Fertilizer Source and Irrigation Depth Affect Nutrient Leaching During Coleus Container Production[1]

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Abstract

Nutrient leaching during nursery container production can have negative effects on plant growth and the environment. The objective of this study was to evaluate effects of fertilizer source at two irrigation depths on nutrient leaching during coleus [*Plectranthus scutellarioides* (L.) Codd] 'Solar Sunrise' container production to develop best management practices. Coleus received no fertilizer, a controlled-release fertilizer (CRF), or a water-soluble fertilizer (WSF) applied at 0.30 kg N and P per m^3 (0.02 lb per ft^3) and were irrigated at 1.9 or 3.8 cm·day^{-1} (0.7 or 1.5 in·day^{-1}) for 56 days after planting (DAP). Leachate was analyzed every 7 DAP for inorganic N and dissolved total P (DTP). At 56 DAP, root biomass, leaf quality, and plant growth index were similar between CRF and WSF treatments at both irrigation depths. Highest inorganic N and DTP losses occurred within 21 DAP. Application of WSF resulted in higher cumulative N and DTP losses compared to CRF applications. Coleus irrigated at 3.8 cm·day^{-1} and fertilized with WSF resulted in higher DTP losses compared to CRF applications regardless of irrigation depth. Reducing irrigation reduced inorganic N leaching for each fertilizer source. Application of CRF provided consistent growth while curbing nutrient losses across both irrigation depths compared to WSF.

Index words: controlled-release fertilizer, water-soluble fertilizer, nursery producers, best management practices.

Chemicals used in this study: Micronutrients mix (Micromax®); controlled-release fertilizer (Osmocote® Classic); water-soluble fertilizer (Grower's Special).

Species used in this study: Coleus [*Plectranthus scutellarioides* (L.) Codd] 'Solar Sunrise'.

Significance to the Horticulture Industry

It is well accepted that nutrient leaching from nursery container production is associated with increased eutrophication and negative environmental impacts to surrounding water bodies and ecosystems. As a result, nursery managers should consider practices not only to generate profit, but also to minimize environmental impact. Fertilization and irrigation are primary practices affecting nutrient leaching in the nursery industry; however, there is little research regarding the use of traditional water-soluble fertilizers and more recently available controlled-release fertilizers and their interactions with varying irrigation depths, especially in areas with humid, subtropical climates. Therefore, this research provides critical information to nursery managers on how to tailor their fertilization and irrigation strategy to reduce nutrient leaching without slowing nursery container production of short-cycle crops such as coleus. Our findings indicate applying controlled-release fertilizer is a simple, recommended management practice to reduce nutrient leaching losses and produce salable plants. If a traditional water-soluble fertilizer is applied, decreasing irrigation depth is recommended as a means to reduce nutrient leaching losses.

Introduction

Nursery producers often utilize organic substrates with low nutrient- and water-holding capacities during container plant production (Owen et al. 2008) that require supplemental fertilization and irrigation (Bilderback 2002, Fulcher et al. 2012). Traditionally, water-soluble fertilizers (WSF) and frequent irrigation are applied (Liu et al. 2014) in greenhouse production to ensure nutrient sources are readily available for plant uptake and growth. However, excessive irrigation and/or unpredictable rainfall can significantly increase nutrient availability and thus movement (Fraisse et al. 2010, Wolf 1999).

Over time there has been a greater emphasis within the nursery industry to reduce negative environmental impacts associated with fertilizer nutrient leaching losses (Fare et al. 1994, Million et al. 2007, Warsaw et al. 2009). Excessive application of fertility and irrigation has been shown to contribute to eutrophication of surrounding water bodies (Bayer et al. 2015, Scheiber et al. 2008). Management of nutrients, specifically nitrogen (N) and phosphorus (P), and irrigation is critical to improving water quality of local waterways (Majsztrik et al. 2017). Along the Gulf Coast of the United States, an area that encompasses the Mississippi River watershed, nutrient pollution from agriculture and urban runoff has impaired local watersheds as well as contributed to hypoxic zones within the Gulf of Mexico (Louisiana Department of Environmental Quality 2015). Continued development and improvement of best management practices (BMP) are needed in the nursery industry to reduce offsite fertilizer movement (Million et al. 2011) without compromising plant production and salability.

Nutrient losses during container nursery production are largely affected by fertilizer source (Bayer et al. 2014, Du et al. 2011, Fernandez-Escobar et al. 2004). Commonly applied WSF are susceptible to leaching (Colangelo and Brand 2001, Liu et al. 2014). Alternatively, controlled-release fertilizers (CRF), a potential substitute for WSF

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(Birrenkott et al. 2005, Morgan et al. 2009), can reduce nutrient leaching losses as well as enhance plant nutrient uptake efficiency (Du et al. 2011, Liu et al. 2014), depending on species and environmental conditions. For example, Fernandez-Escobar et al. (2004) found that CRF application increased N-use efficiency in container-grown olive trees (*Olea europaea* L.) and reduced total N leaching losses compared to application of WSF sources such as ammonium nitrate and calcium nitrate. Other research evaluating fertilizer source and release mechanisms (Birrenkott et al. 2005, Catanazaro et al. 1998) during container production has generally reported reduced nutrient leaching when CRF was applied compared to WSF, particularly for species grown over extended periods.

Several controlled-release mechanisms for fertilizers have been developed but the primary CRF utilized in the nursery industry continues to be polymer-coated, water-soluble granules. Polymer-coated CRF are designed to regulate encapsulated granular nutrient diffusion into the growing substrate for plant uptake (Morgan et al. 2009); however, environmental factors, including substrate moisture content and temperature, have been reported to influence nutrient availability and thus losses of these materials (Cabrera 1997, Medina et al. 2009). Nutrient release of CRF is calculated based on laboratory-performed dissolution tests, but estimated nutrient availability often differs from practical nutrient availability during field production due to fluctuations in environments and application practices (Birrenkott et al. 2005). As a result, application of CRF is more common in outdoor container production for species grown over extended periods versus species produced for a short-cycle inside a greenhouse.

In addition to fertilizer source, it is well accepted that irrigation practices also affect nutrient losses during nursery container production. For example, Warsaw et al. (2009) reported application of higher irrigation volumes during the growth of *Deutzia gracilis* (Sieb. and Zucc.) 'Duncan' and several other ornamental species resulted in increased leachate volumes and consequently led to increased NO_3-N and PO_4-P losses. Controlling irrigation to meet plant requirements is often complicated due to variability in species tolerances, substrate characteristics, and multiple-species production operations. This has led to an expansion in research efforts (Bayer et al. 2014, Colangelo and Brand 2001, Scheiber et al. 2008) with a focus on developing integrated sensor-controlled irrigation systems (Fulcher et al. 2012, Million et al. 2011) to better manage irrigation to reduce or eliminate leaching. However, to date, there is limited research comparing WSF and CRF regarding the impact of irrigation depth (Million et al. 2011), specifically for container production of short-cycle crops.

As consumer preferences shift toward the purchase of larger plants, more research is needed to better understand the interactions of irrigation practices and nutrient sources to provide nursery producers with options on how to best implement fertilization and irrigation practices (Bayer et al. 2015, Chen et al. 2017) specific to their operation. Therefore, the objective of this study was to evaluate the influence of fertilizer source at two common irrigation depths on plant growth and N and P leaching losses during container production of a short-cycle crop, coleus (*Plectranthus scutellarioides* (L.) Codd) 'Solar Sunrise'.

Materials and Methods

Experimental design. A study was conducted on container production of coleus under greenhouse conditions for 56 days. Experiments were initiated July 2015 and March 2016 at the Ornamental and Turf Research Area of the Louisiana State University Agricultural Center Botanic Gardens located in Baton Rouge, LA (30°24′25.3″N 91°06′09.5″W). Seventy-two coleus liner plants, grown in 105-cell trays, were selected for uniform height and quality for transplanting into 4 L (1 gal) containers. All containers were filled with a pine bark-based substrate composed of 3:1:1 coarse pine bark:peat moss:vermiculite with 80% of dry weight pine bark particles within 19 to 0.71 mm (#25 Standard Test Sieve) and the remaining 20% of particles below 0.35 mm (#45 Standard Test Sieve). Substrate had a bulk density of 0.21 $g{\cdot}cm^{-3}$, water holding capacity of 67%, and air porosity of 20% for a total porosity of 87%. Substrate was amended with a micronutrient mix (Micromax Micronutrients, Burton, Ohio) at 0.30 $kg{\cdot}m^{-3}$ and dolomitic lime (MK Minerals, Inc., Wathena, KS) at 4.75 $kg{\cdot}m^{-3}$. Fertilizer treatments included an unfertilized control, a CRF (14-14-14, 90-day) (Osmocote Classic, BWI, Nash, TX), and a WSF (13-13-13) (Grower's Special, Shell Beach, Inc., Many, LA). Fertilizers were incorporated into the substrate at 0.30 kg N and $P{\cdot}m^{-3}$ prior to planting. Plants were irrigated at either 1.9 or 3.8 $cm{\cdot}d^{-1}$ (0.75 or 1.5 $in{\cdot}d^{-1}$) with municipal water treated with sulfuric acid to achieve a pH range of 6.5 to 7.0. Greenhouse temperatures and light intensities averaged 28.1 C (82.6 F) and 14,790.7 lx, respectively. Coleus was arranged in a completely randomized split-plot design with 3 replications for fertilizer treatments representing subplots and two replications for irrigation regimen representing main plots.

Plant growth measurements. Coleus growth index and leaf quality were measured every 14 days for 56 days after planting (DAP). Coleus growth index was calculated using the plant growth index formula:

$$\text{Plant Growth Index} = \frac{(\text{plant height}) + ((\text{plant width}_1 + \text{plant width}_2)/2)}{2}$$

(Irmak et al. 2004). Leaf quality measurements were performed based on visual appearance on a scale of 1 to 9 with 1 representing poor leaf size and color and 9 representing ideal leaf size and color for the 'Solar Sunrise' cultivar. Coleus root and shoot biomasses were collected at 0, 28, and 56 DAP. Root tissue was separated from shoot tissue before being washed to remove substrate particles. Plant tissue was dried at 40 C (104 F) for 72 h, and biomass determined gravimetrically.

Leachate collection and analysis. Leachate was collected using 11.4 L (3 gal) plastic reservoirs. Circular openings

Table 1. **Shoot biomass, root biomass, and total biomass (g) from container-grown coleus fertilized at 0.30 kg N and P per m^3 with either a controlled-release fertilizer (CRF) or water-soluble fertilizer (WSF); and irrigated at either 1.9 or 3.8 cm·day^{-1} for 56 days after planting (DAP).**

Fertilizer Treatment[z]	Irrigation Depth	Days after Planting[y]	Shoot Biomass		Root Biomass		Total Biomass	
	cm·day^{-1}		g[x]					
Control	1.9	0	0.52	c[w]	0.18	d	0.7	c
		28	1.69	c	1.18	bcd	2.87	c
		56	1.29	c	0.41	d	1.7	c
Control	3.8	0	0.38	c	0.15	d	0.53	c
		28	1.1	c	0.39	d	1.49	c
		56	1.65	c	0.62	cd	2.27	c
CRF	1.9	0	0.41	c	0.2	d	0.61	c
		28	2.68	c	1.62	abcd	4.3	c
		56	9.95	b	2.19	abc	12.14	b
CRF	3.8	0	0.49	c	0.15	d	0.64	c
		28	1.94	c	0.93	bcd	2.86	c
		56	11.94	b	2.51	ab	14.44	b
WSF	1.9	0	0.41	c	0.14	d	0.56	c
		28	2.48	c	0.64	cd	3.11	c
		56	19.32	a	3.32	a	22.64	a
WSF	3.8	0	0.38	c	0.1	d	0.48	c
		28	3.9	c	0.87	bcd	4.77	c
		56	11.99	b	3.09	a	15.09	b

[z]Control = unfertilized; CRF = controlled-release fertilizer; WSF = water-soluble fertilizer.

[y]Days after planting = DAP.

[x]Dry weight measured in g.

[w]Means not followed by the same letter are significantly different according to Tukey's HSD procedure at P=0.05.

were removed from the center of each reservoir lid with coleus containers fitted inside. The junction between the container and reservoir lids were sealed with silicone sealant to prevent irrigation water entering the reservoir. Leachate volume was measured every 7 DAP for 56 days with 25-mL subsamples collected for analysis of inorganic extractable nitrate (NO_3^-) and ammonium (NH^{4+}) using the inorganic N microplate method (Hood-Nowotny et al., 2010). Nitrogen was analyzed in triplicate with N leached reported as a combined total of inorganic N ($NO_3^- + NH_4^+$). Leachate samples were also submitted to the Louisiana State University Soil Testing and Plant Analysis Laboratory (Louisiana State University, Baton Rouge, LA) for quantitation of dissolved total phosphorus (DTP) using inductively coupled plasma (ICP) optical emission spectroscopy (ICP SPECTRO ACRCOS Model FH E12, Kleve, Germany).

Statistical analysis. Coleus growth and leaf quality parameters and weekly N and DTP leaching losses were analyzed over time following the mixed procedure using Statistical Analysis Software (SAS Version 9.4, SAS Institute Inc., Cary, North Carolina). Fixed effects included fertilizer source and irrigation depth with experimental run treated as a random effect. Nitrogen data was transformed using the natural log. Means for plant shoot and root biomass and cumulative N and DTP losses were separated following Tukey's procedure (α = 0.05). Coleus growth index, leaf quality, and nutrient losses were graphed with standard errors applied to means.

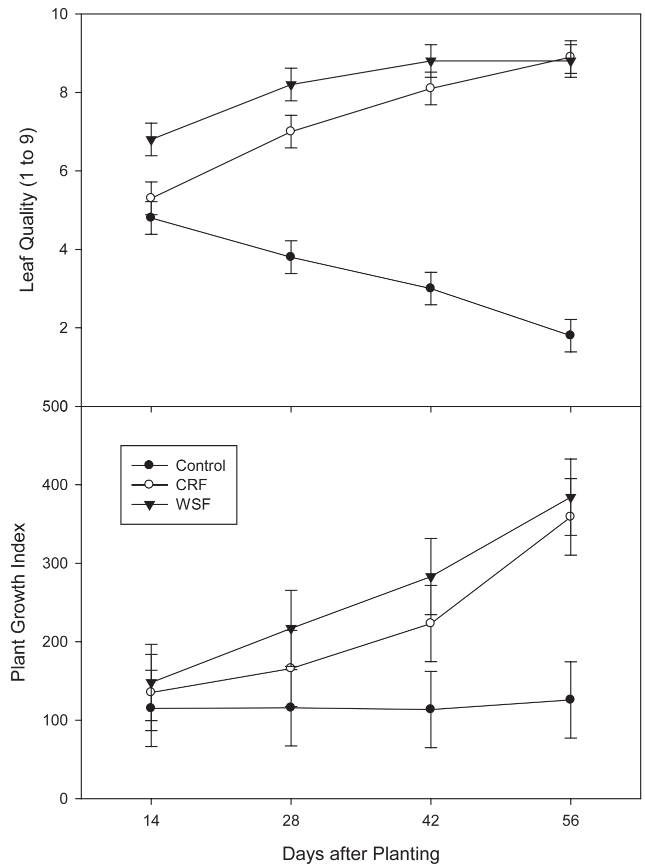

Fig. 1. **Leaf quality (1 to 9 scale) and plant growth index (unitless) averaged over irrigation rate from container-grown coleus fertilized at 0.30 kg N and P per m^3 with either a controlled-release fertilizer (CRF) or water-soluble fertilizer (WSF) for 56 days after planting (DAP). The bars represent standard errors at P=0.05.**

Results and Discussion

Coleus growth response. Applications of WSF are common in the nursery industry and have been reported to be effective when producing commercial-quality plants (Andiru et al. 2013, Birrenkott et al. 2005, Fernandez-Escobar et al. 2004, Mikkelsen et al. 1994, Morgan et al. 2009). In this study, coleus fertilized with WSF or CRF, regardless of irrigation depth, increased in leaf quality, growth index, and biomass to reach marketable size and quality within 56 DAP (Table 1 and Fig. 1). Only unfertilized coleus resulted in stagnant or declining leaf quality, growth index, and biomass. During the production period, WSF-treated coleus exhibited higher leaf quality at 14 and 28 DAP compared to CRF; however, by 42 DAP, leaf quality of CRF-treated coleus increased to be comparable to WSF-treated coleus. Coleus treated with WSF and subjected to the lower irrigation depth exhibited the highest shoot biomass at 19.32 g at 56 DAP, but did not exhibit significantly higher leaf quality, larger growth indices, or increased root biomass compared to other fertilizer and irrigation treatments with the exception of unfertilized coleus at 56 DAP. This increase in shoot biomass appeared to be correlated to visibly denser canopy; however, no other benefits to plant growth were observed and plant marketability was comparable to CRF-treated coleus at 56 DAP.

Increased WSF-coleus shoot biomass at the lower irrigation depth appears to be a function of greater nutrient retention of readily available, water-soluble nutrients (Liu et al. 2014) rather than deleterious effects associated with increased substrate moisture given the lack of differences in irrigation effects on CRF-coleus growth. In simulated landscapes, Scheiber et al. (2008) reported coleus (*Plectranthus scutellarioides* (L.) Codd 'Yalaha') to be tolerant to a range of irrigation depths and frequencies with no differences in plant growth. In comparison, the advantage of CRF is the consistency in coleus growth and leaf quality across irrigation depths as a result of regulating nutrient release (Du et al. 2011) and thus losses versus WSF. The consistency in CRF nutrient release reflects its 90-day longevity with respect to environmental conditions. Of course, effects of irrigation practices and environmental conditions are also species dependent (Bayer et al. 2015), necessitating more species-specific research to determine potentially confounding effects between irrigation depths and nutrient availability on plant growth.

Nutrient leaching losses. As the need for more sustainable nursery production systems has become paramount, research over the last few decades has focused on the effects of fertilization and irrigation best management practices (Majsztrik et al. 2017, Million et al. 2011) to reduce nutrient losses (Andiru et al. 2013). In this study, the benefit of CRF, beyond consistent plant growth across irrigation depths, was the significant reductions in initial and cumulative inorganic N and DTP losses compared to WSF. Water-soluble fertilizers typically release nutrients shortly after irrigation application (Liu et al. 2014), making nutrients readily available for plant uptake and/or leaching (Fernandez-Escobar et al. 2004, Mikkelsen et al. 1994). In contrast, CRF are designed to regulate granular nutrient diffusion for plant uptake over an extended duration (Morgan et al. 2009), depending on polymer coating characteristics and environmental conditions (Cabrera 1997).

Nutrient leaching losses for coleus fertilized with either WSF or CRF were highest the first 21 DAP, followed by a decline in nutrient losses over the remainder of the production period (Fig. 2). For WSF applications, nutrient losses that occurred within the first 21 DAP accounted for 85 to 89% cumulative N losses and 95 to 98% cumulative DTP losses. However, applying CRF significantly decreased initial inorganic N and DTP losses and reduced cumulative inorganic N losses 57 to 70% and cumulative DTP losses 75 to 80%, compared to applying WSF. Even though WSF and CRF were both applied at 0.30 kg N and P m^{-3}, nutrient leaching losses occurred within a narrower range for CRF applications compared to WSF applications. More specifically, cumulative inorganic N and DTP losses ranged from 108.7 to 133.7 mg for CRF treatments; whereas for WSF treatments cumulative inorganic N and DTP losses ranged from 253.1 to 679.9 mg. These findings are similar to other research that has shown the regulation of nutrient release through CRF application not only supports plant growth but also governs nutrient availability

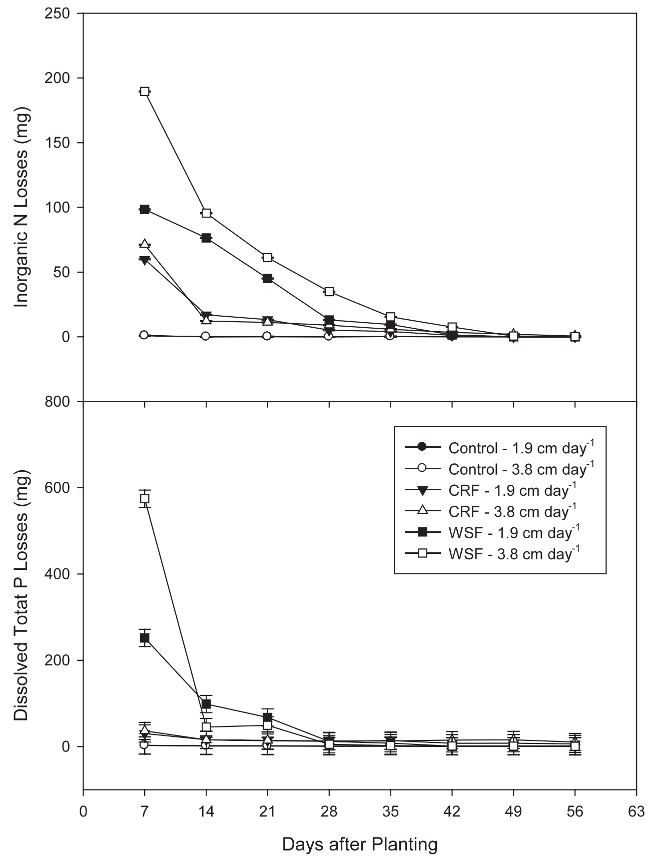

Fig 2. Inorganic N and dissolved total P leaching losses (mg) from container-grown coleus fertilized at 0.30 kg N and P per m^3 with either a controlled-release fertilizer (CRF) or water-soluble fertilizer (WSF); and irrigated at either 1.9 or 3.8 $cm \cdot day^{-1}$ for 56 days after planting (DAP). The bars represent standard errors at P=0.05.

to reduce N and P leaching losses during container production (Fare et al. 1994, Fernandez-Escobar et al. 2004, Liu et al. 2014, Million et al. 2007, Warsaw et al. 2009).

The other factor affecting nutrient leaching during coleus container production was irrigation. Applying the lower irrigation depth reduced inorganic N and DTP losses, regardless of the type of fertilizer applied. Lowering the irrigation depth from 3.8 to 1.9 $cm \cdot day^{-1}$ decreased cumulative leachate volumes 45% from 48.9 to 26.7 L (12.9 to 7.1 gal) (data not shown) and consequently reduced inorganic N and DTP losses. Many studies have demonstrated a direct correlation between decreasing effluent volumes and nutrient losses (Bayer et al. 2015, Bayer et al. 2014, Bilderback 2002, Colangelo and Brand 2001, Fare et al. 1994, Fernandez-Escobar et al. 2004, Merhaut et al. 2006, Million et al. 2007). For example, Warsaw et al. (2009) found that reducing applied irrigation 25% led to 59 and 74% reductions in N and P concentrations, respectively, across several ornamental species fertilized with a CRF (17-3.5-6.6).

Lowering irrigation not only reduced overall water use by 50%, but also resulted in 39 and 35% reductions in cumulative inorganic N and DTP losses, respectively, for WSF applications here and elsewhere compared to

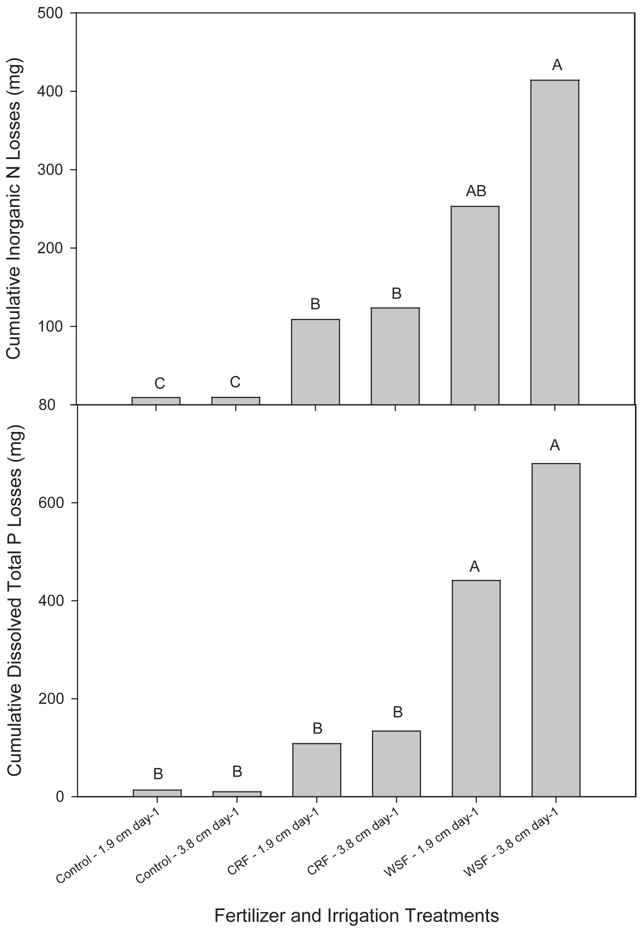

Fig. 3. Cumulative inorganic N and dissolved total P leaching losses (mg) from container-grown coleus fertilized at 0.30 kg N and P per m^3 with either a controlled-release fertilizer (CRF) or water-soluble fertilizer (WSF); and irrigated at either 1.9 or 3.8 $cm \cdot day^{-1}$ at 56 days after planting (DAP). Means not followed by the same letter are significantly different according to Tukey's HSD procedure at p=0.05.

corresponding reductions of 12 and 19% for CRF applications (Fig. 3). Cumulative losses for WSF applications irrigated at 3.8 $cm \cdot day^{-1}$ were 414.1 mg N and 679.9 mg DTP; compared to 123.5 mg N and 133.7 mg DTP for CRF applications at the same irrigation depth. As expected, unfertilized coleus had low cumulative inorganic N and DTP losses regardless of irrigation depth, with losses ranging from 9.1 to 13.3 mg, which were most likely a result of mineralization and nitrification of the pine bark substrate. Although lowering the irrigation depth reduced nutrient losses, discrepancies between N and P losses occurred, particularly with WSF treatments. Lowering the irrigation depth consistently led to significantly lower inorganic N losses, regardless of fertilizer treatment applied (Fig. 4). Conversely, lowering the irrigation depth reduced cumulative DTP losses from 679.9 to 441.2 mg for WSF applications but only a slight reduction occurred in cumulative DTP losses of 133.7 to 108.3 mg for CRF applications.

Due to its negative charge, N in the form of NO_3^- is poorly retained in substrates, making N susceptible to leaching (Cabrera 1997, Fernandez-Escobar et al. 2004). It

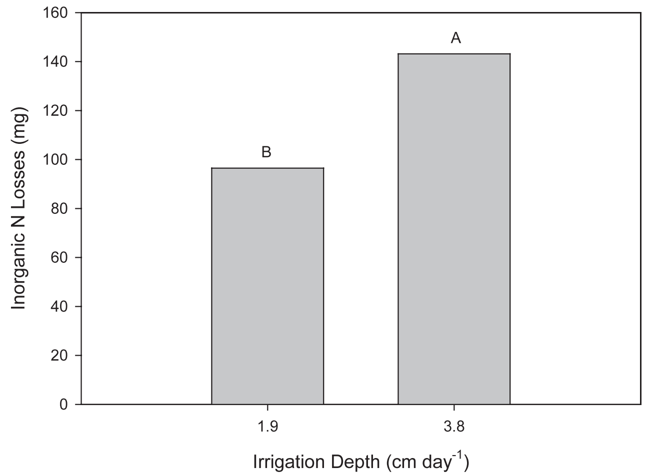

Fig 4. Inorganic N leaching losses averaged over fertilizer source from container-grown coleus fertilized at 0.30 kg N and P per m^3; and irrigated at either 1.9 or 3.8 $cm \cdot day^{-1}$ at 56 days after planting (DAP). Means not followed by the same letter are significantly different according to Tukey's HSD procedure at P=0.05.

is also possible N losses occurred through other mechanisms such as increased denitrification (Cabrera 2003) as a result of fluctuations in substrate moisture. On the other hand, P, in the forms of $H_2PO_4^-$ and HPO_4^{2-}, is readily adsorbed and retained in soils or substrates with high CEC (Owen et al. 2008) and is not subject to volatile losses. The substrate used in this study exemplifies the low nutrient-binding and water-holding capacity of substrates commonly utilized throughout the nursery industry for container production. It is also important to note that the P requirement for coleus is an order of 2 to 3 times less than that for N (Mills and Jones 1996). Therefore, greater P availability of WSF, a substrate with low CEC and water-holding capacity, higher plant N requirements relative to P, as well as other potential mechanisms for N losses all contributed to the increased DTP leaching losses compared to inorganic N leaching losses as effluent volumes increased.

Lowering irrigation to decrease leachate volumes reduced overall nutrient losses, but further reduction of DTP losses may have been achieved through altering P application rates relative to N. Several studies have shown the application of fertilizers based on N rates can lead to over-application of other nutrients (Owen et al. 2008, Williams and Nelson 1992), especially P. More recent research has also indicated P fertility rates could be reduced for container production of coleus (*Coleus hybridus* cv.) (Chen et al. 2017) and other container-grown ornamental species including hydrangea (*Hydrangea macrophylla* (Thunb.) Ser.) and Japanese holly (*Ilex crenata* Thunb.) (Shreckhise et al. 2019).

Reducing P losses relative to N is especially important in areas with environmental conditions conducive to high nutrient losses. Acceptable water quality criteria of rivers and streams for P is 0.06 mg $P \cdot L^{-1}$, an order of 9x lower concentration than the acceptable criteria for N at 0.57 mg $N \cdot L^{-1}$ (Texas-Louisiana Coastal and Mississippi Alluvial Plains Ecoregion X) (USEPA, 2019a). In fact, surface waters with even lower concentrations have been linked to eutrophication (Carpenter et al. 1998, Rice and Horgan 2011, USEPA 2019b). Therefore, lowering the fertilizer composition ratio of P versus N may be a simple BMP when applying WSF in addition to regulating leachate, but also when selecting a CRF, given the consistent leaching losses measured for this study.

Consumer preferences have shifted towards larger transplants for use in both indoor spaces and outdoor landscapes (Khatamian and Stevens 1994, Mason et al. 2008). As the nursery industry produces larger, short-cycle crops, such as coleus (Ball Horticultural Company 2013, Mills et al. 1996) to meet consumer demands, nursery producers will need to implement best management fertility practices, especially given the rising awareness surrounding sustainable practices (Andiru et al. 2013) and potentially forthcoming governmental regulation (Louisiana Department of Environmental Quality 2015, USEPA 2019b). The combination of fertilizer and irrigation treatments evaluated in this study clearly demonstrated reducing irrigation can limit nutrient leaching and conserve water regardless of fertilizer source selected. However, applying a polymer-coated CRF provided consistent coleus growth while curbing nutrient losses across irrigation depths compared to WSF. Therefore, selecting a CRF as an alternative to WSF is a simple and effective management practice to produce marketable plants as well as significantly reduce nutrient leaching losses during an 8-week production cycle of coleus.

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