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Influence of Fertilizer Source and Irrigation Regimen on Containerized Production of Coleus (Plectranthus scutellarioides (L.) Codd) 'Solar Sunrise' and Management of Bermudagrass (Cynodon dactylon (L.) Pers. x C. transvaalensis Burtt-Davy) 'Tifway'

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INFLUENCE OF FERTILIZER SOURCE AND IRRIGATION REGIMEN ON CONTAINERIZED PRODUCTION OF COLEUS (*PLECTRANTHUS SCUTELLARIOIDES* (L.) CODD) 'SOLAR SUNRISE' AND MANAGEMENT OF BERMUDAGRASS (*CYNODON DACTLYON* (L.) PERS. X *C. TRANSVAALENSIS* BURTT-DAVY) 'TIFWAY'

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ABSTRACT

Fertilizer nutrient losses through leachate and runoff from excessive irrigation in nursery container production and turfgrass management can be high and have negative environmental impacts. The objective of this research was to examine the influence of fertilizer source and irrigation regimen on nutrient losses during nursery container production and turfgrass management. During the container production of coleus (*Plectranthus scutellarioides* (L.) Codd) 'Solar Sunrise', four fertilizer treatments: an unfertilized control; a controlled-release (CRF); a water-soluble (WSF); and a combination of 10% WSF and 90% CRF, were incorporated into a pine bark substrate at 0.30 kg N and P$\cdot$m^{-3} in 3.7-L containers and irrigated at 1.9 cm$\cdot$day^{-1} or 3.8 cm$\cdot$day^{-1} under greenhouse conditions for 56 days. Plant quality was measured every 14 days and total biomass was measured every 28 days. Leachate was collected weekly and analyzed for N (NO_3^- and NH_4^+) and P (dissolved total P, DTP). Plant growth was similar across CRF, combination (WSF and CRF), and WSF treatments and irrigation regimens. Fertilizer source did affect nutrient leaching losses. Coleus fertilized with WSF resulted in higher total N (NO_3^--N + NH_4^+-N) and DTP losses compared to coleus fertilized with CRF or combination fertilizer regardless of irrigation regimen. Decreasing irrigation regimen for WSF treatment resulted in a reduction of total N losses, but did not reduce total DTP losses. Three fertilizer treatments: an unfertilized control; a controlled-release (CRF); and a water-soluble fertilizer (WSF), were applied at 97.6 kg N and P$\cdot$ ha^{-1} to bermudagrass (*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy) 'Tifway' established in runoff trays. Plant growth was measured every 14 days. Rainfall simulation events were held every 4 weeks for 12 weeks during which water samples were collected following 30 minutes of simulated rainfall output at 0.12 $cm \cdot min^{-1}$ and analyzed for N (NO_3^- + NH_4^+) and DTP. There were no differences in bermudagrass plant growth between WSF and CRF treatments. WSF treatment resulted in highest total N and DTP losses. Nutrient leaching can be reduced without sacrificing plant growth during coleus container production and bermudagrass management through the application of CRF.

CHAPTER 1. INTRODUCTION

Fertilizer nutrient losses through leaching and surface runoff can occur when fertilization and irrigation practices are improperly managed during nursery container production or turfgrass management. Nutrient losses can lead to negative environmental impacts. As a result, Federal and State government agencies are working to establish regulations to protect water quality and reduce potential for nutrient pollution. There is a need for research that focuses on the influence of fertilization and irrigation practices implemented during production to reduce nutrient losses. The objective of this research was to examine the relationship between fertilization and irrigation practices in nursery container production and turfgrass management.

1.1 Coleus Characterization and Management

Coleus (*Plectranthus scutellarioides* (L.) R. Br.) is an herbaceous perennial of the Lamiaceae family (Missouri Botanical Garden, n.d.; United States Department of Agriculture [USDA], n.d.b). Coleus is native to southeastern Asia and is also commonly known as flame nettle, painted nettle or painted leaf (Croxton & Kessler, 2007). Coleus, known for its brightly colored leaf patterns and variegations, is commonly grown in the landscape and indoor plant industries.

As a member of the Lamiaceae family, coleus demonstrates the family's characteristic square-shaped stems. Plants have an upright growth habit and typically range from 0.15 to 0.9 m in height and spread (Missouri Botanical Garden, n.d.). Coleus leaf margins can be ruffled, serrated, deeply lobed, entire, or toothed. Leaf shapes vary from heart-shaped, tapered, round, to oval (Croxton & Kessler, 2007). Leaves are arranged in an opposite pattern on the main stem. Cultivar colors are diverse and include: green, red, cream, orange, yellow, peach, pink, white and purple (Missouri Botanical Garden, n.d.). The 'Solar Sunrise' cultivar, (*Plectranthus scutellarioides*) ‘Solar Sunrise', used in this research exhibits purple and magenta leaves with bright green coloring around leaf veins and margins (Rosy Dawn Gardens, 2016). Plants typically bloom from mid-summer to late-summer and produce tall, linear inflorescences with small, tubular flowers that are purple to white in color. The flowers are generally considered to be unattractive and it is a common practice to remove flowers before development. Removing flowers stops seed production and redirects energy toward producing colorful foliage. Coleus thrives in hardiness zones 10 and 11 but does not usually survive cold conditions (Missouri Botanical Garden, n.d.).

Typically, coleus is produced through nursery container production in a greenhouse setting. Plants can be produced either by seed or by stem cuttings (Croxton & Kessler, 2007). It is suggested that plants be kept in night temperatures between 18^{o} to 21^{o} C and day temperatures between 25^{o} to 29^{o} C during production (Croxton & Kessler, 2007). If propagated through rooted cuttings, plants take approximately 6 to 8 weeks before reaching market quality (Mills & Jones, 1996; Croxton & Kessler, 2007).

1.2 Bermudagrass Characterization and Management

Bermudagrass (*Cynodon dactylon* (L.) Pers.) is a warm-season perennial grass of the Poaceae family (USDA, n.d.a.; Stubbendieck, Hatch & Landholt, 2003). It is native to Africa but can be found throughout the world in tropical to warm, temperate climates (Carey, 1995). It grows best in soil temperatures between 27^{o} and 35^{o} C and can be found across the southern United States (United States Environmental Protection Agency [USEPA], 2009; Lee, Harris & Murphy, 2013) growing in pastures, fields and the understory of open woods and forests (Carey, 1995). Bermudagrass is characterized by creeping, mat-forming culms that reach 10 to 50 cm tall (Carey, 1995; Stubbendieck et al., 2003). Leaf edges are smooth and sharply pointed at the tips. Leaves are alternately arranged on erect culms with a thin, rounded, paper-like leaf sheath at each node (Cudney, Elmore & Bell, 2007; Stubbendieck et al., 2003). Inflorescences generally have two to seven digitate spikelet branches which originate in one single whorl (Carey, 1995; Cudney et al., 2007). Bermudagrass can reproduce by seed but spreads most rapidly through rhizomes and stolons (Carey, 1995).

During a typical growing season, bermudagrass begins growth in the spring, continues during the summer and enters into dormancy when temperatures cool in the fall (Carey, 1995). Bermudagrass is heat and drought tolerant and performs well in regions with high temperatures and low precipitation compared to other warm-season turfgrass species (Christians, 2004). Bermudagrass exhibits few pest problems, though differences in pest tolerance are cultivar dependent (McCarty, 2001).

Bermudagrass has value as a forage crop for livestock but is commonly grown as a turfgrass in highly maintained areas (Cudney et al., 2007; Carey, 1995). For use as a turfgrass, hybrids cultivars, such as Tifgreen, Tifdwarf, Tifway, and Santa Ana, have been developed for improved drought and heat tolerance characteristics (Cudney et al., 2007). Hybrid cultivars do not produce viable seed; therefore, most hybrid cultivars require vegetative establishment through sod or sprigs (Cudney et al., 2007). The cultivar used for this research, Tifway, (*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy) 'Tifway', exhibits dark green leaves that are medium fine in texture (Phillip Jennings Turf Farms, 2009).

1.3 Nitrogen Cycle

Nitrogen (N) is generally considered to be the most important essential nutrient for plant growth (Joo, Lerman & Li, 2013; Vitousek & Howarth, 1991). N is a constituent of amino acids, proteins, nucleic acids and coenzymes; and is involved in forming organic compounds (Evans & Sorger, 1966; Mengel & Kirkby, 1987; Taiz & Zeiger, 2006). N is mobile in the plant and is usually taken up in the inorganic forms of ammonium (NH_4^+) and nitrate (NO_3^-). N has six important oxidation states [N_2 (0), NO_3^- (+5), NO_2 (+4), NO_2^- (+3), NO (+2), NH_4^+/NH_3 (-3) and organic N (-3)] involved in the reactions that drive N transformations within the N cycle (Joo et al., 2013). Fixation, mineralization and nitrification result in an increase of plant available N, and denitrification, volatilization, immobilization and leaching result in a decrease of plant available N (Johnson, Albrecht, Ketterings, Beckman & Stockin, 2005).

Fixation: Nitrogen fixation occurs when atmospheric N (N_2) is converted to a plant available form, NH_4^+ or NO_3^-. Fixation occurs as either an abiotic process or a biological process. Abiotic fixation generally occurs through industrial fertilizer production, which converts N gas (N_2) to ammonia (NH_3). Biological fixation most commonly occurs when symbiotic bacteria use energy, enzymes and minerals to convert N_2 to NH_3 for amino acid production.

Mineralization: Mineralization occurs when organic N is converted to plant available forms of N, such as NH_4^+ or NO_3^-. This occurs as a byproduct of the decomposition of organic matter by soil microorganisms. The rate of mineralization is dependent on C:N ratios, quantity of soil organic matter, size of soil organic matter, soil temperature, moisture, and oxygen within the soil.

Nitrification: Nitrification occurs when soil microorganisms convert NH_3 and/or NH_4^+ to NO_3^-, the most plant available form of N. Microorganisms perform this process to obtain energy from mineral N. The rate of nitrification is dependent on pH, soil moisture, soil temperature, NH_4^+ substrate concentrations, and oxygen availability within the soil.

Denitrification: Denitrification occurs when microorganisms convert nitrite (NO_2^-) or NO_3^- to N gas. This commonly occurs when soils are saturated with water and oxygen is unavailable. The result is a loss of available N from the soil.

Volatilization: Volatilization occurs when NH_4^+ is converted to ammonia gas. Ammonia gas is typically lost from the soil to the atmosphere. Urea is susceptible to volatilization.

Immobilization: Immobilization, the reverse of mineralization, occurs when plant available forms of N, such as NH_4^+ and NO_3^-, are immobilized by microorganisms in the soil and are unavailable for plant uptake. Immobilization results in a reduction of plant available N. Inorganic N will become available again after microorganisms' death and decomposition in the soil.

Leaching: Leaching occurs when nutrients are lost through downward water movement in the soil. Nitrate is highly susceptible to leaching because of its negative charge and limited interaction with charged soil particles. Leaching is dependent on water availability, soil type, drainage, and nitrate concentration in the soil (Johnson et al., 2005; Joo et al., 2013).

1.4 Phosphorus Cycle

Phosphorus (P) is an essential plant nutrient important for energy storage and structural integrity of plants. Phosphorus is a component of sugar phosphates, nucleic acids, coenzymes, and phospholipids; and plays a key role in ATP reactions (Evans &

Sorger, 1966; Mengel & Kirkby, 1987; Taiz & Zeiger, 2006). Plants take up inorganic P in the form of orthophosphates, HPO_4^{2-} and $H_2PO_4^-$. Organic P, adsorbed P and primary mineral P are unavailable for plant uptake, but all are involved in the P transformations that occur within the P cycle (Hyland et al., 2005). Weathering, mineralization and desorption result in an increase of plant available P; and immobilization, precipitation and adsorption result in a decrease of plant available P (Busman, Lamb, Randall, Rem & Schmitt, 2009; Hyland et al., 2005).

Weathering: Weathering, or dissolution, occurs when primary or secondary minerals that are rich in P break down over time and slowly release plant available orthophosphates (HPO_4^{2-} and $H_2PO_4^-$). This process is highly dependent on soil pH.

Mineralization: Mineralization occurs when microorganisms break down organic matter in the soil and convert organic P to plant available orthophosphates (HPO_4^{2-} and $H_2PO_4^-$). HPO_4^{2-} is more common in alkaline conditions and $H_2PO_4^-$, in acidic conditions. Mineralization occurs rapidly when soil is warm and moist.

Desorption: Desorption occurs when adsorbed P is released into the soil solution and is available for plant uptake.

Immobilization: Immobilization occurs when plant available orthophosphates (HPO_4^{2-} and $H_2PO_4^-$), are converted to unavailable organic P by microorganisms. This process is not permanent as organic P will eventually be released back into the soil once microorganisms die and decompose. Immobilization is influenced by C:P ratio, soil organic matter and soil temperature.

Precipitation: Precipitation occurs when plant available inorganic P reacts with dissolved iron, aluminum, manganese or calcium in the soil. Upon reacting with these minerals, inorganic P forms phosphate minerals (i.e. Fe/$AlPO_4$, $CaHPO_4$) and becomes unavailable for plant uptake. This transformation is more permanent because the chemical properties of P are altered.

Adsorption: Adsorption occurs when inorganic soil P is chemically bound to soil particles, making it adsorbed ("fixed") P and unavailable for plant uptake. Adsorption occurs rapidly compared to desorption and is reversible.

Surface runoff and leaching are also related to the P cycle. Surface runoff occurs when soil-bound P from eroded soil and dissolved P from applied fertilizer are lost through water movement across the soil surface. Leaching occurs when dissolved P from the soil is lost through vertical water movement. Both are a major concern when soil P concentrations are high and can decrease plant available P (Busman et al., 2009; Hyland et al., 2005).

1.5 Comparison of Water-Soluble Fertilizer and Controlled-Release Fertilizer

Managing nutrients – especially N and P – for plant growth can be challenging. An understanding of the advantages and disadvantages of fertilizers is important for making informed management decisions. Two types of fertilizers commonly used in plant production are water-soluble fertilizer (WSF) and controlled-release fertilizer (CRF) (Cabrera, 1997).

Traditional, commercial WSF releases nutrients in a short time period with addition of irrigation or precipitation (Liu et al., 2014; Colangelo & Brand, 2001). They include products such as ammonium nitrate, ammonium sulfate and potassium phosphate. Although WSF nutrients are made available at a consistent rate (Trenkel, 2010), the nature of their quick release pattern does not always coincide with the changing nutrient requirements of developing plants (Liu et al., 2014). This can lead to inefficient nutrient uptake in the plant, leaf burning and nutrients losses; and, is traditionally why when using WSF, frequent applications are necessary to maintain plant growth (Liu et al., 2014).

In contrast to WSF, CRF is designed to release nutrients over an extended period of time (Birrenkott, McVey & Craig, 2005; Cabrera, 1997; Colangelo & Brand, 2001; Sharma, 1979). The Association of American Plant Food Control Officials (AAPFCO) (2015) defines a CRF as:

> A fertilizer containing a plant nutrient in a form which delays its availability for plant uptake and use after application, or which extends its availability to the plant significantly longer than a reference 'rapidly available nutrient fertilizer' such as ammonium nitrate or urea, ammonium phosphate or potassium chloride. Such delay of initial availability or extended time of continued availability may occur by a variety of mechanisms. These include controlled water solubility of the material by semi-permeable coatings, occlusion, protein materials, or other chemical forms, by slow hydrolysis of water-soluble low molecular weight compounds, or by other unknown means.

The slow release pattern of CRF more closely parallels the nutrient requirements of a plant throughout its growth and developmental stages (Liu et al., 2014; Colangelo & Brand, 2001; Sharma, 1979), which allows plants to more efficiently use nutrients and reduce nutrient losses through leaching (Du, Duan & Hu, 2000; Fernandez-Escobar, Garcia-Novelo, Herrera & Benlloch, 2004).

1.6 Management of Nitrogen and Phosphorus in Container Production

In 2014, the United States sold $13.8 billion in floriculture, nursery and other specialty crops (USDA, 2016). The development of container production has significantly contributed to the rapid growth of these industries (Robbins & Klingman, n.d.; Dunwell & Vanek, 2013; Colangelo & Brand, 2001) and accounts for approximately

60% of nursery acreage in the United States (Owen & White, n.d.). Container production has transformed traditional nursery production by providing a means to produce a wide variety of trees, shrubs and flowers in less space and a longer growing season (Dunwell & Vanek, 2013; Robbins & Klingman, n.d.). As the nursery container production industry continues to increase so does the demand for resources, such as nutrients and water, required to support it. Best management practices (BMPs) determined by current research are vital for the container production industry to balance production growth and environmental impacts.

In container production, soilless substrate is typically used as a growing medium and is composed of materials such as peat moss, vermiculite, perlite, sand and pine bark (Colangelo & Brand, 2001; Whitcomb, 1988). These materials provide adequate pore space for drainage as well as sufficient water holding capacity, both of which are critical for managing irrigation in container production (Halcomb & Fare, 2010; Warsaw, Andresen, Cregg & Fernandez, 2009; Alam, Lumis, Llewellyn & Chong, 2009). However, these materials have a limited capacity for retaining nutrients (Owen & White, n.d.; Warsaw et al., 2009), thus nutrient management is critical. Nutrients are provided through substrate fertilizer application. Management of N and P applied through fertilizers is particularly important as both of these essential nutrients limit plant growth (Evans & Sorger, 1966; Mengel & Kirkby, 1987; Taiz & Zeiger, 2006) and have potential for negatively impacting water quality if lost through leaching (USEPA, n.d.a; USEPA, n.d.b). Nutrient losses through leaching can be influenced by fertilizer source and irrigation practices (WSF or CRF) (Fare, Gilliam & Keever, 1992; Million, Yeager & Albano, 2007; Warsaw et al., 2009; Liu et al., 2014).

Understanding the pattern of nutrient losses is important for managing plant growth and reducing potential nutrient losses through leaching (Fulcher, Geneve & Buxton, 2012; Bilderback, 2002; Million, Albano & Yeager, 2010). It has been reported up to 74 to 87% of applied water can fall between containers when overhead irrigation is used in container production (Weatherspoon & Harrell, 1980). This water loss increases surface runoff volume and promotes movement of nutrients away from production sites to nearby water sources (Warsaw et al., 2009; Fulcher et al., 2012). Yeager et al. (1993) found that at different points throughout the production cycle, nitrate levels from a nursery site's runoff can exceed the United States Environmental Protection Agency (USEPA) limit of 10 mg L^{-1}. There is a strong need for research that focuses on enhancing nutrient uptake efficiency, improving water use efficiency and reducing nutrient runoff from production sites (Million et al., 2011; Newman, Blythe, Merhaut & Albano, 2006). One study reported that nitrate leachate concentrations were reduced when irrigation volume was reduced from 13 to 6 mm (Fare et al., 1992). Million et al., (2007) produced sweet viburnum (*Viburnum odoratissimum* (L.) Ker-Gawl) in containers with controlled-release fertilizer (Osmocote) and found increasing irrigation from 1 to 2 cm, increased leaching losses by 34% for N and 38% for P under a low fertilizer rate (15 g/container). Similarly, another study compared daily water use (DWU) during the production of several ornamental species and reported nitrate and phosphate concentrations in leachate averages were 38% and 46% lower, respectively, for 100% DWU irrigation volumes, and 59% and 74% lower, respectively, for 75% DWU irrigation volumes compared to a control irrigation volume of 19 mm (Warsaw et al., 2009).

1.7 Management of Nitrogen and Phosphorus in Turfgrass Management

According the National Turfgrass Federation [NTF] (n.d.), there are approximately 50 million acres of managed turfgrass in the United States, putting turfgrass third in total acreage across the country. Turfgrass is estimated to be a $40 billion industry and growing (NTF, n.d.). Managed turfgrass areas include residential lawns, commercial landscapes, athletic fields, golf courses and sod production farms. Whatever the function of a turfgrass, managers and homeowners rely on best management practices (BMPs) to make informed decisions on how to balance turfgrass management and environmental impacts (Schwartz & Shuman, 2005).

Managing high maintenance turfgrass requires inputs of fertilizer and irrigation (Schwartz & Shuman, 2005; Shuman, 2002; Rice & Horgan, 2011; Carey, 1995); which, if poorly managed can result in nutrient losses (Saha, Unruh & Trenholm, 2007; Easton & Petrovic, 2004; Petrovic, 1990). In residential areas, over-irrigating is common (USEPA, 2009). Over-irrigation can have negative effects on turfgrass health, including: shallow root systems; increased disease, weed or insect invasion; reduced drought tolerance; increased thatch; excessive growth; and reduced tolerance to other stresses (USEPA, 2009; Trenholm & Unruh, 2003). Over-irrigation can also lead to runoff, which results in a reduction of plant available nutrients such as N and P (Easton & Petrovic, 2004; Snyder, 1984; Schwartz & Shuman, 2005; Shuman, 2004). Nitrogen and P can limit plant growth (Evans & Sorger, 1966; Mengel & Kirkby, 1987; Taiz & Zeiger, 2006); thus, their management is critical for plant health. In addition to reducing plant available nutrients, surface runoff, a major pathway for nutrient transport (Vadas, Sharpley & Owens, 2008) is also associated with pollution of waterways (Shuman, 2006).

Irrigation is difficult to manage in the field because precipitation intensity and frequency are uncontrollable and often unpredictable. Therefore, turfgrass managers must implement practices to reduce potential nutrient losses through surface runoff. Fertilizer source may be one way to reduce potential nutrient losses through surface runoff (Easton & Petrovic, 2004; Brown, Duble & Thomas, 1977; Shuman, 2006). Water-soluble fertilizers (WSF) and controlled-release fertilizers (CRF), are commonly applied fertilizers in turfgrass management. It has been shown that applying CRF can minimize nutrient losses from turfgrass (Saha et al., 2007; Killian, Attoe & Engelbert, 1966). One study examined the effect of different fertilizer sources to bermudagrass (*Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis* Burtt-Davy) 'Tifgreen'. It was reported, when calculating N losses as a fraction of N applied, urea fertilizer application resulted in 33.6 to 61.5% N losses and ammonium sulfate fertilizer application resulted in 20.7 to 46.3% N losses (Picchion & Quiroga-Garza, 1999). In another study examining bermudagrass, it was reported application of ammonium nitrate resulted in 8.6 to 21.9% nitrate losses and application of slow-release fertilizer resulted in only 0.2% to 1.6% nitrate losses (Brown, Thomas & Duble, 1982). Urea fertilizer leached up to 10% of applied N compared to controlled-release fertilizer which leached only 1.7% of applied N (Paramasivam & Alva, 1997). Shuman (2006) compared several fertilizers applied at a rate of 12 kg N ha^{-1} and found nitrate-N leached was 10.2% for ammonium nitrate, 4.3% for soluble 20-20-20 and 0.14% for sulfur-coated urea. There are few studies which focus on P losses in turfgrass, though it has been shown that P can be transported from bermudagrass during simulated rainfall at a 5% slope (Shuman, 2002). Another study found leached P to be highest from soluble fertilizer application compared to CRFapplication (Shuman, 2003). There is limited research which compares fertilizer sources (Sloan & Anderson, 2011; Picchioni & Quiroga-Garza, 1999) and how they influence N and P losses through turfgrass surface runoff.

1.8 Environmental Impacts of Nitrogen and Phosphorus Losses

There is growing concern regarding the potential environmental impacts of nutrient loading in the United States. Through the enactment of the Clean Water Act in 1972, the United States Environmental Protection Agency (USEPA) established regulations and nutrient control programs to reduce pollutant discharge and improve water quality (USEPA, 2016c). One issue on which the USEPA is focused on is nutrient pollution. Nutrient pollution, which can lead to eutrophication, is an excess of N and P in the air or water (USEPA, 2016b). One of the primary sources of nutrient pollution to water is agriculture, which includes nursery container production sites and managed turfgrass areas (USEPA, 2016b). Nitrogen and P can enter surface and ground water through leaching and surface runoff (USEPA, 2016b) and is often related to fertilizer application (Bayer, Whitaker, Chappell, Ruter & van Iersel, 2015; Scheiber, Wang, Pearson, Beeson & Chen, 2008).

Nitrogen and P pose a threat to surface waters at relatively low levels (Easton & Petrovic, 2004; Parry, 1998). Surface water with a P concentration as low as 0.025 mg L^{-1} and a N concentration as low as 1 mg L^{-1} have been linked to increased algal growth (Rice & Horgan, 2011; Walker & Branham, 1992). When N and P concentrations increase, algae grows more rapidly than ecosystems can handle (USEPA, 2016b). If algal growth is prolific, an algal bloom can occur. Algal blooms reduce water quality and habitat and decrease available oxygen to fish and other aquatic life (USEPA, 2016b).

Some algal blooms can even release toxins which can be harmful to fish, animals and humans (USEPA, 2016a). Once a body of water becomes eutrophic, the effects are persistent and recovery is slow (Carpenter et al., 1998). Nutrient pollution can also result in dead zones, or hypoxia, areas where oxygen concentrations are so low, little to no aquatic life can survive (USEPA, 2016a). Oxygen concentrations decrease during algae death and decomposition (USEPA, 2016a). The Gulf of Mexico dead zone, which was measured at 5,840 square miles in 2013, is the largest dead zone in the United States and occurs because of nutrient pollution from the Mississippi River Basin (USEPA, 2016a).

1.9 References

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CHAPTER 2: COMPARISON OF FERTILIZER SOURCE AND IRRIGATION REGIMEN ON PLANT GROWTH AND NUTRIENT LOSSES DURING CONTAINER PRODUCTION OF COELUS (*PLECTRANTHUS SCUTELLARIOIDES* (L.) CODD) 'SOLAR SUNRISE'

2.1 Abstract

Nutrient leaching from excessive irrigation during nursery container production can have potentially negative environmental impacts. Past research has reported that fertilizer and irrigation practices can influence nutrient leaching during container production. The objective of this study was to examine the influence fertilizer source and irrigation regimen has on nutrient leaching during container production of coleus (*Plectranthus scutellarioides* (L.) Codd) ‘Solar Sunrise'. Four fertilizer treatments were evaluated: an unfertilized control; a controlled-release fertilizer (CRF) (14-14-14); a water-soluble fertilizer (WSF) (13-13-13); and a combination of 10% WSF and 90% CRF. Fertilizers were incorporated at 0.30 kg N and P·m^{-3} into a pine bark substrate. Coleus was planted in 3.7-liter containers and irrigated at 1.9 cm·day^{-1} or 3.8 cm·day^{-1} under greenhouse conditions for 56 days. Coleus leaf quality and plant growth index were measured every 14 days while root, shoot, and total biomass were measured every 28 days. Leachate was collected weekly and analyzed for NO_3^--N, NH_4^+-N, and DTP. At 56 days, coleus leaf quality, plant growth index, and total biomass were similar amongst CRF, WSF, and combination (WSF and CRF) treatments and irrigation regimens. However, fertilizer source did affect nutrient leaching losses. Coleus fertilized with WSF irrigated at the higher regimen resulted in greater total N (NO_3^-+ NH_4^+) and total DTP losses compared to coleus fertilized with CRF or combination fertilizer. Decreasing irrigation regimen for WSF treatment resulted in a reduction of total N losses, but did not reduce total DTP losses. Highest N and DTP losses occurred within

21 days after planting and declined over the 56-day study for all CRF, WSF, and combination (WSF and CRF) treatments. During coleus container production, the application of CRF can reduce nutrient leaching without sacrificing coleus growth in container production.

2.2 Introduction

Nursery producers often utilize organic substrates with low water and nutrient holding capacities during containerized plant production (Owen, Warren, Bilderback, & Albano, 2008). Therefore, management of irrigation and nutrients is essential to produce high quality marketable plants (Fulcher, Geneve, & Buxton, 2012; Bilderback, 2002). As a result there has been a greater emphasis within the nursery industry to reduce potential negative environmental impacts associated with fertilizer losses from excessive irrigation (Fare, Gilliam & Keever, 1992; Million, Yeager, & Albano, 2007; Warsaw, Andresen, Cregg, & Fernandez, 2009). Improperly managed fertility and irrigation practices have been shown to contribute to eutrophication of surrounding water bodies (Bayer, Ruter, & van Iersel, 2015; Louisiana Department of Environmental Quality [LDEQ], 2015; Scheiber, Wang, Pearson, Beeson, & Chen, 2008).

In areas such as the Mid-South 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. Therefore, management of nutrients – specifically N and P – is critical for improving water quality of local waterways to reduce hypoxic zones (LDEQ, 2015). Nutrient pollution, specifically nitrates, which originate from fertilizers applied at nursery sites (Scheiber et al., 2008), have been linked to groundwater contamination. Therefore, continued development and refinement of best management practices is needed in nursery container production to reduce offsite fertilizer movement (Million et al., 2011).

Fertilizer type has been reported to affect nutrient leaching losses during container production (Fare et al., 1992; Million et al., 2007; Warsaw et al., 2009; Liu, Zotarelli, Li, Dinkins, Wang, & Ozores-Hampton, 2014). Highly water-soluble fertilizers (WSF) commonly applied in nursery container production are prone to leaching (Colangelo & Brand, 2001; Liu et al., 2014). In contrast, controlled-release fertilizers (CRF), have been reported to enhance plant nutrient uptake efficiency (Du, Duan, & Hu, 2000; Liu et al., 2014; Birrenkott, McVey, & Craig, 2005),) as well as reduce nutrient leaching losses (Morgan, Sato, & Cushman, 2009; Fernandez-Escobar, Garcia-Novelo, Herrera, & Benlloch, 2004). Although, several CRF have been developed for the ornamental industry, water soluble fertilizer granules coated with multiple polymer layers continue to be the primary CRF applied (Birrenkot et al., 2005). Polymer coated CRF are designed to regulate nutrient release within the growing substrate for plant uptake (Morgan et al., 2009). However, factors such as substrate moisture content and temperature have been reported to affect nutrient availability from polymer coated CRF (Medina, Obreza, & Sartain, 2009). Nutrient availability from CRF is calculated based on laboratory conducted dissolution tests; therefore, estimated nutrient availability often varies under differing nursery container production environments and practices (Birrenkott et al., 2005).

Irrigation practices have also been shown to affect nutrient leaching during container production (Fare et al., 1992; Million et al., 2007; Warsaw et al., 2009; Liu et al., 2014). Warsaw et al. (2009) reported application of higher irrigation volumes during the growth of *Deutzia gracilis* (Sieb. and Zucc.) ‘Duncan’; *Kerria japonica* (L.) DC. ‘Albiflora’; *Thuja plicata* (D. Don.) ‘Atrovirens’,; and *Viburnum dentatum* (L.) ‘Ralph Senior’ applied with CRF, resulted in increased leachate volumes and higher NO^{3-}-N and PO_4^{3-}-P losses. Fare et al. (1992) showed NO^{3-}-N concentrations in leachate were reduced as irrigation volume was reduced from 13 to 6 mm. However, there is limited research regarding the relationship between irrigation regimen and nutrient release in nursery container production, making it difficult for nursery producers to determine best management practices (Million et al., 2011; Bayer et al., 2015).

The objective of this study was to investigate the interaction of fertilizer source and irrigation regimen on plant growth and nutrient leaching losses during production of coleus (*Plectranthus scutellarioides* (L.) Codd) 'Solar Sunrise'.

2.3 Materials and Methods

Experimental Design*.* Two 56-day experiments were conducted in 2015 and 2016 on coleus (*Plectranthus scutellarioides* (L.) Codd) 'Solar Sunrise' container production under greenhouse conditions. Experiments were conducted at the Ornamental and Turf Research Area of the Louisiana State University Agricultural Center Botanic Garden located in Baton Rouge, LA (30^{o}24'25.3"N 91^{o}06'09.5"W). Seventy-two coleus liners, grown in 105-cell trays, were selected for transplant into 3.7-L containers. All containers were filled with a 3:1:1 coarse pine bark:peat moss:vermiculite amended with micronutrient mix (Micromax® Micronutrients, Burton, Ohio) and dolomitic lime at rates of 0.30 kg m^3 and 4.75 kg m^3, respectively.

Coleus was fertilized with 3 fertilizer treatments in 2015 and 4 fertilizer treatments in 2016. The 2015 experiment treatments included: an unfertilized control; controlled-release fertilizer (CRF) (14-14-14) (Osmocote® Classic, BWI, Nash, Texas); and water-soluble fertilizer (WSF) (13-13-13) (Grower's Special, Shell Beach, Inc., Many, Louisiana). The 2016 experiment treatments included the treatments from 2015 with the addition of a fourth fertilizer treatment, the combination of 90% CRF (14-14-14) (Osmocote® Classic, BWI, Nash, Texas) and 10% WSF (13-13-13) (Grower's Special, Shell Beach, Inc., Many, Louisiana). All fertilizers were applied at a rate of 0.3 kg N and P $\cdot m^{-3}$ and incorporated within the substrate prior to potting. Each treatment was irrigated at 1.9 $cm \cdot d^{-1}$ or 3.8 $cm \cdot d^{-1}$ with municipal water treated with sulfuric acid to achieve a pH range of 6.5 to 7.0. Coleus was arranged in a split-plot design with 3 replications with irrigation regimen representing the main plot and fertilizer treatments representing subplots.

Plant Response. Coleus growth index and leaf quality were measured every 14 days for 56 days after planting (DAP) during each experiment. Coleus growth index was calculated using the plant growth index formula ([plant height + (plant $width_1$ + plant $width_2$)] /2) (Irmak, Haman, Irmak, Jones, & Crisman, 2004). Leaf quality measurements were based 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, shoot, and total biomass were collected at 0, 28, and 56 DAP. Coleus shoots were separated from root tissue at the substrate interface and dried at 40^{o} C for 72 hours. Shoot, root, and total biomasses were determined gravimetrically.

Leachate Collection. Leachate was collected using 11.4-L plastic containers placed below coleus planted containers. Circular centers were cut into the collection container lids to allow coleus planted containers to fit tightly within the lid for leachate collection.

Sealant was applied around the coleus planted container-lid interface to allow for leachate drainage into the collection container. Leachate was collected every 7 days for 56 days during each experiment. Total leachate was weighed (lbs) and later converted to volume (L). Twenty-five mL subsamples were collected from each leachate container and stored at 4^oC until laboratory analyses for nitrate (NO_3^--N), ammonium (NH^{4+}-N), and dissolved total P were conducted.

Leachate Analysis. Leachate samples were analyzed for extractable inorganic NO_3^--N and NH^{4+}-N using the inorganic N microplate method (Hood-Nowotny, Hinko-Najera, Inselbacher, Wanek, & Lachouani, 2010). Reagents for ammonium determination, including sodium salicylate solution, 1.5M NaOH, bleach/NaOH solution and ammonium stock solution (100 ppm) and reagents for nitrate determination, including 0.5M HCl, vanadium (III) and nitrate stock solution (100 ppm), were mixed within 24 hrs prior to conducting analyses. Microplates (96-well, PS, F-Bottom, VWR International, Sugar Land, Texas) used for ammonium analysis were loaded with 100 µL of sodium salicylate solution, 40 µL of leachate and 100 µL of bleach/NaOH solution in triplicate for each leachate and standard sample. Samples were then incubated at room temperature for 50 minutes in the dark. Microplates used for nitrate analysis were loaded with 200 µL of vanadium (III) and 40 µL of sample in triplicate for each leachate and standard sample. Samples were incubated at 37^o C for 1 hour in the dark. Following incubation, ammonium and nitrate concentrations were quantified at 650 nm and 540 nm, respectively, using an Eon™ Microplate Spectrophotometer (BioTek Instruments, Inc., Winooski, Vermont). Concentrations for NO_3^--N and NH^{4+}-N were determined using standard concentrations of 0, 0.1, 0.5, 1, 2, 5, 10 and 15 ppm for ammonium and nitrate for each microplate. Blank and known samples were also used to ensure quality control during ammonium and nitrate analyses.

Leachate samples were also submitted to the Louisiana State University Soil Testing and Plant Analysis Laboratory (125 Madison B. Sturgis, Louisiana State University Campus, Baton Rouge, Louisiana) for analysis of total dissolved P. Samples were analyzed using Inductively Coupled Plasma Mass Spectrometry.

Statistical Analysis. The study was a split-plot design with three replications and irrigation regimen as the main plots and fertilizer treatments as the subplots. Coleus growth and quality parameters and weekly N and DTP leaching losses were analyzed over sampling dates. Only cumulative N and DTP losses over the 56 day measurement periods were not analyzed over sampling dates. Data for each parameter were analyzed using Statistical Analysis Software (SAS Version 9.4, SAS Institute Inc., Cary, North Carolina) with mean separations following Tukey's Test procedure ($\alpha = 0.05$).

2.4 Results

Coleus Response. During the 56-day production cycle in 2015 and 2016 (Figure 2.1 and Figure 2.2), coleus growth index was affected by fertilizer source and sampling date. In 2015, coleus fertilized with WSF increased in growth index from 162.9 to 316.3 and 449.2 at 0, 28, and 56 days after planting (DAP), respectively, compared to coleus fertilized with CRF which increased in growth index during the same period from 174.2 to 220, and 373.8, respectively. A similar pattern was observed in 2016 for coleus fertilized with CRF, WSF, and combination of CRF and WSF. At 56 DAP in 2016, coleus fertilized with CRF, WSF, and combination of CRF and WSF resulted in growth indices of 282.9, 341.3, and 303.3, respectively (Figure 2.2).

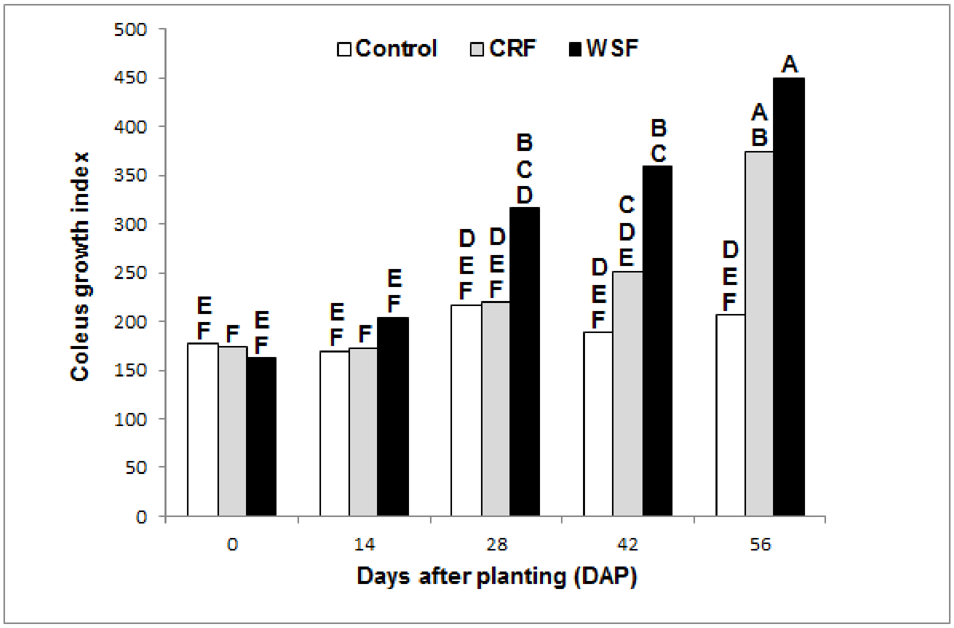

Figure 2.1 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on coleus growth index ([plant height + (plant width$_1$ + plant width$_2$)] /2) over 56 days in 2015. CRF and WSF were applied at 0.3 kg N and P $\cdot m^{-3}$ in a pine bark substrate and irrigated at 1.9 or 3.8 cm$\cdot$day^{-1}. Different letters are significant ($p<0.05$) based on Tukey's Test.

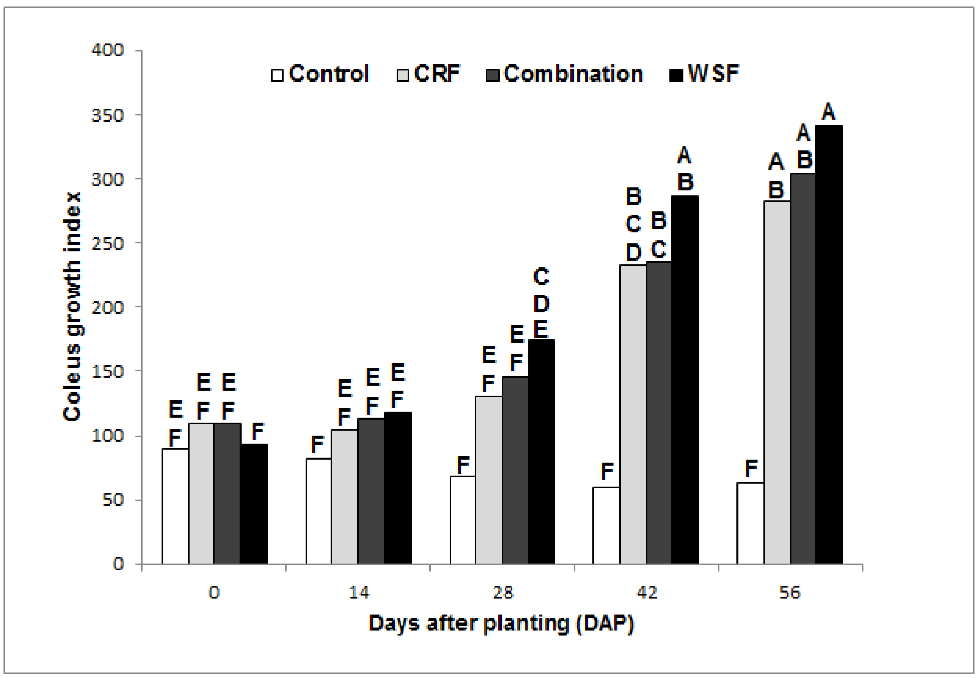

Figure 2.2 Comparison of a controlled-release fertilizer (CRF), water-soluble fertilizer (WSF), and combination of 90% CRF and 10% WSF on coleus growth index ([plant height + (plant width$_1$ + plant width$_2$)] /2) over 56 days in 2016. CRF, WSF, and combination fertilizers were applied at 0.3 kg N and P $\cdot m^{-3}$ in a pine bark substrate and irrigated at 1.9 or 3.8 cm$\cdot$day^{-1}. Different letters are significant ($p<0.05$) based on Tukey's Test.

In 2015 and 2016, coleus leaf quality was affected by fertilizer source and sampling date (Figure 2.3 and Figure 2.4). Except for the unfertilized control, coleus leaf quality ratings increased across all fertilizer treatments during the 56-day production cycle within both years. In 2015, leaf quality of coleus fertilized with WSF increased from 4.3 to 8.7 and 8.8 at 0, 28, and 56 DAP, respectively, compared to leaf quality of coleus fertilized with CRF, which increased from 4.7 to 6.3 and 8.7, respectively. In 2016, effects of fertilizer treatment trends were similar to those observed in 2015, including the combination of CRF and WSF treatment which increased in leaf quality from 5 to 7.8 and 8.7 at 0, 28, and 56 DAP, respectively. At 56 DAP in 2016, leaf quality of coleus fertilized with CRF, WSF and combination of CRF and WSF, were 8.5, 9, and 8.7, respectively (Figure 2.4).

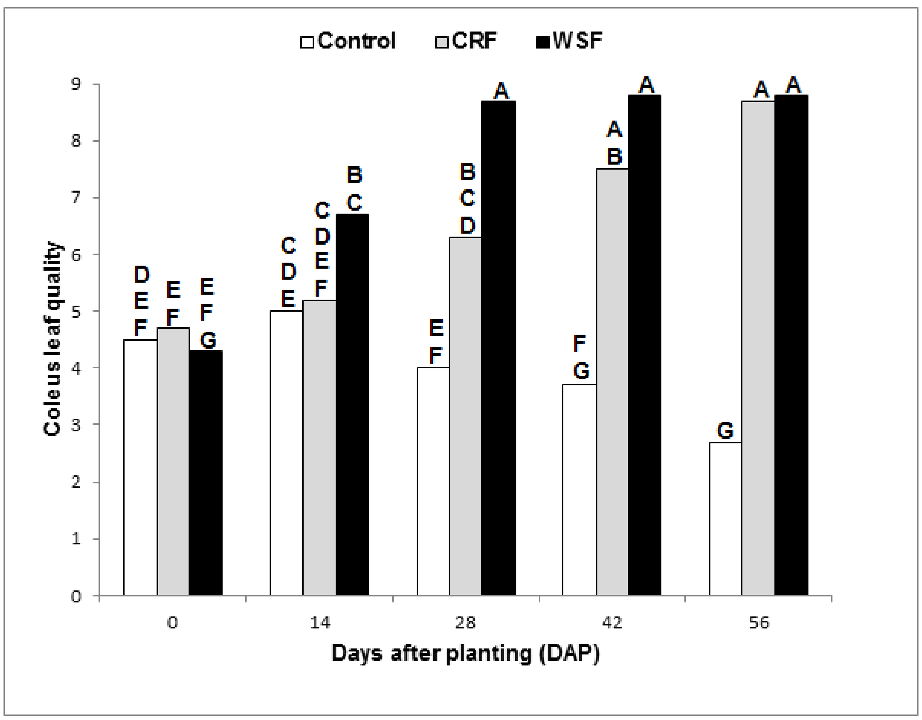

Figure 2.3 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on coleus leaf quality (1=dead; 5=acceptable; 9=ideal) over 56 days in 2015. CRF and WSF were applied at 0.3 kg N and P $\cdot m^{-3}$ in a pine bark substrate and irrigated at 1.9 or 3.8 $cm \cdot day^{-1}$. Different letters are significant ($p<0.05$) based on Tukey's Test.

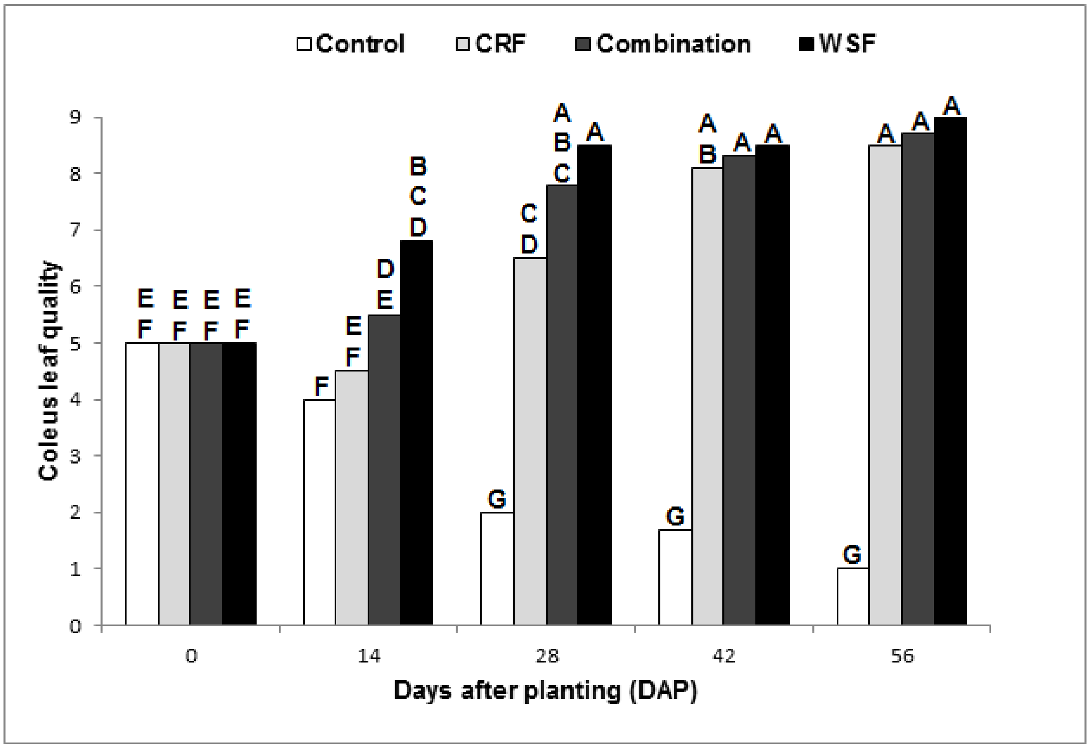

Figure 2.4 Comparison of a controlled-release fertilizer (CRF), water-soluble fertilizer (WSF), and combination of 90% CRF and 10% WSF on coleus leaf quality (1=dead; 5=acceptable; 9=ideal) over 56 days in 2016. CRF, WSF, and combination fertilizers were applied at 0.3 kg N and P $\cdot m^{-3}$ in a pine bark substrate and irrigated at 1.9 or 3.8 $cm\cdot day^{-1}$. Different letters are significant ($p<0.05$) based on Tukey's Test.

Root biomass was affected by both fertilizer source and irrigation regimen over time during the 56-day production cycle in 2015 and 2016 (Table 2.1).Coleus fertilized with CRF and irrigated at 1.9 $cm\cdot day^{-1}$ and 3.8 $cm\cdot day^{-1}$ resulted in root biomasses of 4.9 and 1.2 g, respectively at 56 DAP. Irrigation regimen did not affect root biomass in coleus fertilized with WSF in 2015. At 56 DAP, root biomass was 3.4 and 4.6 g for coleus fertilized with WSF and irrigated at 1.9 $cm\cdot day^{-1}$ and 3.8 $cm\cdot day^{-1}$, respectively. During the 56-production cycle in 2016, coleus root biomass was similar between all fertilizer treatments and irrigation regimens, excluding the unfertilized control, and ranged from 1.1 to 1.9 g at 56 DAP.

Table 2.1 Comparison of a controlled-release fertilizer (CRF), water-soluble fertilizer (WSF), and combination of 90% CRF and 10% WSF on coleus root biomass (g) over 56 days in 2015 and 2016. CRF, WSF, and combination fertilizers were applied at 0.3 kg N and P $\cdot m^{-3}$ in a pine bark substrate and irrigated at 1.9 or 3.8 $cm \cdot day^{-1}$.

			Root Biomass^{w}		
Year	Fertilizer Source^{x}	Irrigation^{y}	0 DAP^{z}	28 DAP	56 DAP
2015	Control	1.9	0.3d^{u}	2.1bcd	1d
		3.8	0.3d	1cd	2.5abcd
	CRF	1.9	0.2d	0.9cd	4.9a
		3.8	0.2d	0.5d	1.2cd
	WSF	1.9	0.2d	0.4d	3.4abc
		3.8	0.1d	1.2cd	4.6ab
2016	Control	1.9	0.1ef^{v}	0.3def	0.1ef
		3.8	0.2ef	0.3def	0.1f
	CRF	1.9	0.1ef	2.3a	1.9ab
		3.8	0.1ef	1.5abcde	1.6abcd
	Combination	1.9	0.1ef	0.4cdef	1.8ab
		3.8	0.1ef	2.1a	1.1abcdef
	WSF	1.9	0.1f	0.4cdef	1.7abc
		3.8	0.1ef	0.5bcdef	1.6abcd

^{u}Values followed by different letters are significant ($p<0.05$) according to Tukey's test in 2015.
^{v}Values followed by different letters are significant ($p<0.05$) according to Tukey's test in 2016.
^{w}Dry weight measured in g.
^{x}Control = unfertilized; CRF = controlled-release fertilizer; WSF = water-soluble fertilizer; Combination = 10% WSF + 90% CRF.
^{y}Applied $cm \cdot day^{-1}$.
^{z}Days after planting.

In 2015 and 2016, coleus shoot biomass was affected by fertilizer source and sampling date (Table 2.2). Throughout the 56-day production cycle in both years, all fertilizer treatments increased coleus shoot biomass, with the exception of the unfertilized control in 2016. There was a significant difference in coleus shoot biomass between fertilizer treatments in 2015. At 56 DAP coleus fertilized with WSF had the highest shoot biomass, 18 g, compared to coleus fertilized with CRF and unfertilized coleus, at 12 g and 2.6 g, respectively. In 2016, shoot biomass was comparable for coleus regardless of fertilizer treatment, excluding the unfertilized control. At 56 DAP, shoot biomass was 10, 13.3, and 8.7 g for coleus fertilized with CRF, WSF, and combination of CRF and WSF, respectively.

Table 2.2 Comparison of a controlled-release fertilizer (CRF), water-soluble fertilizer (WSF), and combination of 90% CRF and 10% WSF on coleus shoot biomass (g) over 56 days in 2015 and 2016. CRF, WSF, and combination fertilizers were applied at 0.3 kg N and P $\cdot m^{-3}$ in a pine bark substrate and irrigated at 1.9 or 3.8 $cm \cdot day^{-1}$.

		Shoot Biomass[w]		
Year	Fertilizer Source[x]	0 DAP[z]	28 DAP	56 DAP
2015	Control	0.5c[u]	2.3c	2.6c
	CRF	0.5c	1.8c	12b
	WSF	0.5c	4.6c	18a
2016	Control	0.4b[v]	0.5b	0.3b
	CRF	0.4b	2.8b	10a
	Combination	0.3b	2.1b	8.7a
	WSF	0.3b	1.8b	13.3a

[u]Values followed by different letters are significant ($p<0.05$) according to Tukey’s test in 2015.
[v]Values followed by different letters are significant ($p<0.05$) according to Tukey's test in 2016.
[w]Dry weight measured in g.
[x]Control = unfertilized; CRF = controlled-release fertilizer; WSF = water-soluble fertilizer; Combination = 10% WSF + 90% CRF.
[z]Days after planting.

Coleus total plant biomass was affected by fertilizer source by sampling date in both 2015 and 2016 (Table 2.3). Coleus total plant biomass increased over the 56-day production cycle for all fertilizer treatments, with the exception of the unfertilized control in 2016. In 2015, coleus fertilized with WSF increased in total plant biomass from 0.6 to 5.4 and 22 g at 0, 28, and 56 DAP, respectively, compared to coleus fertilized with CRF at 0.7 to 2.5 and 15 g, at 0, 28, and 56 DAP, respectively. A similar trend was observed amongst fertilizer treatments in 2016, excluding the unfertilized control. At 56 DAP; total plant biomass was 11.7, 15, and 10.2 g for coleus fertilized with CRF, WSF, and combination of CRF and WSF, respectively.

Table 2.3 Comparison of a controlled-release fertilizer (CRF), water-soluble fertilizer (WSF), and combination of 90% CRF and 10% WSF on coleus total plant biomass (g) over 56 days in 2015 and 2016. CRF, WSF, and combination fertilizers were applied at 0.3 kg N and P $\cdot m^{-3}$ in a pine bark substrate and irrigated at 1.9 or 3.8 $cm\cdot day^{-1}$.

		Total Plant Biomass[w]		
Year	Fertilizer Source[x]	0 DAP[z]	28 DAP	56 DAP
2015	Control	0.8cd[u]	3.8cd	4.2cd
	CRF	0.7cd	2.5cd	15b
	WSF	0.6d	5.4c	22a
2016	Control	0.5c[v]	0.8c	0.4c
	CRF	0.4c	4.7bc	11.7a
	Combination	0.4c	3.4c	10.2ab
	WSF	0.4c	2.2c	15a

[u]Values followed by different letters are significant ($p<0.05$) according to Tukey's test in 2015.
[v]Values followed by different letters are significant ($p<0.05$) according to Tukey's test in 2016.
[w]Dry weight measured in g.
[x]Control = unfertilized; CRF = controlled-release fertilizer; WSF = water-soluble fertilizer; Combination = 10% WSF + 90% CRF.
[z]Days after planting.

Leachate Analysis. In 2015, N loss (NO_3^--N + NH_4^+-N) through leachate was affected by fertilizer source over time (Table 2.4). Nitrogen losses for both the CRF and WSF treatments were highest within 21 DAP; although, N losses in WSF-fertilized coleus leachate were significantly higher than N losses in CRF-fertilized coleus leachate. In WSF-fertilized coleus leachate, N losses were 136.9, 85.6, and 107.9 mg at 7, 14, and 21 DAP, respectively. In CRF-fertilized coleus leachate, N losses were 49, 10.8, and 9.3

mg at 7, 14, and 21 DAP, respectively. From 21 to 56 DAP, N losses in WSF-fertilized coleus leachate were inconsistent, ranging from 0 to 26.2 mg, while N losses in CRF-fertilized coleus leachate were consistent, ranging from 2.6 to 4.4 mg. In 2016, N losses were affected by fertilizer source and irrigation regimen (Table 2.5). Similar to 2015, N losses for all fertilizer treatments as well as for all irrigation regimens were highest

Table 2.4 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on coleus leachate nitrogen losses (mg) (NO_3^- -N + NH_4^+-N) over 56 days in 2015. CRF and WSF were applied at 0.3 kg N and P $\cdot m^{-3}$ in a pine bark substrate and irrigated at 1.9 or 3.8 $cm \cdot day^{-1}$.

Fertilizer Source[x]	Nitrogen Leaching Losses[w]							
	7 DAP[z]	14 DAP	21 DAP	28 DAP	35 DAP	42 DAP	49 DAP	56 DAP
Control	2.1e[v]	0e	0.04e	0e	0.4e	0e	0e	0e
CRF	49cd	10.8e	9.3e	4.4e	3.2e	6.4e	5.2e	2.6e
WSF	136.9a	85.6bc	107.9ab	26.2de	7.6e	1.7e	0.09e	0e

[v]Values followed by different letters are significant ($p<0.05$) according to Tukey's test.
[w] NO_3^- -N and NH_4^+-N combined for nitrogen losses in mg.
[x]Control = unfertilized; CRF = controlled-release fertilizer; WSF = water-soluble fertilizer; Combination = 10% WSF + 90% CRF.
[z]Days after planting.

within the first 21 DAP in 2016. Nitrogen losses were significantly higher in WSF-fertilized coleus leachate compared to CRF-fertilized or combination-fertilized coleus leachate. For example, WSF-fertilized coleus leachate N losses at 7 DAP ranged from 157.3 to 273.3 mg while N losses of CRF-fertilized and combination-fertilized coleus leachate at 7 DAP ranged from 77.5 to 82.1 mg and 95.1 to 155.3 mg, respectively. Irrigation regimen affected N losses in WSF-fertilized coleus leachate. In WSF-fertilized coleus leachate at 7DAP, there was a 42.5% reduction in N loss when irrigation was decreased from 3.8 $cm \cdot day^{-1}$ to 1.9 $cm \cdot day^{-1}$.

Table 2.5 Comparison of a controlled-release fertilizer (CRF), water-soluble fertilizer (WSF), and combination of 90% CRF and 10% WSF on coleus leachate nitrogen leaching losses (mg) (NO_3^- -N + NH_4^+-N) over 56 days in 2016. CRF, WSF, and combination fertilizers were applied at 0.3 kg N and P·m^{-3} in a pine bark substrate and irrigated at 1.9 or 3.8 cm·day^{-1}.

Fertilizer Source[x]	Irrigation[y]	Nitrogen Leaching Losses[w]							
		7 DAP[z]	14 DAP	21 DAP	28 DAP	35 DAP	42 DAP	49 DAP	56 DAP
Control	1.9	1k[v]	0k	0.08k	0k	0.2k	0k	0k	0k
	3.8	1.4jk	0k	0.1k	0k	0.3k	0.1k	0k	0k
CRF	1.9	82.1def	23.1hijk	17.1hijk	13.6hijk	13.1hijk	2.8jk	0k	0k
	3.8	77.5defg	16.9hijk	11.6ijk	10.7ijk	7.7ijk	7.2ijk	7.7ijk	2.6jk
Combination	1.9	95.1cde	73.8defgh	29fghijk	17.5ghijk	11hijk	0.3ijk	0ijk	0ijk
	3.8	155.3bc	66.6defghi	28.5efghijk	18.2ghijk	7.5hijk	1.1jk	0jk	1.2jk
WSF	1.9	157.3b	79defg	54.1defghij	19.2hijk	16.3hijk	4.1k	0k	0k
	3.8	273.5a	98.3cd	88.4df	38.2eghijk	33.4eghijk	11.6ijk	2jk	0.1k

[v]Values followed by different letters are significant ($p<0.05$) according to Tukey's test.

[w]NO_3^- -N and NH_4^+-N combined for nitrogen losses in mg.

[x]Control = unfertilized; CRF = controlled-release fertilizer; WSF = water-soluble fertilizer;
Combination = 10% WSF + 90% CRF.

[y]Applied cm·day^{-1}.

[z]Days after planting.

Total N losses, the total leachate losses from the 56-day production cycle, were affected by fertilizer source and irrigation regimen in both 2015 and 2016 (Figure 2.5 and Figure 2.6). In both years, N losses were highest in WSF-fertilized coleus leachate. In 2015, total N losses in WSF-fertilized coleus leachate ranged from 305 to 427.1 mg compared to total N losses in CRF-fertilized coleus leachate, which ranged from 59.8 to 120.5 mg. Irrigation regimen had an effect on total N losses in WSF-fertilized coleus leachate in both 2015 and 2016. By decreasing irrigation from 3.8 cm·day^{-1} to 1.9 cm·day^{-1}, total N losses in WSF-fertilized coleus leachate was reduced 28.6 and 46.6% in 2015 and 2016, respectively. In 2016, total N losses in WSF-fertilized coleus leachate were comparable to total N losses in both CRF-fertilized and combination-fertilized coleus leachate regardless of irrigation regimen. Total N lost of applied N from CRF, combination and WSF treatments ranged from 5-21%, 18-23%, and 26-56%, respectively, in 2015 and 2016.

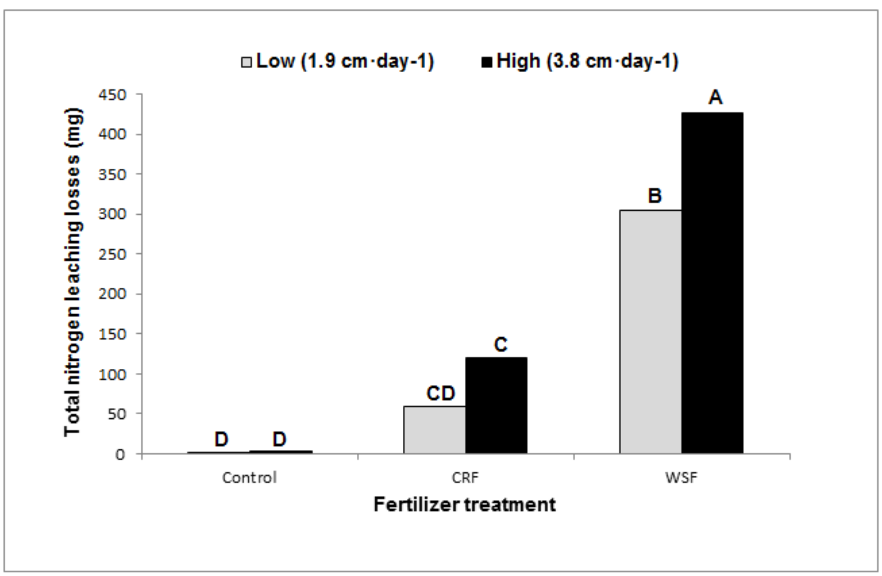

Figure 2.5 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on coleus leachate total nitrogen losses (mg) (NO_3^- -N + NH_4^+-N) in 2015. CRF and WSF were applied at 0.3 kg N and P ·m^{-3} in a pine bark substrate and irrigated at 1.9 or 3.8 cm·day^{-1}. Different letters are significant ($p<0.05$) based on Tukey's Test.

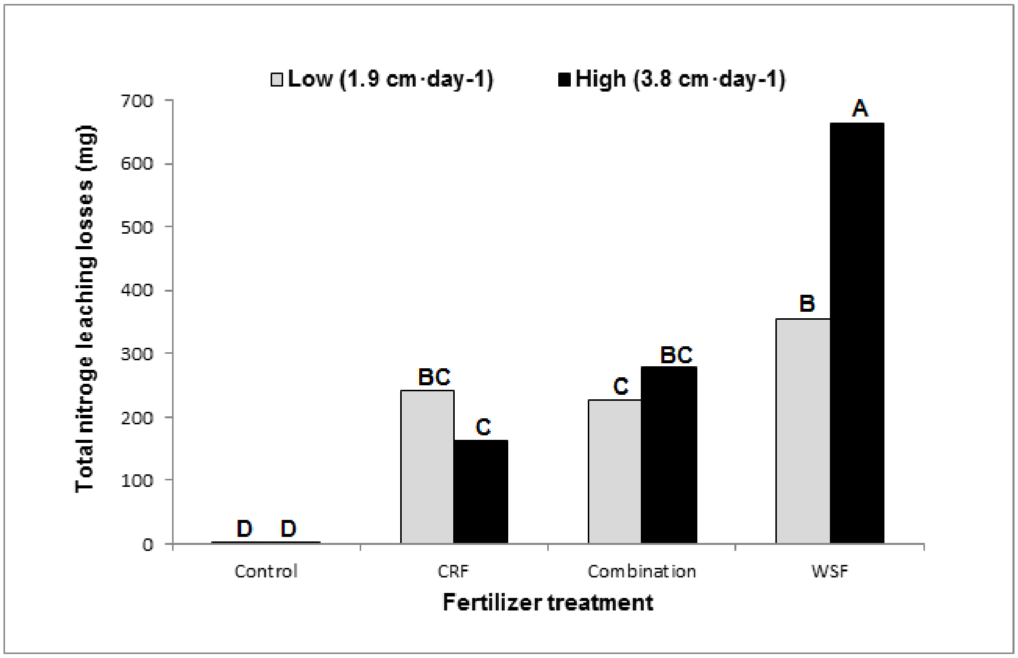

Figure 2.6 Comparison of a controlled-release fertilizer (CRF), water-soluble fertilizer (WSF), and combination of 90% CRF and 10% WSF on coleus leachate total nitrogen losses (mg) (NO_3^- -N + NH_4^+-N) in 2016. CRF, WSF, and combination fertilizers were applied at 0.3 kg N and P $\cdot m^{-3}$ in a pine bark substrate and irrigated at 1.9 or 3.8 $cm \cdot day^{-1}$. Different letters are significant ($p<0.05$) based on Tukey's Test.

In 2015 and 2016, DTP leachate losses were affected by fertilizer source and irrigation regimen (Table 2.6). Phosphorus losses were highest within 21 DAP during the 56-day production cycle within both years. Phosphorus losses in WSF-fertilized coleus leachate were significantly higher than in CRF-fertilized and combination-fertilized coleus leachate. Irrigation regimen did not affect P losses for CRF and combination treatments in either year; however, it did effect WSF treatment in both years. At 7 DAP, decreasing irrigation from 3.8 $cm \cdot day^{-1}$ to 1.9 $cm \cdot day^{-1}$ resulted in a 53.9% and 61.1% reduction in P losses in 2015 and 2016, respectively, in WSF-fertilized coleus leachate. In both years, CRF and combination treatments had more consistent release patterns from 28 to 56 DAP compared to WSF treatment.

Table 2.6 Comparison of a controlled-release fertilizer (CRF), water-soluble fertilizer (WSF), and combination of 90% CRF and 10% WSF on coleus leachate phosphorus losses (mg) over 56 days in 2015 and 2016. CRF, WSF, and combination fertilizers were applied at 0.3 kg N and P·m^{-3} in a pine bark substrate and irrigated at 1.9 or 3.8 cm·day^{-1}.

			Phosphorus Leaching Losses[w]							
Year	Fertilizer Source[x]	Irrigation[y]	0 DAP[z]	14 DAP	21 DAP	28 DAP	35 DAP	42 DAP	49 DAP	56 DAP
2015	Control	1.9	3.1c[u]	2.5c	2.4c	1.4c	0.9c	0.7c	0.9c	1.1c
		3.8	5.2c	2.7c	2.8c	1.7c	1.5c	1.3c	0.9c	1.2c
	CRF	1.9	21.5c	17.4c	15.8c	11.3c	11.4c	8.2c	10.2c	7.4c
		3.8	37.9c	16.2c	18c	11.6c	11.5c	18.1c	16.5c	9.3c
	WSF	1.9	356b	86.5c	101.4c	12.6c	6.7c	0.4c	0.8c	1c
		3.8	771.4a	60.8c	92.7c	7.5c	3c	2.6c	2.1c	1.7c
2016	Control	1.9	1.1e[v]	1.2e	0.9e	0.8e	1.4e	1.1e	0.8e	1.1e
		3.8	1.5e	0.8e	0.7e	0.7e	1.4e	1.1e	1.3e	1.2e
	CRF	1.9	40de	15e	12e	14.3e	17.4e	7.8e	6.7e	5.8e
		3.8	34.1de	14.4e	10e	13.8e	13.8e	11.3e	13.8e	10.9e
	Combination	1.9	70.9cd	35.3de	14.4e	9.7e	10.5e	4.8e	3.4e	2.5e
		3.8	111bc	30.6de	11.6e	11.8e	9.7e	6.2e	12.4e	13.8e
	WSF	1.9	147.2b	110.1bc	33de	11.1e	8.6e	1e	0.2e	0.2e
		3.8	378.7a	30.4de	6.8e	4.3e	2.6e	0.7e	0.6e	0.5e

[u]Values followed by different letters are significant ($p<0.05$) according to Tukey's test in 2015.
[v]Values followed by different letters are significant ($p<0.05$) according to Tukey's test in 2016.
[w]Dissolved total phosphorus losses in mg.
[x]Control = unfertilized; CRF = controlled-release fertilizer; WSF = water-soluble fertilizer; Combination = 10% WSF + 90% CRF.
[y]Applied cm·day^{-1}.
[z]Days after planting.

In 2015 and 2016, total P loss, the total lost through leachate throughout the 56-day production cycle, was affected by fertilizer source (Figure 2.7 and Figure 2.8). In both years, total P losses were significantly higher in WSF-fertilized coleus leachate. In 2015, total P losses in CRF-fertilized coleus leachate were 121.1 g compared to 756.6 mg in WSF-fertilized coleus leachate. Applying CRF compared to WSF reduced total P losses by 83.6% in 2015. In 2016, total P losses in CRF-fertilized, combination-fertilized, and WSF-fertilized coleus leachate were 120.6, 179.3, and 367.9 mg, respectively. Compared to applying WSF, applying CRF reduced total P losses by 67.2% and applying a combination of CRF and WSF reduced total P losses by 51.3%. The total DTP losses of applied P from CRF, combination, and WSF treatments ranged from 10.2-10.3%, 14.6%, and 31-64%, respectively, across 2015 and 2016.

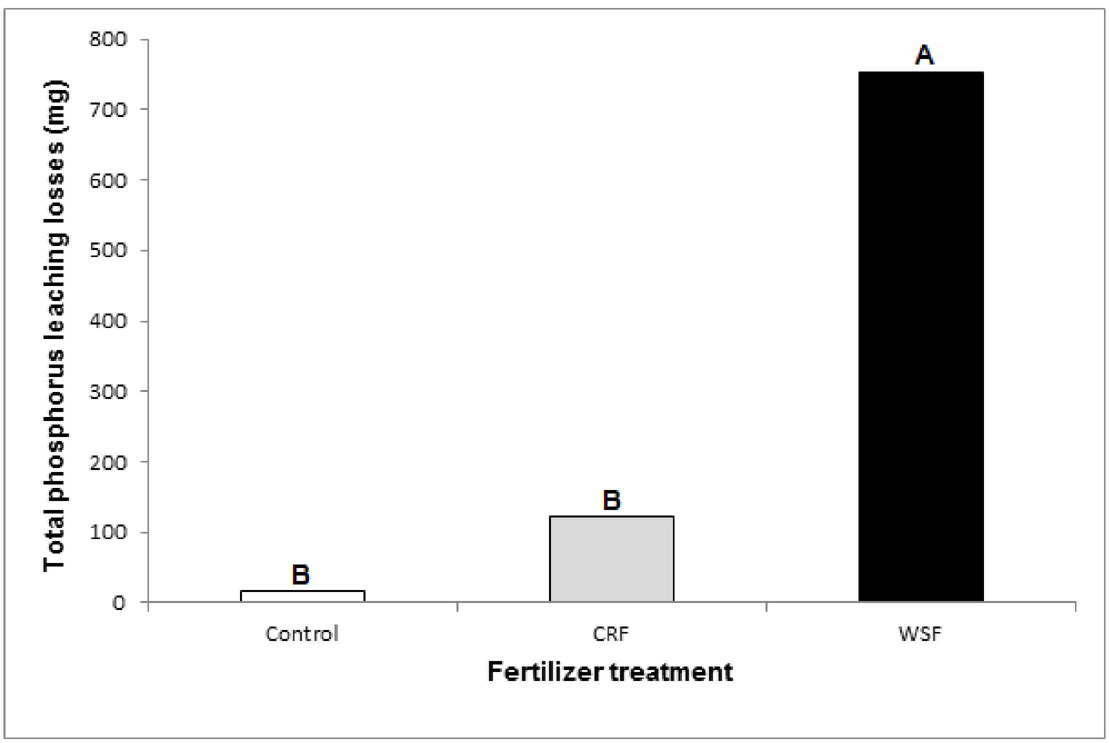

Figure 2.7 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on coleus leachate total phosphorus losses (mg) (DTP) in 2015. CRF and WSF were applied at 0.3 kg N and P $\cdot m^{-3}$ in a pine bark substrate and irrigated at 1.9 or 3.8 $cm\cdot day^{-1}$. Different letters are significant ($p<0.05$) based on Tukey's Test.

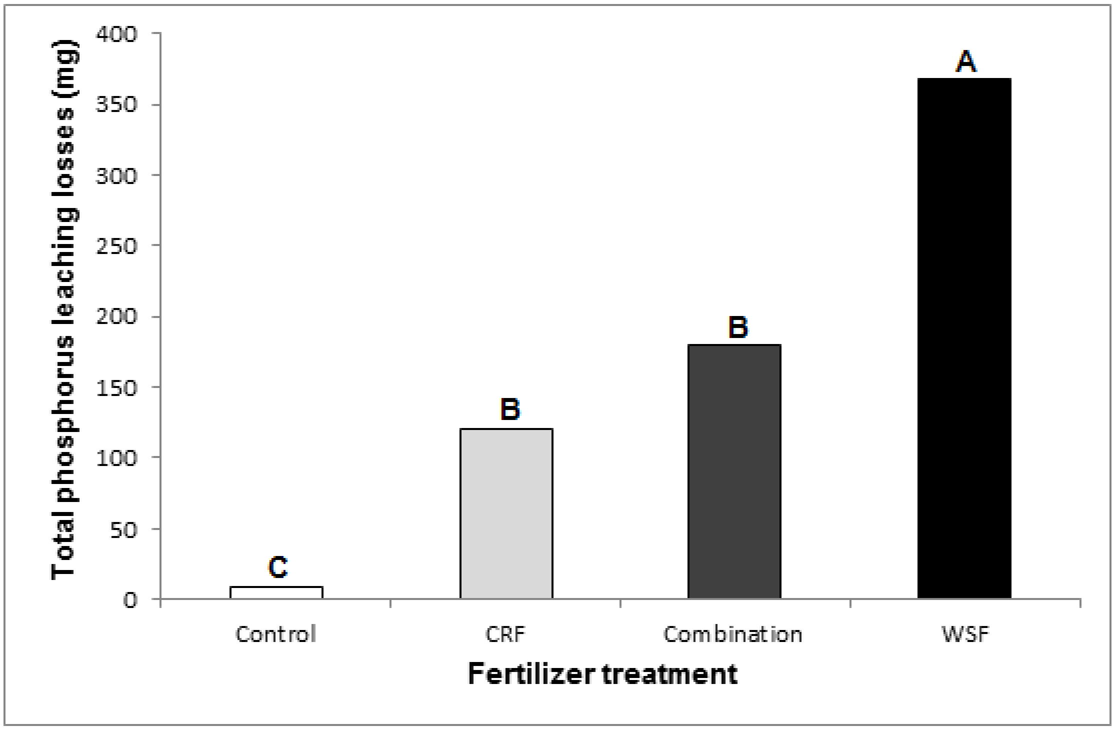

Figure 2.8 Comparison of a controlled-release fertilizer (CRF), water-soluble fertilizer (WSF), and combination of 90% CRF and 10% WSF on coleus leachate total phosphorus losses (mg) (DTP) in 2016. CRF, WSF, and combination fertilizers were applied at 0.3 kg N and P $\cdot m^{-3}$ in a pine bark substrate and irrigated at 1.9 or 3.8 $cm \cdot day^{-1}$. Different letters are significant ($p<0.05$) based on Tukey's Test.

2.5 Discussion

The objective of this research was to examine the influence fertilizer source and irrigation regimens have on plant growth and nutrient losses during containerized production of coleus. Within the parameters of this experiment, coleus growth and quality was similar between CRF, WSF and combination of CRF and WSF treatments. Although coleus fertilized with the WSF achieved higher leaf quality at 28 DAP compared to CRF, growth index, root, shoot, and total biomass measurements were similar between WSF and CRF coleus at the conclusion of the 56-day production cycle. Research has shown that CRF can be used to produce marketable containerized plants. It was reported impatiens (*Impatiens wallerana*) achieved commercially acceptable quality when CRF (Osmocote, 16-9-12) was applied at rates of 3.4-6.8 kg m^3 (Andiru, Jourdan, Frantz, & Pasian, 2013). Another study reported CRF generally out performed soluble fertilizers in stimulating plant growth and increasing N concentrations during the container production of euonymus (*Euonymus patens*) over a 27-week period (Mikkelsen, Behel, & Williams, 1994). Fernandez-Escobar et al. (2004) found CRF increased NUE and N content in container grown olive trees (*Olea europaea*) when applied at a rate of 2 g/plant and resulted in significantly greater plant growth in comparison to urea, ammonium sulfate, ammonium nitrate or calcium nitrate.

The other aspect of production examined during this research was irrigation regimen. Results indicate irrigation regimen had little to no effect on coleus growth as measured through growth index, leaf quality, shoot biomass, or total biomass. Scheiber et al. (2008) produced coleus in a simulated landscape irrigated with varying irrigation volumes and frequencies treated with CRF (18-2.6-9.9, Osmocote) and reported neither irrigation quantity nor irrigation frequency affected final shoot dry weight, root dry weight, plant height or growth indices. The only difference reported between irrigation treatments in this study was an increase in coleus root biomass in 2015 for the CRF treatment irrigated at the lower irrigation regimen. Overall, effects of irrigation practices on plants grown in containers vary among species and environmental conditions (Bayer et al., 2015). For example, it has been reported irrigation had no effects on shoot dry weight of *Lantana camara* ‘Sunny Side Up’ (Bayer, Whitaker, Chappell, Ruter, & van Iersel, 2014). Million et al. (2007) reported plant height of *Viburnum odoratissimum* was unaffected by irrigation volume. The lack of major differences in coleus growth and quality between irrigation regimens in this study suggests coleus is not sensitive to the irrigation regimens applied. However, it is worth noting the lower irrigation regimen not only provided adequate irrigation for the production of marketable coleus but reduced the applied water volumes by 50%.

Unlike the similarities in coleus growth observed between WSF and CRF treatments, interactions between fertilizer source and irrigation regimen and their effect on nutrient leaching losses were observed during this research. Coleus fertilized with WSF at the highest irrigation regimen resulted in the highest N and DTP losses. Fertilizers with high water solubility are prone to leaching (Colangelo & Brand, 2001; Liu et al., 2014). Mikkelsen et al. (1994) reported daily application of a WSF resulted in constant N leaching losses. Fernandez-Escobar et al. (2004) found WSF sources resulted in higher total N losses compared to CRF sources. In this study, irrigation regimen affected N losses only for WSF treatment. Decreasing irrigation for WSF coleus reduced N leaching losses by 28.6 to 46.6% in 2015 and 2016. In contrast, irrigation regimen did not have an effect on N leaching losses for coleus fertilized with CRF or combination treatments, nor did it affect DTP losses within any fertilizer treatments. Losses from CRF treatments appeared more constant after initial losses from 21 to 56 DAP. The difference in CRF effects on DTP leaching losses compared to N leaching losses was most likely due to P being adsorbed to substrate particles or forming precipitates with other compounds to reduce leaching losses. Although this study did not see irrigation regimen affect N and DTP losses for CRF, other studies have reported a relationship between increasing irrigation and increasing nutrient losses for CRF. Million et al. (2007) found increased N and P leaching losses from CRF combined with a higher irrigation regimen for sweet viburnum (*Viburnum odoratissimum* (L.) Ker-Gawl).

Similarly, another study evaluated daily water use (DWU) during the production of several ornamental species and found that nitrate and phosphate concentration in leachate averages were 38 and 46% lower, respectively, for 100% DWU irrigation volumes and 59 and 74% lower, respectively, for 75% DWU irrigation volumes compared to a control irrigation volume of 19 mm (Warsaw et al., 2009).

The most consistent factor to affect nutrient leaching losses was fertilizer source. The use of CRF can be an effective strategy to reduce N and P leaching losses for containerized production of many species (Fare et al., 1992; Million et al., 2007; Warsaw et al., 2009; Liu et al., 2014). In this study, coleus fertilized with CRF consistently resulted in the lowest N and DTP losses across each irrigation regimen for fertilized coleus. In 2015 and 2016, compared to WSF treatment, CRF treatment reduced total P losses by 83.6 and 67.2 %, respectively. The interaction between fertilizer source and nutrient leaching parallels the design differences in release patterns between CRF and WSF. Water soluble fertilizers typically release nutrients shortly after application of irrigation because of their high water solubility (Liu et al., 2014); therefore, nutrients are readily available for plant uptake as well as leaching. In contrast, CRF are designed to regulate granular nutrient diffusion for plant uptake over an extended duration (Morgan et al., 2009); therefore, lower nutrient concentrations are available for leaching. The application of CRF provides a simple method to reduce potential nutrient losses during container production of coleus across the irrigation regimens examined.

Although results of this study did not find a consistent interaction between irrigation and fertilizer source on nutrient losses for the fertilizers evaluated, it was observed that fertilizer source did consistently affect nutrient losses. This research suggests applying a CRF as an alternative to WSF could be a beneficial practice in nursery container production with regards to reducing nutrient leaching, even for a plant such as coleus which is produced in less than 3 months. No deleterious effects from CRF on coleus plant growth and quality were observed while total N and DTP leaching losses were reduced. Taking into consideration the existing and future regulations on nutrient leaching, application of CRF is a simple strategy for container nursery managers to produce marketable plants while reducing potential nutrient losses.

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CHAPTER 3: COMPARISON OF FERTILIZER SOURCE ON BERMUDAGRASS (*CYNODON DACTYLON* (L.) PERS. X *C. TRANSVAALENSIS* BURTT-DAVY) 'TIFWAY' QUALITY AND NUTRIENT LOSSES DURING SURFACE RUNOFF

3.1 Abstract

Fertilizer nutrient losses through surface runoff from excessive irrigation or increased precipitation can be great in commercial or home lawns where turfgrass is managed. Nutrient losses can have negative environmental impacts to local surface waters. The objective of this study was to examine the effect of fertilizer source on nutrient losses through surface runoff of bermudagrass (*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy) 'Tifway'. Three fertilizer treatments were evaluated: an unfertilized control; a controlled-release (CRF); and a water-soluble fertilizer (WSF). Fertilizers were applied at 97.6 kg N and P·ha^{-1} to bermudagrass established in runoff trays, with WSF treatment applied as a split-application at 0 and 45 days after fertilization. Plant growth measurements such as quality, color, and canopy height were measured every 14 days for 84 days. Rainfall simulation events were held every 4 weeks for 12 weeks during which runoff water samples were collected following 30 minutes of simulated rainfall output at 0.12 cm·min^{-1} and analyzed for NO_3^-N, NH_4^+-N, and DTP. There were no differences in bermudagrass growth between WSF and CRF treatments, except for an increase in quality and color at 84 days after fertilization (DAF) in CRF treatment. Water-soluble fertilizer treatment resulted in highest total N and DTP losses. Initial losses were highest at 3 DAF regardless of fertilizer source. In bermudagrass management, CRF application can reduce the potential for nutrient losses through surface runoff into the environment.

3.2 Introduction

As urbanization continues there is greater potential for negative impacts to the environment from urban runoff. Some negative impacts are linked to turfgrass management. Turfgrass is commonly established in residential, recreational, and commercial developments in and around urban areas. High fertilizer and irrigation inputs are required to establish and maintain turfgrass health. Among all the land uses in the United States, turfgrass systems are one of the most intensely managed (King, 2001). If poorly managed, fertilizer application combined with excessive irrigation can lead to high nutrient losses through surface runoff. High nutrient losses have negative environmental impacts and reduce overall turfgrass quality; therefore, research regarding nutrient losses through surface runoff is critical for determining best management practices.

High levels of N and P in water bodies increase algal blooms, sometimes to the point where an ecosystem is overloaded. Increased algal blooms result in poor water quality, reduced fish health, decreased oxygen levels, and can potentially contaminate drinking water through toxin production (United States Environmental Protection Agency [USEPA], 2016; Shuman, 2006; Carpenter et al., 1998). Urban sources which contribute to N and P loading include runoff from roads, highways, parking lots, urban storm water, gardens and lawns; all of which are recognized as nonpoint sources of pollution (Louisiana Department of Environmental Quality [LDEQ], 2001). Lawn fertilization is believed to contribute to nonpoint pollution and increases potential for higher levels of nitrate in groundwater (Saha, Unruh, & Trenholm, 2007). Quality of groundwater as well as surface water is a major concern because it affects human and ecosystem health.

To mitigate adverse environmental impacts of nutrient losses through turfgrass surface runoff, changing traditional fertilizer application practices could be essential. Application of controlled-release fertilizers (CRF) may be a beneficial alternative to water-soluble fertilizers (WSF). Fertilizer solubility has been shown to influence N losses through leachate (Brown, 1977). Controlled-release fertilizer sources release N in smaller amounts, making it available for plant uptake and slowing leaching rate compared to WSF sources (Shuman, 2006). Applying CRF has been reported to minimize nutrient leaching from turfgrass (Saha et al., 2007; Killian, Attoe, & Engelbert, 1966). In a golf course green study, it was found ammonium nitrate application resulted in 8.6 to 21.9% nitrate losses compared to CRF application which resulted in only 0.2% to 1.6% nitrate losses (Brown, Thomas, & Duble, 1982). It was also reported that P losses were highest in leachate from soluble sources compared to CRF sources (Shuman, 2003). However, there is little research available which compares multiple fertilizers sources under like environmental conditions (Sloan & Anderson, 2001; Picchioni & Quiroga-Garza, 1999). The objective of this study was to examine the influence of fertilizer source on nutrient loss through surface runoff of a commonly grown turfgrass, bermudagrass (*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy) ‘Tifway’.

3.3 Materials and Methods

Experiment Design. Two 84-day experiments held in 2015 and 2016 were conducted under greenhouse conditions at the Ornamental and Turf Research Area of the Louisiana State University Agricultural Center Botanic Gardens located in Baton Rouge, Louisiana (30^{o}24'25.3"N 91^{o}06'09.5"W). Bermudagrass (*Cynodon dactylon* (L.) Pers. x

C. transvaalensis Burtt-Davy) 'Tifway' was established for 2 months prior to the study in two runoff trays, measuring 6.1 m x 1.8 m x 0.3 m. Bermudagrass was established on soil composed of 18% sand, 62% silt, and 19% clay. Treated plywood dividers created 15 plots between both trays, measuring 1.39 m^2 each. Dividers were sealed flush to the tray lip with silicone caulk. From the joints of dividers to the tray lip, 2 right-angle-inserts were attached to the tray to direct surface runoff to a gutter drop outlet on the underside of the tray lip. Water was captured in plastic containers placed beneath drop outlets.

For both the 2015 and 2016 experiments, 3 fertilizer treatments: unfertilized control, controlled-release fertilizer (CRF) (14-14-14) (Florikote™, Florikan®, Sarasota, Florida); and water-soluble fertilizer (WSF) (13-13-13) (Grower's Special, Shell Beach, Inc., Many, Louisiana), were applied to experimental plots using a shaker jar at a rate of 97.6 kg N and $P \cdot ha^{-1}$. The WSF was applied through a split application, applied at initial application and 45 days after initial application. To simulate rainfall, a PVC apparatus installed above runoff trays and equipped with stainless steel nozzles (2HH-SS30WSQ, Spraying Systems Co., Wheaton, Illinois) which output water at 0.12 $cm \cdot min^{-1}$. Trays were elevated at a 7% slope.

Plant Response. Bermudagrass growth was measured at 3 days after fertilization (DAF) and every 14 days for 84 days. Bermudagrass parameters included: turfgrass quality (1=dead; 5=acceptable; 9=ideal), color (1=dead; 5=acceptable; 9=ideal), and canopy height (mm). Measurements were collected based on the National Turfgrass Evaluation Program (NTEP) Turfgrass Evaluation Guidelines (Morris & Shearman, n.d.). All plant growth measurements were collected prior to rainfall simulation events. Bermudagrass was maintained at 75 cm.

Surface Runoff Collection. Surface runoff samples were collected 3, 28, 56, and 84 DAF following rainfall simulation events. Plastic collection containers were placed under gutter drop outlets to collect runoff water from each plot. Stopwatches were used to track each plot beginning at time of runoff (when a steady stream of water consistently exited the plot) and ending after 30 minutes of rainfall. After the rainfall simulation was complete, total leachate weight (lb) was measured and converted to volume (L). Following total leachate measurement, 25 mL water samples were collected and stored at 4^{o}C until analysis.

Leachate Analysis. Leachate samples were analyzed for extractable inorganic nitrate (NO_3^--N) and ammonium (NH_4^+-N) using the inorganic N microplate method (Hood-Nowotny, Hinko-Najera, Inselbacher, Wanek, & Lachouani, 2010). Reagents for ammonium determination, including sodium salicylate solution, 1.5M NaOH, bleach/NaOH solution and ammonium stock solution (100 ppm), were mixed prior to analysis. Reagents for nitrate determination, including 0.5M HCl, vanadium (III) and nitrate stock solution (100 ppm) were also mixed prior to analysis. Using a pipette, ammonium microplates (96-well, PS, F-Bottom, VWR International, Sugar Land, Texas) were loaded with 100 µL of sodium salicylate solution, 40 µL of sample and 100 µL of bleach/NaOH solution and incubated in the dark at room temperature for 50 minutes. Nitrate microplates were loaded with 200 µL of vanadium (III) and 40 µL of sample and incubated in the dark at 37^{o} C for 1 hour. Following incubation, ammonium and nitrate microplates were read on an Eon™ Microplate Spectrophotometer (BioTek Instruments, Inc., Winooski, Vermont) at 650 and 540 nm, respectively. Concentrations were compared against standard concentrations of 0, 0.1, 0.5, 1, 2, 5, 10 and 15 ppm for both ammonium and nitrate.

Leachate samples were also submitted to the Louisiana State University Soil Testing and Plant Analysis Laboratory (125 Madison B. Sturgis, Louisiana State University Campus, Baton Rouge, Louisiana) for ICP analysis of dissolved total P (DTP).

Statistical Analysis. The study was a complete randomized design with three replications for the three fertilizer treatments. Bermudagrass growth and weekly N and DTP losses were analyzed by sampling dates and across years. Total N and DTP losses were analyzed for the 84 day measurement periods. Data for each parameter were analyzed using Statistical Analysis Software (SAS Version 9.4, SAS Institute Inc., Cary, North Carolina) with mean separations following Tukey's procedure ($\alpha = 0.05$).

3.4 Results

Bermudagrass Response. Fertilizer treatment affected bermudagrass quality in 2015 and 2016 during the 84-day experiment, however sampling date was not significant in 2016 (Figure 3.1 and Figure 3.2). In 2015, from 14 to 84 DAF, the unfertilized control bermudagrass declined in quality from 7.7 to 5.3, respectively. Quality of bermudagrass fertilized with WSF declined from 7.7 to 5 at 3 and 84 DAF, respectively. Bermudagrass fertilizer with CRF increased quality from 7.7 to 8.7 at 3 and 56 DAF, respectively, and decreased to 7 at 84 DAP, where it was significantly higher than WSF treatment at 84 DAF. In 2016, bermudagrass quality was comparable between WSF and CRF treatments, reaching 7.4 and 7.2, respectively (Figure 3.2).

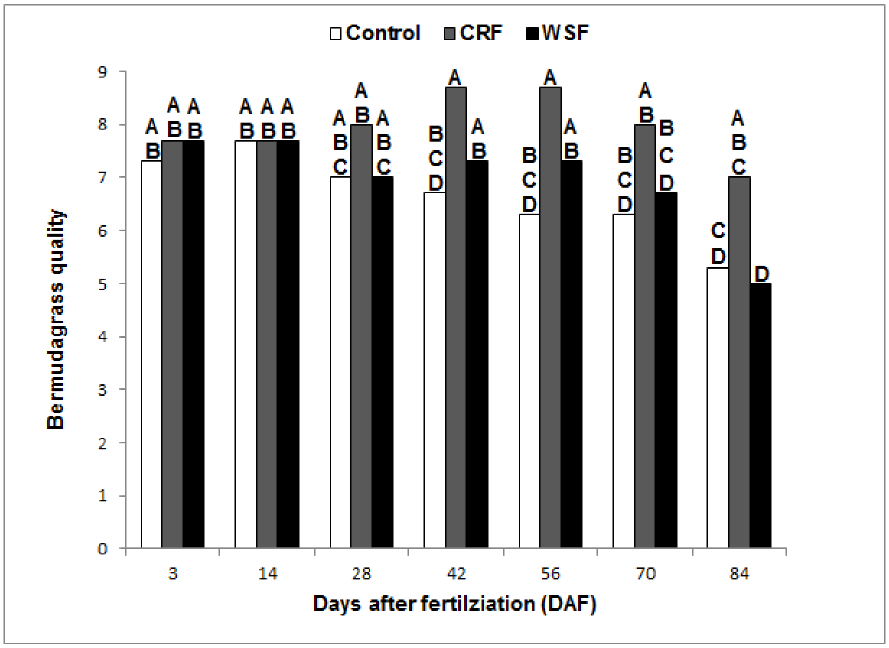

Figure 3.1 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on bermudagrass quality (1=dead; 5=acceptable; 9=ideal) over 84 days in 2015. CRF and WSF were applied at 97.6 kg N and P·ha^{-1}. Different letters are significant ($p<0.05$) based on Tukey's Test.

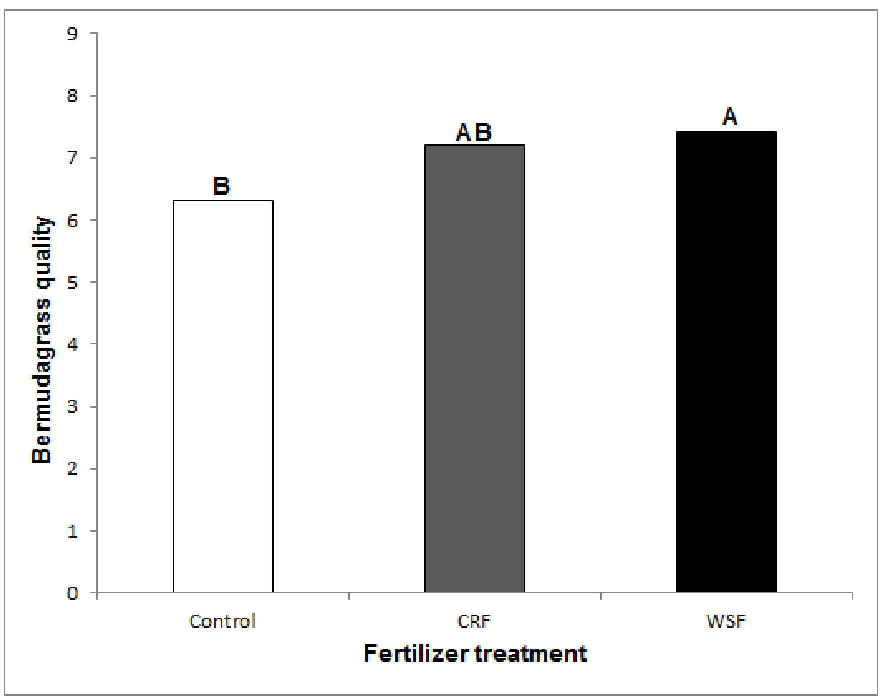

Figure 3.2 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on bermudagrass quality (1=dead; 5=acceptable; 9=ideal) over 84 days in 2016. CRF and WSF were applied at 97.6 kg N and P·ha^{-1}. Different letters are significant ($p<0.05$) based on Tukey's Test.

In both the 2015 and 2016 84-day experiments, bermudagrass color rating was affected by fertilizer treatment (Figure 3.3 and Figure 3.4). In 2015, unfertilized control bermudagrass color continually decreased from 8 to 6.3 at 14 and 84 DAF, respectively. Under WSF treatment, bermudagrass color was variable from 3 to 42 DAF reaching 8 at 42 DAF and then continually decreasing until reaching 5.7 at 84 DAF. CRF treated bermudagrass color consistently increased from 3 to 56 DAF, reaching 7 and 9, respectively, and declining to 7.7 at 84 DAF where it was significantly higher than WSF. In 2016, CRF and WSF treatments resulted in comparable color ratings, reaching 7.4 and 7.3, respectively, compared to the unfertilized control, which reached only 6.3 (Figure 3.4). There were no significant differences between fertilizer treatments observed in bermudagrass canopy height, which ranged from 72 to 78 mm throughout the 84-day study within both years.

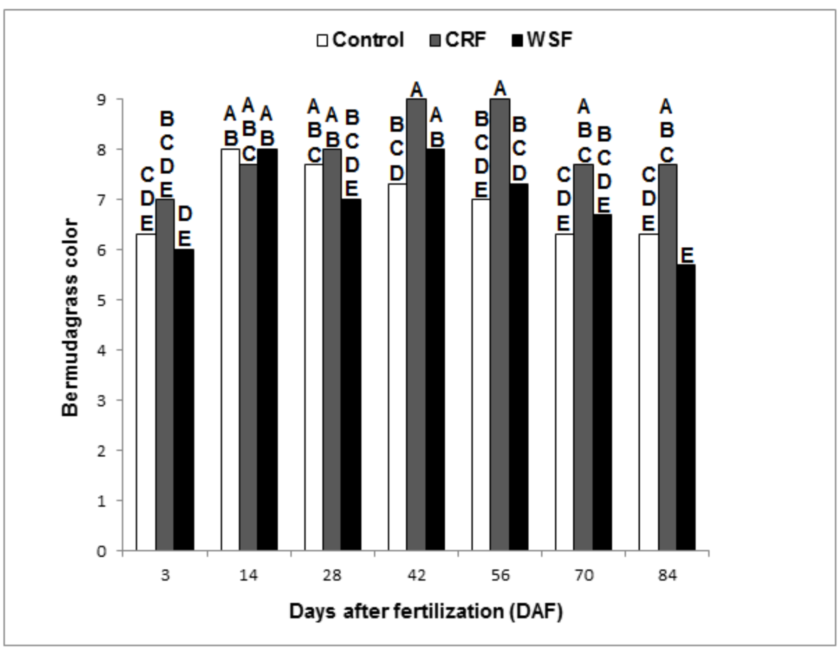

Figure 3.3 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on bermudagrass color (1=dead; 5=acceptable; 9=ideal) over 84 days in 2015. CRF and WSF were applied at 97.6 kg N and P·ha^{-1}. Different letters are significant ($p<0.05$) based on Tukey's Test.

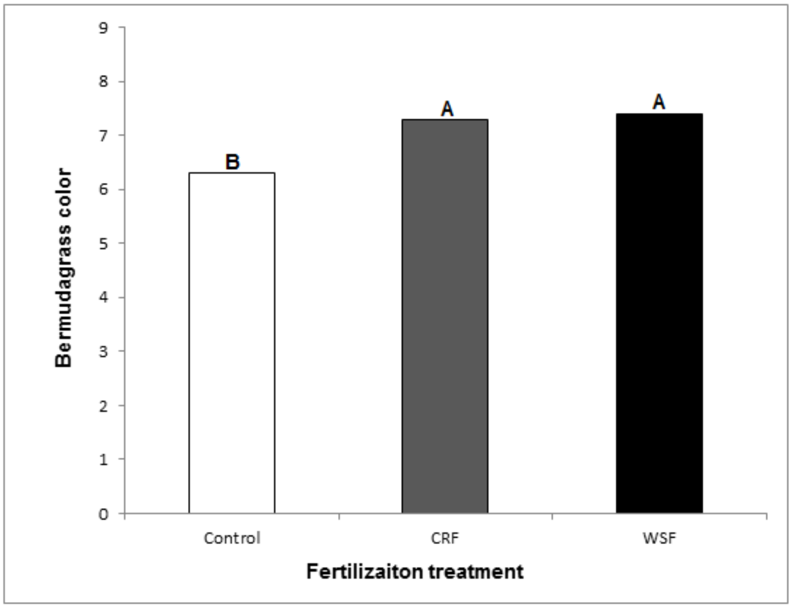

Figure 3.4 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on bermudagrass color (1=dead; 5=acceptable; 9=ideal) over 84 days in 2016. CRF and WSF were applied at 97.6 kg N and P·ha^{-1}. Different letters are significant ($p<0.05$) based on Tukey's Test.

Runoff Analysis. Nitrogen (NO_3^--N + NH_4^+-N) losses through surface runoff was affected by fertilizer source and sampling date during the 84-day study with no effect across years (Table 3.1). Nitrogen losses were highest for all fertilizer treatments 3 DAF. At 3 DAF, a difference was observed between bermudagrass N losses for WSF, CRF and the unfertilized control treatments, at 800, 373.6, and 79.9 mg, respectively, with no significant differences observed from 28 to 84 DAF. Total N losses were also affected by fertilizer source across both years (Figure 3.5). There was a significant difference in total N losses observed between the WSF, CRF, and unfertilized control treatments, at 1101.2, 841.2, and 270.4 mg, respectively. Bermudagrass fertilized with WSF lost 76.4% of total N losses at 3 DAF compared to bermudagrass fertilized with CRF, which lost 44.4% of total N losses at 3 DAF. By applying CRF to bermudagrass, total N losses were reduced 23.6% compared to WSF. Water-soluble treatment and CRF lost 76.4% and 44.4%, respectively, of applied N across 2015 and 2016.

Table 3.1 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on bermudagrass surface runoff nitrogen losses (mg) (NO_3^- -N + NH_4^+-N) over 84 days in 2015 and 2016. CRF and WSF were applied at 97.6 kg N and P·ha^{-1}.

	Nitrogen Surface Runoff Losses[w]			
Fertilizer Source[x]	3 DAF[z]	28 DAF	56 DAF	84 DAF
Control	79.9c[v]	76c	57.7c	139.6c
CRF	373.6b	208.8c	146.3c	112.4c
WSF	800.9a	65.7c	110.8c	123.8c

[v]Values followed by different letters are significant ($p<0.05$) according to Tukey's test.
[w]NO_3^- -N and NH_4^+-N combined for nitrogen losses in mg.
[x]Control = unfertilized; CRF = controlled-release fertilizer; WSF = water-soluble fertilizer.
[z]Days after fertilization.

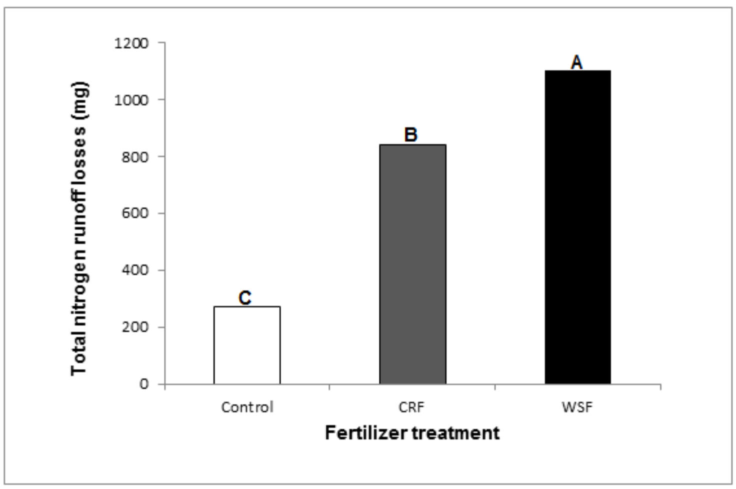

Figure 3.5 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on bermudagrass surface runoff total nitrogen losses (mg) (NO_3^- -N + NH_4^+-N) in 2015 and 2016. CRF and WSF were applied at 97.6 kg N and P·ha^{-1}. Different letters are significant ($p<0.05$) based on Tukey's Test.

Dissolved total phosphorus losses through bermudagrass surface runoff were also affected by fertilizer source and sampling date during the 84-day study (Table 3.2). Similar to N losses, DTP losses between 2015 and 2016 were highest in WSF and CRF treatments 3 DAF and at 28 DAF for the unfertilized control. There was a significant difference in DTP losses between bermudagrass fertilized with WSF and bermudagrass fertilized with CRF at 3 DAF, which were 670.5 and 126.3 mg, respectively. After 3 DAF, there were no significant differences in DTP losses between fertilizer treatments. Total DTP losses were affected by fertilizer source with no differences between years (Figure 3.6). There was a significant difference in total DTP losses between WSF and CRF treatments, which were 890.3 and 394.5 mg, respectively. At 3 DAF, WSF and CRF lost 75.3 and 32%, respectively, of their total DTP losses. Compared to WSF application, CRF application reduced P losses by 55.7%. Runoff volume across both years ranged from 46 to 53 L, with no significant differences observed. Minutes to runoff ranged from 3.5 to 5.8 min, with no significant differences observed across years. Water-soluble fertilizer and CRF treatment lost 75.3% and 32%, respectively, of total applied P across both 2015 and 2016.

Table 3.2 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on bermudagrass surface runoff phosphorus losses (mg) (DTP) over 84 days in 2015 and 2016. CRF and WSF were applied at 97.6 kg N and P·ha^{-1}.

	Phosphorus Surface Runoff Losses^{w}			
Fertilizer Source^{x}	3 DAF^{z}	28 DAF	56 DAF	84 DAF
Control	57.1b^{v}	70.7b	44.6b	53.6b
CRF	126.3b	96.9b	98.9b	72.5b
WSF	670.5a	69.9b	82.9b	67.1b

^{v}Values followed by different letters are significant (p<0.05) according to Tukey's test.
^{w}Dissolved total phosphorus losses in mg.
^{x}Control = unfertilized; CRF = controlled-release fertilizer; WSF = water-soluble fertilizer.
^{z}Days after fertilization.

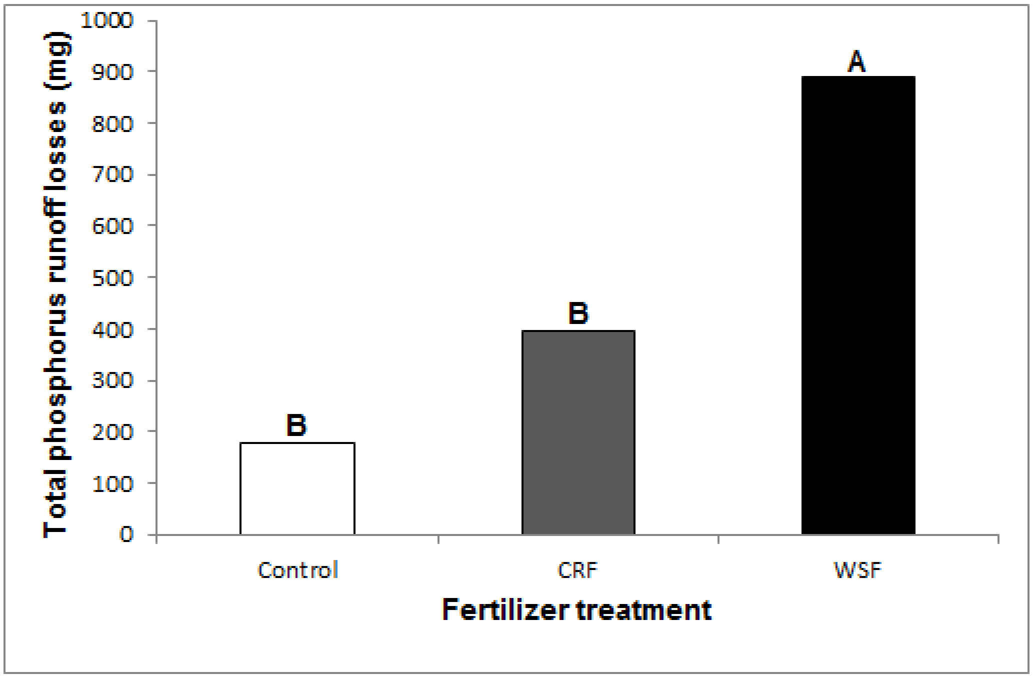

Figure 3.6 Comparison of a controlled-release fertilizer (CRF) and water-soluble fertilizer (WSF) on bermudagrass surface runoff total phosphorus losses (mg) (DTP) in 2015 and 2016. CRF and WSF were applied at 97.6 kg N and P·ha^{-1}. Different letters are significant ($p<0.05$) based on Tukey's Test.

3.5 Discussion

The objective of this research was to examine the influence fertilizer source has on bermudagrass growth and nutrient losses via surface runoff. In general, bermudagrass growth measured as overall quality and color was comparable between WSF and CRF fertilizer treatments. The only differences observed occurred at 84 DAF in 2015 when both quality and color were significantly higher in bermudagrass fertilized with CRF than bermudagrass fertilized with WSF. Similarly, Saha et al. (2007) observed no differences in color, quality or density in St. Augustinegrass (*Stenotaphrum secundatum*) between WSF and CRF treatments in Florida.

While there was little to no difference observed in bermudagrass plant growth between fertilizer treatments, there were differences between fertilizer treatments regarding nutrient losses. Total N and total DTP losses were highest in WSF treatment.

Saha et al. (2007) found that WSF leached higher amounts of nitrate-N compared to CRF and Easton and Petrovic (2004) found that WSF resulted in high P losses compared to other sources. Within the parameters tested in this study, CRF application reduced total N and DTP losses by 23.6% and 55.7%, respectively, compared to WSF application. At 3 DAF, CRF application lost 6.2% of applied N and 2.9% of applied P while WSF lost 16.2% of applied N and 13.1% of applied P.

Applying CRF has been shown to minimize nutrient leaching from turfgrass. Brown et al. (1982) reported nitrate losses of 8.6 to 21.9% in golf course greens when ammonium nitrate was applied and nitrate losses of only 0.2% to 1.6% when a CRF was applied. It was also reported that urea fertilizer sources leached up to 10% of applied N compared to CRF which leached only 1.7% of applied N (Paramasivam & Alva, 1997). When N was applied at 12 kg N ha^{-1}, nitrate-N leached was 10.2% for ammonium nitrate, 4.3% for soluble 20-20-20 and 0.14% for sulfur-coated urea (Shuman, 2006). It has also been reported that P losses were highest in leachate from soluble fertilizer compared to CRF sources (Shuman, 2003). Therefore based on the findings of this study and past research, CRF provides a technology that can regulate nutrient availability and thus losses via surface runoff.

It is worth noting that both CRF and WSF treatments experienced highest nutrient losses at the initial rainfall event, 3 DAF. WSF treatment lost 76.4% and 75.3% of total N and DTP losses, respectively, while CRF treatments lost 44.4% and 32% of total N and DTP losses, respectively. In a similar study where rainfall was simulated, Easton and Petrovic (2004) reported runoff from fertilizers had the highest nutrient concentration in the first runoff event (20 DAF), independent of fertilizer source, and exhibited dramatic reductions in nutrient concentration in the following runoff events. A similar trend was observed in this study. Such initial losses could also occur in the field, where rainfall events are often unpredictable. This potential for higher initial losses further supports CRF application as a practice for mitigating nutrient losses in regions with high average yearly rainfall. It also implies that CRF application may be highly efficient in mitigating nutrient losses in regions where average yearly rainfall is low.

Results of this research found a consistent interaction between fertilizer source and nutrient losses through bermudagrass runoff. Over 84 days, CRF resulted in similar, and sometimes higher, quality turfgrass and reduced total N and DTP losses through surface runoff. These findings suggest that CRF application in bermudagrass management would allow for the production of quality turfgrass as well as reduce the potential for N and P losses through surface runoff and thus, reduce potential for negative environmental impacts.

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CHAPTER 4. CONCLUSIONS

Excessive irrigation in nursery container production or intense precipitation to turfgrasses can lead to high fertilizer nutrient losses through leaching and surface runoff. When nutrients are lost offsite, there can be negative impacts to surface water quality and ecosystem health. The interaction between irrigation and fertilizer management practices in the sectors of nursery container production and turfgrass management is not well understood. Therefore, the objective of this research was two-fold: 1) to examine the influence of fertilizer source and irrigation regimen on plant growth and nutrient losses through leachate in coleus container production; and 2) to examine the influence of fertilizer source on nutrient losses through surface runoff in bermudagrass management.

During container production of coleus four fertilizer treatments were evaluated: an unfertilized control; a controlled-release (CRF); a water-soluble (WSF); and a combination of 10% WSF and 90% CRF, applied at 0.3 kg N and $P \cdot m^{-3}$ during the containerized production of coleus (*Plectranthus scutellarioides* (L.) Codd) 'Solar Sunrise'. Coleus was irrigated at 1.9 $cm \cdot day^{-1}$ or 3.8 $cm \cdot day^{-1}$ under greenhouse conditions for 56 days. To understand effects on coleus plant growth, leaf quality, plant growth index, root, shoot, and total biomass were measured. Leachate was collected weekly and analyzed for NO_3-N^-, NH_4^+-N, and DTP. At the conclusion of 56 days, leaf quality, coleus growth index, and total biomass was similar amongst CRF, combination (WSF and CRF), and WSF treatments at each irrigation regimen. However, nutrient losses were affected by fertilizer source. Coleus fertilized with WSF irrigated at the higher irrigation regimen resulted in greater total N (NO_3-N^-+ NH_4^+-N) and DTP losses compared to coleus fertilized with CRF or combination fertilizer at each irrigation regimen. Decreasing irrigation regimen for WSF treatment resulted in a reduction of total N losses. Irrigation did not reduce total DTP losses regardless of fertilizer source. Highest N and DTP losses occurred within 21 days after planting and declined over the 56-day study for all CRF, combination (WSF and CRF), and WSF treatments. Application of CRF provides a simple practice that can reduce N and DTP leaching across irrigation regimens without reducing coleus production in containers.

Three fertilizer treatments: an unfertilized control; a controlled-release (CRF); and a water-soluble fertilizer (WSF), were applied to bermudagrass (*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy) 'Tifway' established in runoff trays, at 97.6 kg N ha^{-1}. To monitor bermudagrass growth, measurements such as quality, color, and canopy height were measured throughout the 84-day study. Rainfall simulation events were held every 28 days for 84 days, during which runoff water samples were collected following 30 minutes of simulated rainfall output at 0.12 cm min^{-1}, and analyzed for NO_3^--N, NH_4^+-N, and DTP. There were no differences in bermudagrass growth between WSF and CRF treatments, except for an increase in quality and color at 84 days after fertilization (DAF) in CRF treatment. WSF treatment resulted in highest total N and DTP losses. Initial losses were highest at 3 DAF regardless of fertilizer source.

The combined findings from this research support the practice of controlled-release fertilizer application in the nursery container and turfgrass management sectors as a best management practice for mitigating potential negative environmental impacts related to nutrient losses through leaching and surface runoff.

VITA

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