top1/3.

Plant growth: Experiment 2. There were significant effects of formulation, placement, and their interaction on CC and SDW (Table 1). In particular, plants treated with the 8–9CRF bottom had a significantly smaller CC than all other formulation-placement combinations except those treated with 5–6CRF bottom. Plants treated with WSF had the numerically largest CC. Using a multiple comparison test among all nine treatments, plants treated with the 5–6CRF topdressed and WSF had the numerically largest SDW while placing the CRF at the base of the substrate (bottom) produced the smallest SDW when an 8–9CRF was used.

Nutrients leached: Experiment 1. Positioning the CRF prills at the bottom of the substrate resulted in higher P and K content in the leachate regardless of longevity (Table 2). Containers treated with WSF leached about 49 to 63% less total N than any of the 5–6CRF treatments, regardless of placement. At the end of the experiment, containers treated

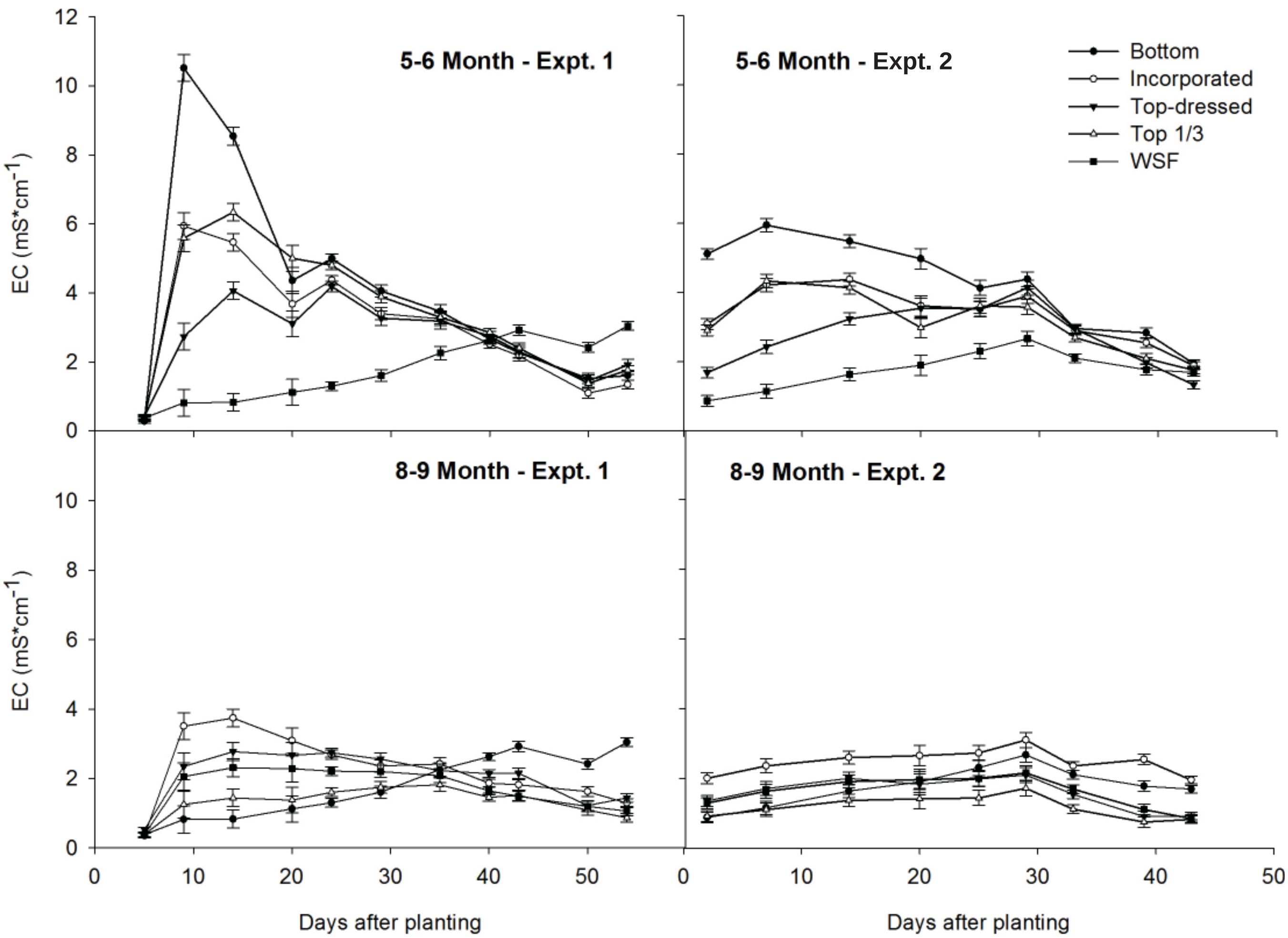

Fig. 1. Electrical conductivity (EC, mS·cm^{-1}) of leachates collected over time from substrates of plants in Experiments 1 and 2. Plants were grown with Osmocote 16-9-12 of 5–6 or 8–9 month longevity applied as top-dressed, incorporated, at the bottom of the substrate (bottom) or top 1/3 of the container. Water soluble fertilizer (WSF) plants were fertigated with a 150 mg·L^{-1} N (150 ppm N) solution of a 20-10-20 Peter's Professional water-soluble fertilizer. Error bars represent standard error of the mean. Values are means of six replications.

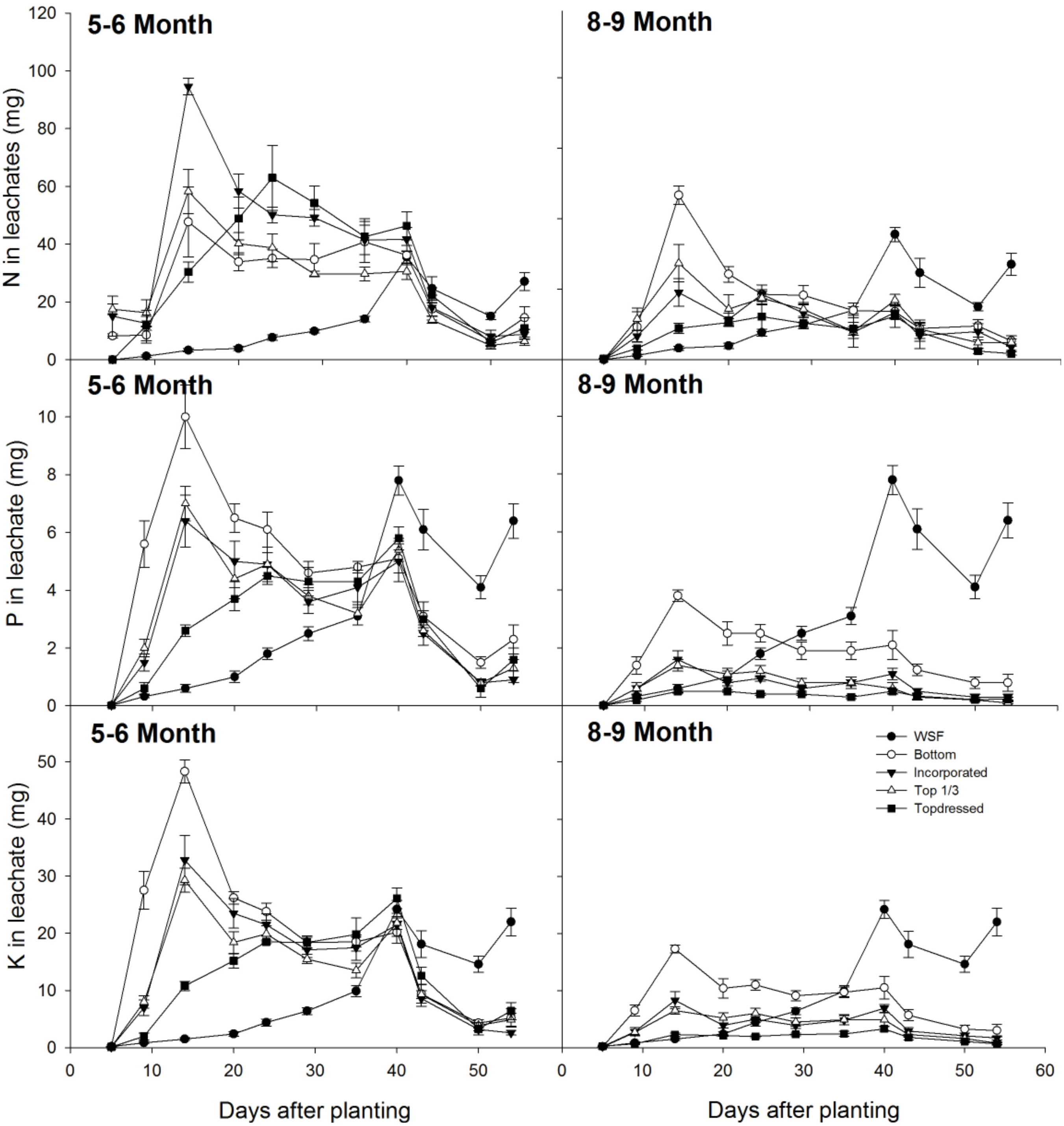

Fig. 2. Amounts of N, P, and K (mg) measured in the leachates over time from containers fertilized in Experiment 1 with Osmocote 16-9-12 of 5–6 or 8–9 month longevity applied either as top-dressed, incorporated, at the bottom of the substrate (bottom) or top 1/3 of the container. Water soluble fertilizer (WSF) plants were grown with a 150 mg·L^{-1} N (150 ppm N) solution of 20-10-20 Peter's Professional fertilizer. Values are means of six replications. Error bars represent standard error.

with 5–6CRF incorporated leached the most N. The N in leachates from containers treated with 5–6CRF top1/3 or those treated with 5–6CRF topdressed were not significantly different from one another, but both had significantly less N than containers treated with the 5–6CRF bottom or the 5–6CRF incorporated. More than twice the amount of N was found in leachates from containers fertilized with 8–9CRF bottom than from containers fertilized with 8–9CRF topdressed while containers treated with WSF leached 45% more N than 8–9CRF topdressed. Containers with 5–6CRF leached more N than containers treated with 8–9CRF.

Overall, containers fertilized with 5–6CRF bottom leached at least 30% more P than any other 5–6CRF placement (Table 2). At the end of the experiment, 8–9CRF bottom-treated

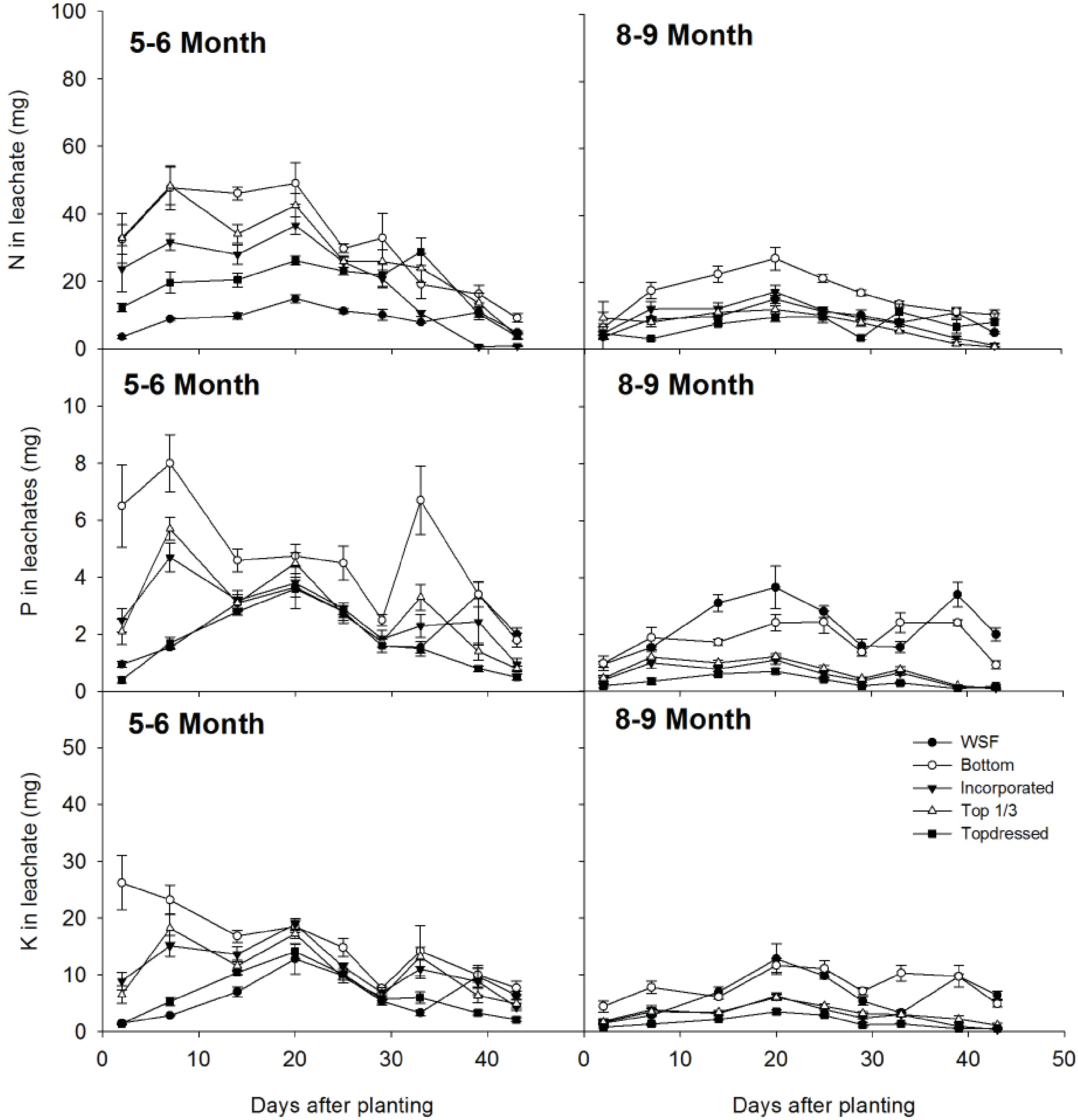

Fig. 3. **Amounts of N, P, and K (mg) measured in the leachates over time from containers fertilized in Experiment 2 with Osmocote 16-9-12 of 5–6 or 8–9 month-longevity applied either as top-dressed, incorporated, at the bottom of the substrate (bottom) or top 1/3 of the container. Water soluble fertilizer (WSF) plants were grown with a 150 mg·L^{-1} N (150 ppm N) solution of 20-10-20 Peter's Professional fertilizer. Values are means of six replications. Error bars represent the standard error.**

containers had leached 63 to 84% more P than containers treated with the 8–9CRF placements. Regardless of the placement of the CRF, total P leached from containers fertilized with WSF was greater (44 to 91%) than any of the 8–9CRF placements. Containers fertilized with 5–6CRF leached more P than any of the containers fertilized with 8–9CRF.

The largest amount of K in the leachate was measured when containers were fertilized with the 5–6CRF bottom (Table 2). No differences were found in K leached among containers fertilized with 5–6CRF incorporated, 5–6CRF top1/3, or 5–6CRF topdressed. Similarly, the largest amount of K leached from containers treated with 8–9CRF was found when the prills were placed at the bottom, while no differences were found among containers fertilized with any of the remaining 8–9CRF treatments. Containers fertilized with WSF leached 28% less K than containers fertilized with

Table 1. **Canopy cover (cm²) and shoot dry weight (g) of bedding impatiens in Expt. 1 and 2. Plants were grown with Osmocote 16-9-12 of 5–6 or 8–9 months longevity applied as top-dressed, incorporated into the substrate, placed under the substrate (bottom) or incorporated in the top 1/3 of the container. Water soluble fertilizer (WSF) plants were grown with a 150 mg·L⁻¹ N (150 ppm N) solution of a 20-10-20 Peter's Professional fertilizer[z].**

	Canopy cover (cm²)		Shoot dry weight (g)	
Treatments	**Expt. 1**	**Expt. 2**	**Expt. 1**	**Expt. 2**
5–6CRF bottom	582.5a	458.6bc	2.8ab	2.3b
5–6CRF incorporated	640.4a	584.1ab	3.3ab	3.5ab
5–6CRF top1/3	664.6a	647.2ab	3.1ab	3.5ab
5–6CRF topdressed	566.7a	655.8ab	2.3b	4.3a
8–9CRF bottom	598.1a	273.2c	2.8ab	1.1c
8–9CRF incorporated	719.2a	630.6ab	3.4ab	3.9ab
8–9CRF top1/3	721.5a	562.2ab	3.7a	3.7ab
8–9CRF topdressed	732.2a	644.2ab	3.7a	3.6ab
WSF	560.0a	693.9a	3.2ab	4.2a

[z]Means (n = 6) with the same letter in a column are not significantly different at a $P \leq 0.05$ by Tukey's multiple comparisons.

5–6CRF or 21% more K than the containers fertilized with 8–9CRF. Significantly less K was measured in leachates from containers treated with 8–9CRF than from containers treated with 5–6CRF.

There was a rapid increase over time of N, P, and K in the leachates that occurred before 20 DAP for most of the containers fertilized with 5–6CRF (Fig. 2). While nutrient concentration in the leachate of containers treated with 5–6CRF tended to decrease after 20 DAP, nutrients in the leachate for containers treated with WSF increased over time. When an 8–9CRF was used, smaller peaks in nutrient leached over time were noticed as opposed to when 5–6CRF was used (Fig. 2).

Nutrients leached: Experiment 2. Containers treated with WSF leached 51 to 71% less N than any of the containers treated with 5–6CRF regardless of placement (Table 2). More N was leached when the CRF was applied at the bottom, regardless of its longevity. Containers treated with 8–9CRF bottom leached 52 to 62% more N than containers treated with WSF or any container treated with 8–9CRF. However, containers treated with WSF or 8–9CRF, except those from the 8–9CRF bottom treatment, leached similar amounts of N.

The amount of P leached from the containers treated with 5–6CRF bottom was greater than from any of the containers treated with 5–6CRF (Table 2). WSF treated containers leached 48% less total P than those treated with 5–6CRF bottom. The containers fertilized with 8–9CRF bottom leached 71 to 81% more P than containers fertilized with other 8–9CRF at any placement. Overall, P leached from 5–6CRF treated containers was greater than the 8–9CRF treated ones.

The largest amount of K was measured in leachates from containers fertilized with 5–6CRF bottom (Table 2). The smallest amount of K leached from containers treated with 5–6CRF was found when CRF was placed as top dressed. WSF treated containers leached less K than from containers treated with any of the 5–6CRF placements except the 5–6CRF topdressed.

There were high levels of leachate N, P, and K early on the cycle of the crop for the 5–6CRF treated containers with a decreasing trend at 20 DAP (Fig. 3). As in Experiment 1, small peaks of nutrients leached over time were observed for N, P, and K when containers were fertilized with 8–9CRF.

CRF placement had a minor effect on SDW. Based only on these results, growers could use any of the placements described in this work. Plants may not be able to utilize the nutrients released at the bottom during the early stages of production because they are young, have smaller nutrient requirements, and smaller root systems. CRF manufacturers recommend top dressing or incorporation in the substrate. These results are in agreement with those presented by Klock-Moore and Broschat (1999), who did not find any difference in SDW between topdressing and incorporation of CRF placements throughout the container. In practice, the easiest methods of application are complete incorpora-

Table 2. **Nitrogen, phosphorus, and potassium leached from the containers during the duration of Expt. 1. (54 d) and Expt. 2 (43 d). Plants were grown with Osmocote 16-9-12 of 5–6 months longevity or 8–9 months longevity applied as top-dressed, incorporated into the substrate, placed under the substrate (bottom) or incorporated at the top 1/3 of the container. WSF plants were grown with a 150 mg·L⁻¹ N (150 ppm N) solution of a 20-10-20 Peter's Professional fertilizer.**

	Total nutrient leached (mg)[z]					
	N		P		K	
Treatment	**Expt. 1**	**Expt. 2**	**Expt. 1**	**Expt. 2**	**Expt. 1**	**Expt. 2**
5–6CRF bottom	282.7a	326.0b	41.5a	49.7a	148.6a	201.8a
5–6CRF incorporated	178.7c	390.7a	24.5cb	34.6b	97.9b	154.4b
5–6CRF top1/3	260.1b	278.0c	25.3b	35.5b	93.6b	144.6b
5–6CRF topdressed	166.7c	281.9c	15.4c	29.4c	57.3cd	133.1bc
8–9CRF bottom	169.9c	166.5d	16.6de	19.0d	73.0bc	86.5d
8–9CRF incorporated	78.7d	107.2ef	5.2f	7.5e	25.7e	42.4e
8–9CRF top1/3	65.5d	125.8de	6.2f	7.0e	28.5de	39.5e
8–9CRF topdressed	63.6d	78.4f	3.0f	3.4e	14.1e	18.8cd
WSF	82.2d	142.8de	20.6cd	33.8bc	58.8cd	104.0cd

[z]Means (n = 6) with the same letter in a column are not significantly different at a $P \leq 0.05$ by Tukey's multiple comparisons.

tion as soil is mixed or topdressing at or immediately after transplanting into containers.

Fertilization with WSF increased leachate EC over time because of continuous addition of fertilizer at each irrigation. The leachate EC from containers with CRF decreased over time, likely due to fewer nutrients released from the prills later in production and because they were more readily absorbed by plants.

Greater amounts of nutrients were measured during the first 14 DAP than towards the end of the experiment in the leachates from containers treated with CRF. Richards and Reed (2004) recovered about 8% of total K leached during the first 14 d compared to 4% for the remainder of the experiment. Adams et al. (2013) observed a similar initial increase in release of nutrients by Osmocote Plus 15-9-12 in 3–4 and 12–14 month longevity products, and a steady decline thereafter. Newman et al. (2006) also noted an early increase in leachate EC and a later reduction and stabilization over time. Initial substrate nutrient addition before planting ('fertilizer charge') might not be necessary for low feeders and salt-sensitive plants, because these plants do not have the capacity to absorb most of the nutrients released during the early phase of the crop. It can be speculated that at the end of our experiments, plants had a better-developed root system, reaching most of the applied CRF, and therefore could maximize nutrient uptake. Additionally, if high fertilizer rates were used, high initial release might not favor growth of young plants due to high substrate EC.

Based on the data presented in these work, it is not possible to explain the differences in nutrients leached over time between Experiments 1 and 2. We speculate that it may be related to the environmental conditions, mainly irradiance. The average daily light integrals were 5.1 and 28 $mol \cdot m^{-2} \cdot d^{-1}$ for Expt. 1 and Expt. 2, respectively. This difference affected the time to harvest (54 d for Expt. 1 and 43 d for Expt. 2, respectively). As a consequence, Expt. 1 had 11 irrigation events while Expt. 2 had nine. It is possible that plants under higher radiation grew faster and were able to absorb more nutrients at a time when the CRF prills release the most nutrients (Richards and Reed 2004, Newman et al. 2006, Adams et al. 2013). As shown in Table 1, this early absorption of nutrients did not affect final SDW. In a future work, it would be important to measure the concentration of nutrients in the plants to see if plants can have similar SDW but different nutrient levels. While the magnitude of the leaching between Experiments 1 and 2 were different, the treatment differences were similar.

CRFs have been postulated as a practical method to reduce nutrient runoff and improve nutrient use efficiency in greenhouses (Merhaut et al. 2006, Cabrera 1997). In the present research, containers treated with WSF leached fewer nutrients than the 5–6CRF, but more nutrients than the 8–9CRF treated containers. In short-cycle crops such as these bedding plant impatiens, it is logical to match a short duration CRF release with this crop. However, the rapid release rate early after imbibition of the prills has the potential of reducing nutrient application efficiency. Therefore, it would be preferable to use longer release CRF types like the 8–9 month longevity used in the present study than the 5–6 month longevity, even on short cycle crops.

Over time, the containers treated with WSF leached more nutrients and eventually had a greater leaching rate than containers treated with CRF. However, the data does not support the idea of utilizing CRF in short-cycle plants such as bedding plants in order to minimize leaching of nutrients compared to WSF. It must be noted, however, that WSF was applied in a fixed volume of water to achieve a 20 to 30% leaching fraction. Additionally, leaching from the container is only one source of offsite nutrient movement; depending on the irrigation method, greater amounts of nutrient loss can occur if WSF application method is not targeted exclusively on the containers (Andiru et al. 2011). It is unclear how much leachate occurs from containers fertilized with WSF using irrigation methods with a higher leaching fraction like those utilized by growers. It should be noted that the CRF rates used in this work were high, though they were slightly lower than the maximum rate suggested by the label. It can be speculated that using a medium or low rate of application would have, most likely, reduced the amounts of nutrients found in the leachates. Yet previous work found that the fertilizer rate used in this research was ideal for both plant quality and garden performance after sale (Andiru et al. 2013). Future research should study the effect of CRF rates of application on nutrient in leachates. Furthermore, the long-term benefits that have been documented previously on field performance of bedding plants (Andiru et al. 2013) may hold more value from a post-production point of view than for reducing nutrients in the leachates.

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