EFFECTS OF CONTROLLED-RELEASE FERTILIZER ON NUTRIENT LEACHING AND GARDEN PERFORMANCE OF IMPATIENS WALLERIANA (HOOK. F. ‘XTREME SCARLET’)

Thesis

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By

Gladys Anguti Andiru, B.S.

Graduate Program in Horticulture and Crop Science

The Ohio State University

2010

Thesis Committee:

Claudio C. Pasian, Advisor
Michelle Jones
Pablo Jourdan
ABSTRACT

This thesis describes the effects of controlled-release fertilizers (CRF) of different formulations and longevities on nutrient leaching out of the containers and garden performance of *Impatiens walleriana* (Hook. f. ‘Xtreme Scarlet’). In the first experiment, impatiens plants were grown with Osmocote Plus 16-9-12 formulation of five to six month (5-6M) and eight to nine month (8-9M) longevities placed at four positions in the container: Topdressed, Incorporated, Top-one-third and Bottom. A 150 mg·L⁻¹ N Peter’s Professional water-soluble fertilizer (WSF) of 20-10-20 formulation was used as a control. Leachates were collected at every irrigation and the concentrations of N, P and Fe in the leachates were measured. Shoot dry weight and canopy cover were also measured. Total amount of water leached and nutrients lost from CRF and WSF were quantified. WSF produced plants of similar quality as CRF treatments except when CRF was applied at the bottom of the container. This fertilizer placement resulted in plants with the lowest shoot dry weight, canopy cover and leached the most P and Fe. CRF applied as topdressed leached the highest amount of N. Irrigating with a known volume of WSF solution leached less N and P but more Fe than 5-6M treatment. The WSF leached similar amount of nutrients as 8-9M CRF. In a second experiment with the same fertilizers, the amounts of water, N, P and Fe leached or lost out of the containers during irrigation with a hose were quantified. Irrigating plants with a hose caused up
to 62% more water loss and up to 95% more nutrient loss during irrigation with WSF than CRF. In a third experiment, Osmocote Plus 15-9-12 of three to four (3-4M), five to six (5-6M), eight to nine (8-9M) and 12-14 (12-14M) month longevities were applied at rates of 1.4, 3.4, 6.8, 10.2 and 13.6 Kg·m$^{-3}$. The same WSF as in the first experiment was used as a control. Impatiens plants were grown in the greenhouse and consumer evaluations were performed. Plant canopy cover, flower cover and shoot dry weight were determined. Commercially acceptable plant quality was achieved with CRF application rates between 3.4 - 6.8 Kg·m$^{-3}$. The aesthetic value of plants was not affected by the differences in shoot dry weight, flower or plant canopy cover. In experiment four, the same treatments as in experiment 1 were used with the addition of a treatment consisting of a 50 - 50% blend of 5-6M and 8-9M. Impatiens plants were grown in the greenhouse and transplanted in the field where no fertilizer was applied. Shoot dry weight, consumer ratings and leaf greenness were obtained. Plants grown with CRF performed better in the field than WSF grown plants. CRF treated plants were less chlorotic, had greater shoot dry and consumer ratings in the field. Based on our study the standard 8-9M longevity CRF at medium rates had the best results. When this formulation was used in our experiment, it resulted in lower N, P and Fe losses, increased shoot dry weight and high canopy and flower cover of plants. Further work with other species is necessary to validate the results obtained with impatiens. However, at least for impatiens and under our experimental conditions, standard 8-9M longevity CRF at medium rates seems to be the best option.
DEDICATION

To God and my family who have always encouraged me to strive for greater heights.
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VITA

September 2, 1978............................................ Born - Moyo, Uganda

2005.................................................................... B. S. in Agronomic Engineering and
Management of Natural Resources,
EARTH University, Costa Rica

2007 to present ............................................. Graduate Teaching and Research
Associate, Department of Horticulture
and Crop Science, The Ohio State
University.

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Chapter 1: INTRODUCTION AND LITERATURE REVIEW

1.1. Statement of Problem

Greenhouse and nursery production systems are intensively managed. They require the application of high amounts of fertilizer to enhance year round production (Richards and Reed, 2004; Colangelo and Brand, 2001). Nitrogen, phosphorus and potassium are the most commonly used plant nutrients during production. These nutrients are generally applied in the form of water-soluble fertilizer (WSF). However, WSF can produce significant leachate from containers. Phosphates and nitrates are prone to leaching in greater quantities because they do not readily bind to negatively charged colloids (Morgan et al., 2009; Newman et al., 2006). As such, these nutrients are likely to appear in runoff in greater quantities. In addition, most greenhouse growers do not capture or recycle leachate during production.

Environmental contamination from nitrates and phosphate runoff from nurseries and their impact on ground and surface water quality is a major concern in many production areas (Broschat and Klock-Moore, 2001; Broschat, 1995; Godoy and Cole, 2000). The U.S Environmental Protection Agency (USEPA) regards nitrate levels greater than 10 mg·L$^{-1}$ in drinking water unsafe for humans (Broschat, 1995; Entry and Sojka, 2007) in drinking water unsafe for humans (Broschat, 1995; Entry and Sojka, 2007). A six state survey of
runoff and well water found that during the peak seasons of nursery operation, nitrate-nitrogen in runoff water could be greater than the 10 mg-L⁻¹ USEPA limit in drinking water (Yeager et al., 1993). According to Blythe et al., (2002), the recommended fertilizer rates for outdoor nursery production are 50 to 100 mg-L⁻¹ nitrate-nitrogen plus 50 mg-L⁻¹ ammonium-nitrogen. However, plants utilize a small portion of this nutrition while a significant portion is leached out of the containers.

High nitrate-nitrogen in runoff causes algal blooms in estuaries and marine environments while high phosphate - phosphorus levels can cause eutrophication and algal blooms in fresh water and estuaries (Entry and Sojka, 2007; Pennsylvania Fish and Boat Commission, 2001). Other water body contaminants are aluminum, iron and manganese. These heavy metals can be toxic to aquatic life, causing stress and possible death of young fish. Iron can settle downstream causing water to appear yellow, eliminating fish shelters and possibly increasing water temperatures (Pennsylvania Fish and Boat Commission, 2001).

Using controlled-release fertilizer (CRF) instead of WSF for container-grown plant production has been reported to effectively limit the loss of nutrients (Haver and Schuch, 1996; Medina et al., 2008). CRF have been identified as a best management practices because they supply localized nutrients to the surrounding substrates over a period of time (Cabrera, 1997; Colangelo and Brand, 2001; Simonne and Hutchinson, 2005). The use of CRF may be a good method to reduce nutrient runoff and improve nutrient use.
efficiency in greenhouses (Klock-Moore and Broschat, 1999; Cabrerra, 1997; Wright, 1992). Fernandez-Escober, et al., (2004) found that CRF produced lower N losses over time as compared to traditional fertilizers, which had higher amount of N losses during the first month of application.

1.2. Evolution of Slow or Controlled-Release Fertilizer

Greenhouse fertilizers were initially derived from organic sources, which degraded slowly due to the microbial activity required to release nutrients in the soil (Nelson, 1991). Slow release technology was introduced during the 1950s. The first products were based on urea formaldehyde and isobutyldiene urea that released N as a result of microbial hydrolysis and degradation (Mikkelsen and Bruulsema, 2005). In the 1960s, ornamental plant production started to use slow release fertilizer (SRF) like sulfur-coated urea as a labor and time saving tool because they replaced multiple applications of soluble fertilizers (Simonne and Hutchinson, 2005).

Today, SRF have been replaced by CRF, which are derived from synthetically coated products with polymers or resin. These fertilizers release nutrients to the surrounding media over a longer period of time. Their release patterns range from a few weeks up to a full year (Fernandez-Escober, et al., 2004). The advantages of using CRF include reduction of nutrients in runoff (Cabrerra, 1997; Chien et al., 2009; Klock-Moore and Broschat, 1999; Shoji et al., 2001), improvement of plant quality, and decreased production costs due to increased nutrient use efficiency (Shaviv, 2001).
1.3. CRF Release Mechanism

CRF nutrient release is generally determined by temperature, the thickness of the coating and individual cultural practices like water management. The intensity and pattern of nutrient release can therefore vary for polymer-coated CRF of similar longevity (Cabrera, 1997; Hulme and Buchheit, 2007). However, factors such as salt composition inside the granule can affect both the release rate and the relative speed at which the different elements will be released (Cabrera, 1997). Osmocote fertilizers are polymer coated with a resin and vegetable oil. According to The Scotts Co. (Scotts, 2005), Osmocote Plus CRF is composed of granules of dry salts containing nutrients encapsulated within multiple layers of polymeric resin. Nutrients are released when water penetrates the permeable cell and dissolves the core. As the core dissolves, an osmotic pressure will develop inside the granule causing an osmotic pressure gradient between the granule and the surrounding substrate. This osmotic pressure gradient will allow nutrients to be released through the coating into the surrounding root zone.

1.4. CRF Use in the Greenhouse and Nursery Industries

CRF use in the nursery and greenhouse industries accounts for about 20% of total CRF usage in the U.S (Merhaut et al., 2006). The same authors stated that the nursery industry has extensively used CRF in the production of containerized woody ornamental plants. However, CRF use in floricultural production has not been extensively explored with the exception of some stock plants or poinsettias where they are used in combination with WSF (C. Pasian, personal communication). One reason for limited use of CRF in
floricultural production could be the inadequate knowledge in their use for herbaceous plant production. Other reasons include the risk of possible plant damage due to problems of salt accumulation when applied at higher rates. Some growers fear the loss of control over their fertigation program and thus feel they are unable to employ techniques such as ‘toning’ crops to meet production goals (Hulme, 2006). Toning is the alteration of fertigation practices at the end of the experiment to obtain the desired plant size and shape.

According to Nelson (1994), establishment of a unified fertigation program for bedding plant production is more difficult than for other plant categories. Most growers use the strategy of producing a wide assortment of bedding plant species and cultivars to stay competitive in the market. This approach makes it difficult to develop a general fertigation program that can meet specific plant nutrient requirements and produce plants with high aesthetic value. As a consequence, fertigation regimes are altered according to plant species or cultivars, growth stage, desired growth rate and shifts in substrate pH level (Nelson, 1994).

1.5. Nutrient Leaching from CRF

Wu and Liu (2008) stated that of the total amount of applied WSF, about 40 -70% N, 80 -90% P and 50-70% K can potentially be lost into the environment. These losses resulted from poor fertilizer use efficiencies. Fernandez-Escober, et. al., (2004) found that CRF use resulted in lower nitrogen losses over time as compared to traditional WSF, which
lost higher amounts of nitrogen during the first month of application. Similarly, Broschat (1995) found in a study conducted to determine the total amount of N, P, and K leached from a container that using WSF resulted in substantial annual losses of 666 Kg·ha\(^{-1}\)N, 49.4 Kg·ha\(^{-1}\) P and 337 Kg·ha\(^{-1}\) K. They concluded that the gradual nutrient release pattern of CRF can lead to improved nitrogen use efficiency and reduced nitrogen leaching.

Several studies (Cox, 1993; Fernandez-Eescober, et al., 2004; Hershy and Paul, 1982; and Rathier and Frink, 1989) have demonstrated non-uniform nutrient release from CRF over time. The largest losses of nitrogen occur during the early stage of the production cycle. Simonne and Hutchinson (2005) determined that Osmocote Plus (The Scotts Co.) and S-9593 (CRF not released in the market at that time) released about 10% of the total available nitrogen in the first two days after the initial irrigation. Early release of nitrogen represents a waste and potential environmental risk.

Numerous studies have shown that N is the primary nutrient limiting production in containers (Ogden et al., 1987, Wright and Niemiera, 1987). According to Fernandez-Eescober, et al. (2004), plants utilize about 20% of the applied nitrogen while 80% is lost to the environment. In the field, nitrogen can be lost into the environment through leaching from heavy rains or poorly controlled irrigation. It can also be lost through volatilization under aerobic conditions in the form of ammonia. N can further be lost
through denitrification under anaerobic conditions by reducing nitrate to nitrogen (N$_2$) gas or nitrogen monoxide (NO).

N in the greenhouse is mainly lost from leaching during irrigation (Klock-Moore and Broschat, 1999). With the high amounts of nitrogen fertilizers applied daily in greenhouse production systems, other forms or sources of nitrogen e.g. from CRF could greatly improve nutrient efficiency. However, CRF use alone does not provide the solution to the problem of nutrient leaching; appropriate supplies as well as matching of nutrients to plant requirements must be considered during production (Broschat and Klock-Moore, 2001; Wu and Liu, 2008). When choosing a CRF for greenhouse production, factors such as type of crop, production time, CRF longevity and application rate should be considered. Normally, three-month longevity types are most commonly recommended for greenhouse production. This is because their release period can correspond to the time of production depending on the type of crop and soil/substrate temperature (Cabrera, 1997; Morgan, et al., 2009; Nelson, 1991)

1.6. Bedding Plant Production

In 2008, the total US crop wholesale value for floricultural crops for the 15-State program for all growers with $10,000 or more in sales was estimated to be $4.22 billion (U.S. Dept. Agr., 2009). Bedding and garden plants were the largest contributor to the value of total floricultural production in 2008, contributing about 46% of wholesale value of all reported crops. Despite the current economic challenges, bedding and garden plant
wholesale value increased by 1% from 2007 (U.S. Dept. Agr., 2009). Of the total bedding plants produced, impatiens is the third most important crop (Geisler, 2008).

Bedding plants add instant color to beautify homes and gardens (Kessler, 2004). Offering homeowners and gardeners quality products has become crucial for increasing sales. Garden performance of bedding plants can be a driving force for growers and retail businesses survival (Kessler, 2009; Klock-Moore, 2001). Growers have to provide the market with consistently high quality plants that are compact, stress tolerant and free from diseases (Borch et. al., 1998). High quality plants can be obtained through improved production, transport and retail practices that can maintain postproduction quality. Postproduction quality of bedding plants can be influenced by plant genetics and/or by production techniques like scheduling, irrigation, fertilizer, and growth regulator applications. Postproduction losses can account for up to 20% of floricultural products becoming damaged or sold at lower prices (Armitage, 1993, Kessler 2009). At 20% of floricultural sales, these losses represent about $844 million annually nationwide.

CRF might improve postproduction quality during retail and garden production phases because they supply gradual and localized nutrients over a period of time - even after production. As growers strive to incorporate more sustainable practices in their production systems, more growers might consider using CRF. Some growers have concerns about possible plant damage due to salt accumulation when CRF are used for production (Banner and Klopsey, 1995; Haver and Schuch, 1996). Salt accumulation
from the use of CRF is possible in irrigation systems with either zero or little leaching. This system could be used for growing salt tolerant plants like *Chrysanthemums* and *Euphorbia pulcherrima* (Haver and Schuch, 1996). An alternative to reduce soluble salt build up is to water until some leaching is achieved (Warncke and Krauskopf, 1983) or use less CRF. Haver and Schuch (1996) found that non-salt tolerant plants like *Impatiens hawkeri* can be successfully grown with CRF as long as moisture levels of the medium are kept high enough to prevent soluble salts from significantly contributing to total water potential of the medium.

1.7. Impatiens Culture

The popular bedding impatiens plants are day neutral, so when proper growing conditions are supplied, most impatiens start flowering early. Generally, they thrive well under low light levels of 30 µmol s$^{-1}$ m$^{-2}$ (Corr, 1998). Day temperatures between 21 to 24°C and 14 to 18°C night temperatures are required for their production. Temperatures above 27°C will cause leaf damage and stem stretching while temperatures below 15°C will delay flowering and slow growth (Corr, 1998; Dole and Wikkins, 2005). Impatiens are low feeders that require EC levels of 1.0 mS·cm$^{-1}$ and a pH range between 6.2 - 6.8 (Corr, 1998; Dole and Wilkins, 2005; Kessler, 2005). The most commonly used fertilizer is a 20-10-20 WSF alternating with 15-0-15. Excessive fertilization can result in lush growth with few flowers or flowers that develop underneath the foliage canopy (Beaulieu, 2007; Corr, 1998; Dole and Wilkins, 2005). Based on the literature review described above,
information about CRF nutrient leaching and effect on plant quality and garden performance is lacking.

The research reported in this thesis includes: a) effects of CRF placement on nutrient leaching, b) effects of CRF longevity on the quality of impatiens, and c) effects of CRF on the garden performance of impatiens.

1.8. Literature Cited


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2.1. Introduction

The use of controlled release fertilizers (CRF) in greenhouse production has not been widely adopted by growers. Some are uncertain if CRF can produce the same crop quality as water-soluble fertilizers (WSF). Researchers have focused on CRF nutrient release pattern as a tool for environmental protection in the nursery and turf industries (Blythe et al., 2002). The same authors mentioned that efficient floricultural crop production requires adequate levels of nutrients to be delivered to plants in a timely manner. The low use of CRF in floricultural production can also be attributed to lack of knowledge by growers, higher costs involved as compared to WSF, or fear of losing control over the fertigation programs (Blythe et al., 2002; Hulme, 2006).

Haver and Schuch (1996), Klock-Moore and Broschat (1999) and Fernandez-Escober, et al., (2004) measured nitrate (NO$_3^-$) in the leachate collected from CRF grown plants and concluded that using this type of fertilizer could reduce NO$_3^-$ losses. Similarly, Richards and Reed (2004) measured EC, pH, and potassium (K) from leachates and found that using CRF resulted in high nutrient use efficiency regardless of method of irrigation.
CRF release patterns have been determined in experiments without plants and most of the nutrients measured were N (NO$_3^-$-N and or NH$_4^+$-N), P and K (Birrenkott et al., 2005; Broschat, 2005; Cabrera, 1997; Entry and Sojka, 2007; Merhaunt, et al., 2008; Newman et al., 2006). These authors found that fewer nutrients were in the leachates from CRF. Broschat and Klock-Moore (2007) measured release rates of N (NO$_3^-$-N and NH$_4^+$-N), P, K, Mg, Fe and Mn from leaching columns containing sand, which resulted in slower release of P than N and K, and poor release rates of Mg, Mn, and Fe. No experiments that measured such nutrients from substrates were found. We are particularly interested in N, P, and Fe leached from substrates containing plants because these elements have a higher pollutant potential.

A common method of delivery of fertigation (defined as applying fertilizer mixed with irrigation water) or irrigation used by bedding plant growers is through a hose. During fertilizer application or irrigation, growers move the hose from plant to plant and from one bench to another. Some of the water/fertilizer falls onto leaves and drains either inside or outside the container, while the rest falls outside the container. It has been estimated that up to about 74% of the solution in overhead irrigation systems falls outside the containers (Colangelo and Brand, 2001), and if fertigation is utilized as a fertilizer delivery method, then a similar amount of fertilizer never reaches the target plants. Richards and Reed (2004) reported that Osmocote CRF fertilizer use efficiency was about 89% while that of WSF was about 46%. CRF can be so efficient because the fertilizer prills are placed into the container and plants are irrigated with water only.
The objectives of this experiment were:

i. To determine the effects of CRF placement inside the container on the growth of impatiens plants.

ii. To measure the amounts of N, P, and Fe leached from substrates fertilized with CRF placed at different positions inside the container.

iii. To quantify the amount of water, N, P, and Fe leached from CRF and WSF treated plants irrigated with a hose.

2.3. Materials and Methods

A 3:1 ratio of Canadian sphagnum peat moss (Sunshine Peat Moss, SunGro Horticulture, Bellevue, Wash):perlite (Therm-O-Rock East inc, New Eagle, PA) substrate was prepared for growing plants. A total of 3 kg·m\(^{-3}\) carbonated lime was added to correct the pH to 5.8 - 6.4. Aqua-Gro L (Scotts Company, Marysville, Ohio) of 7.6 mL in 1 L of water was added to hydrate the substrate. Up to 5L of water were added to reach 30% to 50% container capacity moisture content (Argo & Biernbaum, 1996). The substrate was then placed in a 100 L plastic container and left to equilibrate for 24 hours. Before potting the plants, substrate EC and pH were measured using a 1:2 dilution method with an Accumet Model AP85 pH/Conductivity meter (Fisher Scientific, Pittsburgh, PA). Initial substrate pH was 6.2, which is within the required pH ranges of 5.5 - 6.4 (Argo and Biernbaum, 1996). Initial EC was 0.77 dS·m\(^{-1}\).
2.3.1. Effects of CRF Placement on Plant Growth and Nutrient Leaching

2.3.1.1. Experiment I

Osmocote Plus 16-9-12 of two different longevities and Peters Professional WSF 20-10-20 (WSF) were used for this experiment. Both fertilizer formulations were produced by The Scotts Co., Marysville, Ohio. Based on preliminary experiments, 6.8 kg·m⁻³ (5 g per container) of CRF were applied at different locations in 12.7 cm diameter by 9 cm height plastic containers. The treatments were: a) CRF of 5-6 month longevity (5-6M), b) CRF of 8-9 month longevity (8-9M), and (c) WSF applied at 150 mg·L⁻¹ N. This last treatment was used as a control. The CRF prills were placed at four different positions inside the container (Figure 2.1): i) layered at the top (Topdressed), ii) layered in the top-one-third of container (Top1/3), iii) incorporated throughout the substrate (Incorporated), and iv) layered at the bottom (Bottom).

One plug of Impatiens walleriana ‘Xtreme Scarlet’ was transplanted in each plastic container filled with the substrate. The experiment was a two by four plus one factorial (two CRF formulations, four placements and one control) in a randomized complete block design with six blocks. Each block represented one replication. Plants were grown in a greenhouse with a double layer acrylic roof at The Ohio State University Columbus, OH. The experiment lasted for 55 days between the months of November and December of 2007. Greenhouse temperature was set at 18/21°C (low/high). Outside radiation levels were obtained from the greenhouse data system; average daily light integral (DLI) was 5.1 mol·day⁻¹.
Each container was placed on a 13 cm by 14 cm plastic mesh on top of a 12 cm diameter bowl to facilitate leachate collection (Figure 2.2). CRF-treated plants were hand-irrigated with 200 - 350 mL of tap water while WSF-treated plants were irrigated with the same volume of 150 mg·L⁻¹ N WSF solution. Leachate was collected and the volume measured. EC and pH of the leachate was measured and up to 50 mL of the leachate was stored at 2°C for analysis of N (Scotts Testing Laboratory, Lincoln, NE), P and, Fe (USDA-ARS Laboratory Facility, Toledo, OH). N in the leachate was determined using ion selective electrodes (ISE) while P and Fe were determined using inductively coupled plasma optical emission spectroscopy (model IRIS Intrepid II, Thermo Electron).

At the end of the experiment, pictures of the plant canopies were taken from above with a digital camera (model EX-Z250A, Casio Computer Co, China). A tripod was placed at a fixed position holding the camera about 1 m above ground with the objective lens looking down (Figure 2.3). A mark was made on the ground and each plant was placed on the mark to ensure uniformity under the focus of the camera. Pictures were then analyzed with digital analysis software (Assess Image Analysis, APS Press, St Paul, MN) to measure the exposed leaf area in cm² (canopy cover). This software works on the principle of matching surfaces where the user sets threshold boundaries (color) and the software automatically selects that color range from the original color imagine (Lamari, 2002). The software fills in the areas that have the pixel value within the range specified. Once an image is filled in, data for the measurements (area covered) can be obtained.
Above-ground plant parts were harvested, placed in separate bags and left to dry in a forced-air oven (GS Blue M Electric) at 55°C for 48 h for plant dry weight measurement. Shoot dry weight and canopy cover were analyzed using the general linear model (GLM) with mean separation by LSD procedure (SAS Institute, Cary, NC). Leachate EC, nitrogen, phosphorus and iron were analyzed as repeated measure using the mixed model procedure and mean separation was done by LSD (SAS Institute, Cary, NC).

2.3.1.2 Experiment II

This experiment was a repetition of Experiment I with the exception that plants were grown for 43 days between March and May of 2008. These plants reached a salable size 12 days earlier than those in Experiment I. Greenhouse temperature was set to 18/21°C (low/high) and average DLI was 28.1 mol·day⁻¹.

2.3.2. Water and Nutrient Losses with Hose Fertigation (Experiment III)

The fertilizers and impatiens cultivar used in Experiment I and II were also used in Experiment III. CRF were incorporated throughout the substrate at 6.8 kg·m⁻³ while 150 mg·L⁻¹ N WSF was used for fertigation. All plants were watered/fertigated using a hose as needed. Plants were grown in a greenhouse with a double layer acrylic roof at The Ohio State University, Columbus, OH. The experiment lasted for 42 days between the months of September and November of 2009. Greenhouse temperature was set to 18/21°C (low/high). The experimental setup was a randomized complete block design consisting
of three treatments, 18 plants per treatment grown in three blocks.

During weeks 1, 3, and 6, the flow rate of the irrigation water for each treatment was determined by measuring the time it took to fill a 38 L plastic bucket. Plants were placed on top of a plastic cup to collect leachates during irrigation. This setup (containers on top of plastic cups) was placed inside a plastic box to collect water lost during irrigation when the hose was moved among containers (Figure 2.4). The box initially fitted 18 plants “pot-to-pot” (week 1). As plants grew bigger, the box fitted fewer containers: 12 containers in week 3 and eight in week 6. This set up imitated plant spacing that a typical grower would use during bedding plant production. The boxes with plants inside were placed next to each other and one empty box was placed between treatments to collect water lost when moving the hose from one treatment to another (Figure 2.5). The distance between benches was twice the width of the box. The water collected in the empty box represented the water lost when growers move the hose from one bench to another.

The time to complete the watering of each treatment was recorded. Thirty minutes after irrigation, plants were removed from the boxes. The total volume of water leached from the plants (Leached), water collected inside the box with plants (Wasted), and the water inside the container without plants (Bench) were measured. Six plants from every treatment were randomly selected and a sample of 50 mL per plant of the leachates was stored for nutrient analysis using the same methodology as in Experiment I and II.
The total volume of water used for irrigation was determined by multiplying the flow rate by the time it took to water all the plants from each treatment. Because the width of the empty box was half of the distance between benches, the water collected in this box was doubled to simulate the water lost when the hose is moved between benches. The total volume of water leached was determined by pooling the water collected in all the plastic cups. Total volume of water wasted was determined by pooling the water collected in all the plastic boxes containing the plants. The results of N, P and Fe leached were analyzed using mixed models (proc mixed) and mean separation by LSD using SAS version 9.2 (SAS Institute, Cary, NC).

2.4. Results

2.4.1. Experiment I

2.4.1.1. Plant Growth

There were significant differences in the canopy cover of plants for fertilizer type and placement (Table 2.1). Plants Topdressed with 5-6M were visually smaller and had significantly smaller canopy cover than 5-6M-Top1/3 plants. Plants that received 8-9M CRF at the Bottom were smaller and had smaller canopy cover than plants from the other 8-9M CRF placements. WSF plants had smaller canopy cover than plants from 8-9M applied as Topdressed, Incorporated, and Top1/3. In addition, the canopy covers of 5-6M-Top and 5-6M-Bottom were smaller than 8-9M applied as Incorporated, Topdressed, and Top1/3. Dry weight of 5-6M-Topdressed plants was smaller than all the other
treatments (Table 2.1). The 8-9M-Bottom had a smaller dry weight than the other 8-9M placements. WSF had similar dry weight than all the other treatments except 5-6M-Topdressed.

2.4.1.2. Leachate EC

Leachate EC of all CRF treatments increased to a maximum between 9 to 14 days after planting and then decreased over time (Figure 2.6). Bottom applications of 5-6M had the highest increase in EC between days 5 and 14 compared to the other CRF placements of the same longevity (Figure 2.6.A). From 20 days after planting onwards, EC of all 5-6M placements were similar. EC of WSF gradually increased until the end of the experiment (54 days). The EC of WSF was lower than 5-6M for all placements between 5 - 40 days after planting. However, towards the end of the experiment (43 - 54 days), EC of WSF was greater than all 5-6M CRF placements.

EC of 8-9M reached a maximum at 14 days after planting (Figure 2.6.B). The Bottom placement had the highest EC values between 9 and 14 days after planting. Leachates from 8-9M-Topdressed plants were similar to that of WSF from 9 - 35 days after planting. Their EC was lower than the other placements between the same days. The EC of WSF was higher than all 8-9M placements between 40 - 54 days after planting. Generally, EC of 5-6M either Incorporated, Topdressed, or applied at Top1/3 were at least 30% higher than 8-9M for the same placements. However, EC of 5-6 Bottom between 5 and 14 DAP was about 50% higher than that of 8-9M.
2.4.1.3. Nitrogen Leached

Cumulative N leached from all treatments gradually increased over time (Figure 2.7). From 20 days after planting until the end of the experiment, leachates from 5-6M-Incorporated had higher cumulative N leached than the other 5-6M placements (Figure 2.7.A). Overall, 5-6M applied in the Bottom of the container leached less N than Incorporated and Topdressed. The WSF treatment leached about 49% - 63% less N than 5-6M treatments at the different placements (Table 2.2). At the end of the experiment, 5-6M-Incorporated leached the highest N. The 5-6M-Bottom or 5-6M-Top1/3 applications leached about 14% or 28% less total N than 5-6M-Topdressed or 5-6M-Incorporated, respectively (Table 2.2). Between 35 - 54 days after planting, 8-9M-Topdressed had the lowest cumulative N loss. The 8-9M-Incorporated or 8-9M-Top1/3 leached at least 27% more total N than application at the Bottom (Table 2.2). The WSF-treatment leached 45% more N than 8-9M-Bottom. The 5-6M-Treatments leached an average of 63% more N than 8-9M (Table 2.2).

2.4.1.4. Phosphorus Leached

Cumulative phosphorus leached from 5-6M gradually increased over time (Figure 2.8.A). The 5-6M CRF applied at different locations leached increasingly more P than WSF for the first 43 days after planting. Overall, 5-6M applied at the Bottom leached at least 30% more P than all the other 5-6M placements (Figure 2.8.A and Table 2.2). The 5-6M-Topdressed CRF leached 17% - 42% less total P than the other three placements.
Phosphorus leached from the 8-9M-treatments increased over time for all placements with the Bottom placement leaching more P (Figure 2.8.B). From 40 days after planting onwards, cumulative P leached from the WSF treated plants was greater than all 8-9M treatments. At the end of the experiment, 8-9M applied at the Bottom leached 63% - 84% more total P than all the other placements (Table 2.2). Regardless of CRF placement, total P leached from WSF was greater (44% - 91%) than any of the 8-9M placements. The 5-6M leached more P than the 8-9M CRF: 62% Bottom, 77% Incorporated, 80% Top1/3 and 90% Topdressed.

2.4.1.5. Iron Leached

Cumulative iron leached from 5-6M increased to a maximum between 20 - 24 days after planting and leveled off towards the end of the experiment while Fe leached from WSF treatment kept increasing over time (Figure 2.9.A). The 5-6M-Topdressed leached less Fe than the other 5-6M placements. Cumulative iron leached from WSF was higher than 5-6M treatments from 43 days after planting onwards. At the end of the experiment, total cumulative Fe leached from 5-6M-Topdressed was 57%, 61%, and 64% lower than Incorporated, Top1/3 and Bottom applications, respectively (Table 2.2). At the end of the experiment, the WSF treatment leached 41% - 76% more iron than 5-6M-Treatments.

Cumulative iron leaching from 8-9M increased over time up to 24 days after planting and leveled off thereafter (Figure 2.9.B). The Bottom application leached more Fe compared to the other placements. Cumulative Fe leached from WSF treatment gradually increased
over time. Between 35 - 54 days after planting, WSF leached greater amounts of Fe than 8-9M. At the end of the experiment, WSF leached 55% - 89% more total Fe than all the CRF treatments (Table 2.2).

2.4.2. Experiment II

2.4.2.1. Plant Performance

The interaction between fertilizer type and fertilizer placement was not significant (Table 2.1). Bottom application of CRF had the smallest canopy cover. The 8-9M-Bottom had 44% less canopy cover than the 5-6M-Bottom treatment. Fertilizer placement and fertilizer by placement interaction were significant for shoot dry weight (Table 2.1). The 5-6M-Bottom placement produced 34% - 47% less shoot dry weight than WSF and the other placements. The canopy cover of the 8-9M-Bottom placement was 40% less than 5-6M-Bottom placement. There were no differences in the dry weight between the 5-6M and 8-9M placements of Incorporated, Topdressed, and Top1/3.

2.4.2.2. Leachate EC

Leachate EC of 5-6M applied as Incorporated, Top1/3, and Bottom increased to a maximum 7 days after planting and then gradually decreased thereafter (Figure 2.10.A). The EC from 5-6M-Topdressed plants increased to a maximum at 29 days after planting and then decreased over time. The 5-6M-Bottom placement had the highest EC compared to the other placements between 2 - 25 days after planting. EC was similar for all 5-6M
placements from 25 days after planting onwards. WSF, for the most part of the experiment, had the lowest EC.

EC values for 8-9M and WSF treatments increased up to a maximum at 29 days after planting and then decreased over time (Figure 2.10.B). The EC of 8-9M bottom was higher than that of WSF and the other 8-9M placements. In general, EC of 5-6M applied as Incorporated, Topdressed, and Top1/3 were at least 30% higher than 8-9M for the same placements between 2 and 29 days after planting. EC of 5-6M and 8-9M towards the end of the experiment were similar. Over all, leachates from Experiment I had higher EC than those from Experiment II (Figures 2.6 and 2.10).

2.4.2.3. Nitrogen Leached

Overall, cumulative nitrogen leached from all 5-6M and WSF treatments gradually increased over time to a maximum after 33 days (Figure 2.11.A). WSF leached 51% - 71% less N than 5-6M placements (Table 2.2). The 5-6M-Topdressed leached 11% - 41% more N compared to the other 5-6M placements. Cumulative N leached from 8-9M treatments also increased over time (Figure 2.11.B). The 8-9M-Topdressed treatment leached 52% - 62% more N than WSF and any other 8-9M treatment (Table 2.2). However, WSF and 8-9M treatments except 8-9M-Topdressed leached the same amount of N at the end of the experiment (Figure 2.11 and Table 2.2). The 5-6M CRF leached more total N than 8-9M CRF placements: 62% Bottom, 56% Incorporated, 74% Top1/3, and 40% Topdressed.
2.4.2.4. Phosphorus Leached

The cumulative phosphorus leached from all treatments increased over time (Figure 2.11). The P leached from the 5-6M-Bottom application was greater than any of the other 5-6M-Treatments (Figure 2.12.A and Table 2.2). WSF leached 16% - 48% less total P than 5-6M-Top1/3 or 5-6M-Bottom respectively. However, WSF leached 19% - 86% more P than 5-6M-Topdressed and 8-9M placements at Incorporated, Top1/3, and Topdressed (Table 2.2). The 8-9M-Bottom leached 71% - 81% more P than other 8-9M placements. Overall, P leached from 5-6M was greater than 8-9M: 58% Bottom, 80% Incorporated, 76% Top1/3, and 80% Topdressed.

2.4.2.5. Iron Leached

Overall, cumulative iron leached from all treatments increased over time (Figure 2.13). Bottom application of 5-6M leached more Fe than any other treatment (Figure 2.13.A and Table 2.2). The 5-6M-Topdressed leached 39% - 61% less Fe than WSF and the other 5-6M placements (Table 2.2). The Fe leached from 8-9M also increased over time (Figure 2.13.B). The 8-9M-Bottom and WSF treatment leached similar amounts up to day 33 after planting. At the end of the experiment, 8-9M-Topdressed leached 72%, 64% or 51% less Fe than WSF, 8-9M-Bottom or 8-9M-Incorporation respectively (Table 2.2). The 5-6M fertilizer placements leached more Fe (50% Bottom, 55% Incorporated, 58% Top1/3, and 54% Topdressed) than 8-9M placements.
2.4.3. **Experiment III**

The total volume of water or fertilizer-solution applied during irrigation or fertigation, and the volumes of water leached and wasted increased over time (Table 2.3). Regardless of treatment, about 62% of the applied water/fertilizer was lost either as a leachate (29%) or wasted (33%). In week 1, 5-6M leached 25% more nitrogen, and 40% or 70% more iron, than WSF or 8-9M respectively (Table 2.4). All treatments leached a similar amount of phosphorus during the first week. WSF leached 18% - 29% more nitrogen and 81% phosphorus in week 3. During week 6, WSF leached about 92% more N, 96% more P and 69% more Fe. The water lost outside the containers during irrigation of CRF treated plants contained less nutrients than the water wasted during fertigation with WSF (Table 2.4).

2.5. Discussion

Bottom application of either 5-6M or 8-9M yielded lower shoot dry weight than the other CRF placements (Experiment II) because more nutrients were lost during leaching. High nutrient losses from Bottom application treatments were evident in the EC values, P, and Fe leached in Experiments I and II. When prills are placed at the bottom, leaching from the container occurs faster than topdressing, Top1/3 or Incorporated. Plants may not be able to utilize the nutrients released at the bottom during the early stages of production because they may be young, have smaller nutrient requirements and smaller root systems. CRF companies recommend application as topdressing or incorporation through out the
because in our experiment, CRF placement at Top1/3 yielded similar dry weight and canopy cover as Incorporated and Topdressed plants. Our results were similar to those presented by Klock-Moore and Broschat (1999), who did not find any difference in dry weight between topdressing and incorporation of fertilizer placements throughout the container.

Fertilization with WSF increases leachate EC over time because of continuous addition of fertilizer during each irrigation. The EC of CRF decreased over time possibly because fewer nutrients were released and plants were absorbing more of them. EC of leachates from 5-6M-Topdressed almost doubled that of 8-9M probably because the 5-6M CRF was of a shorter longevity and thus was expected to release more nutrients over a shorter period of time than 8-9M CRF. Increase in cumulative N and P of CRF treatments over time demonstrated that CRF continued to leach nutrients over time. However, CRF stopped leaching Fe 20 - 24 days after planting. The WSF leached more nutrients than 8-9M CRF treatments (except N in Experiment II) because more was being added during fertigation.

In general, greater amounts of nutrients were measured from CRF treatments during the first 14 days after planting than towards the end of the experiment because of high nutrient release during the first few days. Richards and Reed (2004) recovered about 8% of total potassium leached during the first 14 days compared to 4% by the end of the experiment. Initial substrate nutrient charge might not be necessary for low feeders and
salt sensitive plants because this is the time when plants do not have the capacity to absorb most of the nutrients released. Towards the end of the experiment, plants may have had a better-developed root system reaching most of the CRF applied and therefore could maximize the uptake of most of the nutrients. Additionally, if high fertilizer rates were used, high initial release might not favor growth of young plants.

Plants in Experiment I had greater canopy cover than those in Experiments II (Table 2.1) likely due to the differences in light levels and quality during the production periods (spring vs. winter). Light intensity is one of the limiting factors for plant growth; it can vary according to day length and crowded conditions (Karlsson and Larson, 1994). According to Barrett and Erwin (1994), bedding plant production can be affected by light intensity, duration and quality. They noted that different plants react differently to varying light levels; short photoperiods and lower light levels result in smaller light integrals thus causing more lateral branching. In our experiment, lower light levels might have affected plant shape by increasing canopy cover (more lateral branching) of plants in Experiment I. Plants in Experiment II were more compact with possibly fewer lateral branches thus covering less ground area.

Dry weight of plants in Experiment I and II were similar (except for 8-9M Bottom and 5-6M-Topdressed), indicating that differences in canopy cover were not due to accumulation of dry mass but rather due to plant shape. Hughes and Evans (1962) found that increasing light intensity increases stem dry weight of Impatiens parviflora. Their
experiments resulted in dry weight increases of more than three times when crops were produced at high light levels. The high dry weight of plants with small canopy covers during spring production in our experiment might have been due to increased stem dry weight.

Increasing the distance between containers (Experiment III) leads to longer irrigation times, which increased the possibility of water loss, especially the amount of water falling outside the containers. In our experiment, the amount of water that fell outside the containers increased over time due to increased area for irrigation. Increased area of fertigation will require more time to water the plants. Therefore, more water will be lost when moving the hose from container to container.

Hose fertigation with WSF can lead to high nutrient losses due to fertilizer falling outside the containers (Colangelo and Brand, 2001). In our experiment, using CRF caused less than 5% of nutrients to be lost with the water that fell outside the container. Such losses may have been due to some prills splashing outside the container. CRF applied as Topdressed had higher chances of splashing than those from Incorporated treatments. In our experiment, the WSF solution that did not fall inside the container had more than 91% - 98% N, 98% P and 98% Fe than water from CRF treatments. The 5-6M fertilizer lost more initial N and Fe because in its composition has greater amounts of non slow-release N (about 3%; see appendix 1) in the prills than the 8-9M fertilizer (Experiment III). After the first week, the amounts of N and P leached from WSF treated plants were
greater because these nutrients were continuously added to the substrate through irrigation. In our experiments, adding a known volume of fertilizer and water (fertigation) to the container (just enough to sustain plant growth) lead to a smaller cumulative nutrient loss for N, P, and Fe in Experiment I and less N in Experiment II. Nutrient losses from WSF were similar to 8-9M CRF for most of the experimental period.

2.6. Conclusions

Plant growth and canopy cover were affected by fertilizer placement. CRF produced plants of similar quality as WSF except for bottom application. CRF placement as either top-dressed, incorporated or placement at top1/3 of the container produced salable plants. Bottom application resulted in higher nutrient losses and smaller plants. The 5-6M treatments produced more leaching of nutrients than 8-9M for the different placement. When WSF was applied at measured volumes, fewer nutrients were lost compared to 5-6M CRF. Results from Experiment III (water and nutrient losses) indicated that up to 95% of nutrients could be lost during irrigation with WSF as opposed to using CRF.

2.7. Literature Cited


Hulme, F. 2006. Combination Fertilizer Programs for Flowering Pot Plants: Highlight From The Ohio State University Trials. The Exchange Tech Shares. The Scotts Company, Marysville, Oh.


Table 2.1. Canopy cover (cm\(^2\)) and shoot dry weight (g) of plants in Experiment I and II.

Plants were grown with Osmocote 16-9-12 of 5-6M or 8-9M longevity applied as Topdressed, Incorporated, Bottom or Top1/3 of the container. WSF plants were grown with a 150 mg·L\(^{-1}\)N solution of 20-10-20 Peter’s Professional WSF. Values are means of six replications. Means with the same letter in a column are not significantly different.

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**Significance**  
* ns, *, **, or *** nonsignificant or significant at p < 0.05, 0.001 or 0.0001 respectively
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*Significance***  ***  ***  ***  ***  ***  ***

ns=not significant; *,**, *** indicate significant at p<0.05, 0.001 and 0.0001 respectively

Table 2.2. Total nutrients leached (mg) from media during experiment I. Plants were grown with Osmocote 16-9-12 of 5-6M or 8-9M longevity applied as topdressed, incorporated, bottom or at top1/3 of container. WSF plants were grown with a 150 mg·L⁻¹ N solution of 20-10-20 Peter’s Professional WSF. Values are means of six replications. Means with the same letter in a column are not significantly different.
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Table 2.3. Total water applied, leached and lost (wasted) per treatment during irrigation using a hose. Plants were grown with Osmocote 16-9-12 of 5-6M or 8-9M longevity incorporated in the substrate. WSF plants were grown with a 150 mg·L⁻¹ N solution of 20-10-20 Peter’s Professional WSF. “Applied” is the total amount of water used during irrigation, “Leached” is the amount of water leached from containers and “Wasted” is the amount of water lost while moving the hose from one container to another.
Table 2.4. Average nitrogen, phosphorus and iron leached from containers and lost when moving hose from container to container (water that fell outside the container) during hose irrigation. Plants were grown with Osmocote 16-9-12 of 5-6M or 8-9M longevity applied as incorporated. WSF plants were grown with a 150 mg·L⁻¹N solution of 20-10-20 Peter’s Professional WSF. Values are means of 18 plants in 3 blocks. Means with the same letter in a column are not significantly different.
Figure 2.1. Controlled release fertilizer (CRF) placement in 12.7 cm diameter by 9 cm height plastic containers at a rate of 6.3 kg·m$^{-3}$. CRF was layered at the top (Topdressed), top-one-third (Top1/3), incorporated throughout (Incorporated), or layered at the bottom (Bottom) of the container.
Figure 2.2. Experimental setup for leachate collection during Experiments I and II. Picture taken 52 days after planting (Experiment I). Each container (with plant) was placed on a 13 cm by 14 cm plastic mesh placed on top of 12 cm diameter plastic bowl to facilitate leachate collection.
Figure 2.3. Canopy cover pictures were taken by placing a plant at a point of reference marked on a board. The camera was focused so that the top of the plant falls within the area of focus under the tripod.
Figure 2.4. Experimental setup (Experiment III). Plants were placed on top of plastic cups to collect leachates and the setup was placed in plastic boxes during weeks 1, 3, and 6 to collect water lost during irrigation when the end of the hose is moved from container to container.
Figure 2.5. Experimental setup (Experiment III). Plastic boxes were placed next to each other to collect water lost during hose irrigation in weeks 1, 3 and 6. Picture taken on week 6.
Figure 2.6. EC (mS·cm$^{-1}$) of leachates collected from substrates of plants in Experiment I. Plants were grown with Osmocote 16-9-12 of 5-6M (A) or 8-9M (B) longevity applied as Topdressed, Incorporated, Bottom or Top1/3 of the container. WSF plants were grown with a 150 mg·L$^{-1}$N solution of 20-10-20 Peter’s Professional water-soluble fertilizer. Error bars represent standard error of the mean. Values are means of six replications, value are significant at p<0.0001.
Figure 2.7. Cumulative nitrogen leached (mg) in Experiment I. Plants were grown with Osmocote 16-9-12 of 5-6M (A) or 8-9M (B) longevity applied as Topdressed, Incorporated, Bottom or Top1/3 of the container. WSF plants were grown with a 150 mg·L⁻¹N solution of 20-10-20 Peter’s Professional water-soluble fertilizer. Values are means of six replications.
Figure 2.8. Cumulative phosphorus leached (mg) in Experiment I. Plants were grown with Osmocote 16-9-12 of 5-6M (A) or 8-9M (B) longevity applied as Topdressed, Incorporated, Bottom or Top1/3 of the container. WSF plants were grown with a 150 mg·L\(^{-1}\)N solution of 20-10-20 Peter’s Professional water-soluble fertilizer. Values are means of six replications.
Figure 2.9. Cumulative iron leached (mg) in Experiment I. Plants were grown with Osmocote 16-9-12 of 5-6M (A) or 8-9M (B) longevity applied as Topdressed, Incorporated, Bottom or Top1/3 of the container. WSF plants were grown with a 150 mg·L⁻¹N solution of 20-10-20 Peter’s Professional water-soluble fertilizer. Values are means of six replications.
Figure 2.10. EC (mS·cm$^{-1}$) of leachates collected from substrates of plants in Experiment II. Plants were grown with Osmocote 16-9-12 of 5-6M (A) or 8-9M (B) longevity applied as Topdressed, Incorporated, Bottom or Top1/3 of the container. WSF plants were grown with a 150 mg·L$^{-1}$N solution of 20-10-20 Peter’s Professional water-soluble fertilizer. Error bars represent standard error of the mean. Values are means of six replications, value are significant at p<0.0001.
Figure 2.11. Cumulative nitrogen leached (mg) in Experiment II. Plants were grown with Osmocote 16-9-12 of 5-6M (A) or 8-9M (B) longevity applied as Topdressed, Incorporated, Bottom or Top1/3 of the container. WSF plants were grown with a 150 mg·L⁻¹ N solution of 20-10-20 Peter’s Professional water-soluble fertilizer. Values are means of six replications.
Figure 2.12. Cumulative phosphorus leached (mg) in Experiment II. Plants were grown with Osmocote 16-9-12 of 5-6M (A) or 8-9M (B) longevity applied as Topdressed, Incorporated, Bottom or Top1/3 of the container. WSF plants were grown with a 150 mg·L⁻¹ N solution of 20-10-20 Peter’s Professional water-soluble fertilizer. Values are means of six replications.
Figure 2.13. Cumulative iron leached (mg) in Experiment II. Plants were grown with Osmocote 16-9-12 of 5-6M (A) or 8-9M (B) longevity applied as Topdressed, Incorporated, Bottom or Top1/3 of the container. WSF plants were grown with a 150 mg·L⁻¹ N solution of 20-10-20 Peter’s Professional water-soluble fertilizer. Values are means of six replications.
3.1. Introduction

Interest in controlled-release fertilizer (CRF) use for floricultural production has increased due to its potential to reduce nutrient runoff (Cabrerra, 1997; Chien et al, 2009; Klock-Moore and Broschat, 1999; Shoji et al, 2001). CRF can improve plant quality and reduce costs by increasing nutrient use efficiency (Shaviv, 2001). The increasing need to incorporate more sustainable production systems in the green industry has led to more investigations on the use of CRF for bedding plant production. However, CRF-use alone does not provide a complete solution to the problem of nutrient leaching. Appropriate application methods and CRF types must be considered during production (Broschat and Klock-Moore, 2001).

Different CRF formulations and longevities have been developed to meet the needs of different nutritional requirements for different plants (Hulme and Buchheit, 2007; Scotts, 2005). The ideal CRF for greenhouse production will depend on the crop and production time. For greenhouse plants, three-month longevity CRF is the most commonly recommended and used (Nelson, 1991). Depending on the crop, CRF longevity should
correspond to the time of production and plant nutrient uptake in order to increase growth, quality, and reduce nutrient waste (Hulme and Buchheit, 2007; Ivy et al, 2002; Nelson, 1991; Shaviv, 2001; Wright, 1992). CRF have not been commonly used in the production of bedding plants. More research needs to be done in the area of CRF longevity and application rates on the growth and performance of bedding plants. Such information will enable growers to decide what CRF type and longevity to use. The objective of this experiment was to determine the effects of CRF longevity on the growth and quality of impatiens (*Impatiens walleriana* Hook. f. 'Xtreme scarlet').

3.2. Materials and Methods

The growing substrate consisted of 3:1 ratio of Canadian sphagnum peat moss (Sunshine Peat Moss, SunGro Horticulture, Bellevue, Wash):perlite (Therm-O-Rock East inc, New Eagle, PA). A total of 3 kg·m$^{-3}$ carbonated lime was added to correct the pH to 5.8 - 6.4. This substrate was hydrated by adding 7.6 mL of Aqua-Gro L (Scotts Company, Marysville, Ohio) in 1 L of water. Up to 5L of water was added to reach 30% to 50% container capacity moisture content (Argo & Biernbaum, 1996). The substrate was then placed in a 100 L plastic container and left to equilibrate for 24 hours. Before potting the plants, substrate EC and pH were measured using a 1:2 dilution method with an Accumet Model AP85 pH/Conductivity meter (Fisher Scientific, Pittsburgh, PA). Initial substrate pH was 6.2, which is within the required pH ranges of 5.5 - 6.4 (Argo and Biernbaum, 1996). Initial EC was 0.68 dS·m$^{-1}$.
Osmocote Plus 15-9-12 CRF of different longevities and Peters Professional water-soluble fertilizer (WSF) 20-10-20 were used for this experiment. Both fertilizer formulations were produced by The Scotts Co., Marysville, Ohio. CRF of 3-4, 5-6, 8-9, and 12-14 month longevity were incorporated in the substrate at rates of 1.4, 3.4, 6.8, 10.2 and 13.6 kg·m⁻³ (1, 2.5, 5, 7.5 and 10 g/container respectively). A WSF solution of 150 mg·L⁻¹ N was applied using the same volume of water applied to CRF treatments (WSF1) or using a hose (without measuring the volume applied), which is a common irrigation method used by growers (Control), especially small ones.

One plug of ‘Xtreme Scarlet’ impatiens was planted in a 10 cm by 10 cm square plastic container of 8.5 cm height. The experiment consisted of a factorial arrangement of four CRF longevities by five rates plus WSF1 and Control (4 x 5 + 2 factorial arrangement). A total of 20 CRF treatment combinations and two WSF treatments were used. All treatments were arranged in a randomized complete block design with six blocks. Each block represented one replication.

Two experiments were carried out in a greenhouse with a double layer acrylic roof at The Ohio State University (Columbus OH). Greenhouse temperatures and outside radiation levels were obtained from the greenhouse data system for both experiments. In Experiment I, plants were grown for 54 days with temperatures set at 18/21°C (low/high). The average outdoor daily light integral during the production period was 6.5 mol-day⁻¹. Experiment II was a repetition of Experiment I with the exception that plants were grown
for 42 days, the standard time for greenhouse production of bedding plants (Klock-Moore, 2001). The greenhouse temperature was set at 18/21°C (low/high) and average outdoor daily light integral was 18.2 mol·day⁻¹.

Plants were monitored daily and irrigation was supplied as needed depending on plant size and environmental conditions. Plants grown with CRF were irrigated with a measured volume of water (to yield a 20 - 30% leaching fraction) while WSF plants were fertigated with either a measured volume or using a hose with a 150 mg·L⁻¹ N solution. Substrate EC and pH were periodically measured; pH was found to be within the ranges of 5.7 - 6.8 while EC ranged from 0.5 to 6.4 dS·m⁻¹.

Consumer evaluations were conducted by a group of 40 and 35 people for Experiment I and Experiment II respectively. Each panel of evaluators consisted of growers, master gardeners, faculty, staff, and students. Plants were rated on a scale of 1 to 5 where a rating of 5 was assigned when the consumer liked the plants very much and a 1 indicated they disliked the plants.

At the end of the experiment, pictures of the plant canopies were taken from above with a digital camera (model EX-Z250A, Casio Computer Co, China). A tripod was placed at a fixed position holding the camera about 1 m above ground with the objective lens looking down. A mark was made on the ground and each plant was placed on the mark to ensure uniformity under the focus of the camera. Pictures were then analyzed with digital
analysis software (Assess Image Analysis, APS Press, St Paul, MN) to measure the exposed leaf area in cm$^2$ (canopy cover). This software works on the principle of matching surfaces where the user sets threshold boundaries (color) and the software automatically selects that color range from the original color image (Lamari, 2002). The software fills in the areas that have the pixel value within the range specified. Once an image is filled in, data for the measurements (area covered) can be obtained.

Above ground plant parts were harvested, placed in separate bags and left to dry in a forced-air oven (GS Blue M Electric) at 55°C for 48 hrs. Plant dry weight was measured, and the data analyzed using the regression procedure of SigmaPlot (SYSTAT Inc., Chicago, IL). If regressions were significant, the best fit was determined using the values of adjusted R$^2$ and the graph presented. Predicted maximum dry weights were calculated by substituting the value of maximum CRF rate (obtained from $X_{\text{max}} = -b/2a$) in the regression equation. The values of $a$ and $b$ were obtained from the quadratic equation $Y = aX^2 + bX + c$, where $X = \text{CRF rate}$ and $Y = \text{dry weight}$. Differences within fertilizer rates, leaf canopy cover; flower coverage and consumer ratings were analyzed using ANOVA procedure of SAS version 9.2 (SAS Institute, Cary, NC).

Plant quality in this experiment was defined by leaf canopy cover, flower cover and consumer ratings. Longevity was defined as the period of time it takes for CRF to release 80% to 90% of its nutrients.
3.3. Results

3.3.1. Experiment I

Shoot dry weight as a function of fertilizer rate was best described by quadratic equations for all the four CRF longevities (Table 3.1 and Figure 3.1). Shoot dry weight increased with increasing fertilizer rate until a maximum and then decreased. Fertilizer rate accounted for about 35%, 66%, 57% and 74% of the increase in shoot dry weight for 3-4M, 5-6M, 8-9M and 12-14M respectively (Table 3.1). The maximum dry weights were predicted to be achieved at fertilizer rates of 4.2, 4.7, 5.7, and 8.9 g for CRF longevities of 3-4, 5-6, 8-9, and 12-14 month respectively (Table 3.2).

At 1.4 kg·m⁻³, all CRF treatments yielded significantly lower dry weight (23% - 47%) than WSF treatments (Table 3.3). CRF of 12-14 month longevity applied at a rate of 1.4 kg·m⁻³ produced plants of 31% less dry weight than 5-6M at the same rate (Table 3.3). Plants fertilized with 3.4 kg·m⁻³ of 5-6M or 8-9M produced higher dry weight than those fertilized with the same amount of 12-14M (p ≤ 0.0231). There was no significant difference in dry weight of plants grown with either WSF or CRF at 6.8 kg·m⁻³. At the fertilizer rate of 10.2 kg·m⁻³, 3-4M produced significantly lower dry weight the other treatments with the exception of 5-6M (p ≤ 0.002). When CRF was applied at 13.6 kg·m⁻³, the 12-14M produced higher dry weight than all the treatments.

There were significant differences in the leaf canopy cover for all fertilizer rates except
6.8 kg·m⁻³ (Table 3.3). WSF grown plants had 37% - 51% greater leaf canopy cover than plants from all CRF treatments applied at the 1.4 kg·m⁻³ rate. At CRF rate of 3.4 kg·m⁻³, WSF plants had greater canopy cover than 8-9M and 12-14M plants. When CRF was applied at 6.8 kg·m⁻³, all CRF and WSF plants had similar canopy cover. However, at a rate of 10.2 kg·m⁻³, 3-4M and 5-6M CRF had a smaller leaf canopy cover compared to the other treatments. For CRF applied at 13.6 kg·m⁻³, 3-4M, 5-6M, and 8-9M had smaller canopy cover than 12-14M, WSF1 and Control.

At the rate of 1.4 kg·m⁻³, CRF plants (except 12-14M plants) had 27% - 32% more flower cover than WSF plants (Table 3.3). There were no significant differences in flower cover between treatments when CRF was applied at rates of 3.4 or 6.8 kg·m⁻³. Flowers from 3-4M and 5-6M CRF applications at rates of 10.2 kg·m⁻³ or 13.6 kg·m⁻³ covered a smaller part of the plant canopy than the other treatments. Flowers from plants grown with 6.8, 10.2 and 13.6 kg·m⁻³ of 3-4M, 5-6M and 8-9M had white and watery patches at the center of the flowers.

There were significant differences in consumer ratings of plants from all treatments with the exception of 3.4 kg·m⁻³ CRF rate of application (Table 3.4). When CRF was applied at 1.4 kg·m⁻³, consumers preferred WSF plants over all CRF treatments except 12-14M. At CRF application rate of 6.8 kg·m⁻³, 3-4M plants received a lower score than the other treatments except 5-6M. The 3-4M and 5-6M longevities at rates of 10.2 kg·m⁻³ had the lowest rating. At the 13.6 kg·m⁻³ rate, the consumers preferred the 8-9M and WSF plants.
over other treatments.

3.3.2. Experiment II

Predicted shoot dry weight increased with increasing fertilizer rates up to a maximum and then decreased (Figure 3.2). Maximum dry weights were predicted to occur at fertilizer rates of 7.6, 8.6, 10.2 and 10.3 kg·m\(^{-3}\) for 3-4M, 5-6M, 8-9M or 12-14M treatments respectively (Table 3.2). Fertilizer rate explains 65%, 62%, 85%, and 93% of the increases in shoot dry weights for 3-4M, 5-6M, 8-9M, and 12-14M treatments respectively (Table 3.5). Shoot dry weight of the treatments were best described by quadratic equations (Figure 3.2 and Table 3.5). There were significant differences in shoot dry weight at fertilizer application rates of 1.4, 3.4 and 13.6 kg·m\(^{-3}\) (Table 3.6). The dry weights of WSF plants were higher than CRF plants for all longevities tested at rates of 1.4 and 3.4 kg·m\(^{-3}\). At the highest CRF rate (13.6 kg·m\(^{-3}\)), the 3-4M produced plants with the lowest dry weight.

There were significant differences in leaf canopy and flower cover of plants for treatments at 1.4, 3.4, and 13.6 kg·m\(^{-3}\) (Table 3.6). When CRF was applied at rates of 1.4 or 3.4 kg·m\(^{-3}\), the leaf canopy cover of the plants was less than WSF plants. When CRF was applied at 13.6 kg·m\(^{-3}\), the 3-4M and 5-6M treatments had the smallest leaf canopy cover compared to the other treatments. Leaf canopy was similar for all treatments when CRF was applied at 6.8 or 10.2 kg·m\(^{-3}\). WSF plants had lower flower cover than 3-4M CRF plants at fertilizer rates of 1.4 kg·m\(^{-3}\) (Table 3.6). When CRF was applied at 3.4 kg·m\(^{-3}\), the 5-6M and 12-14M had higher flower cover than WSF plants. All plants had
similar flower cover at CRF rates of 6.8 and 10.2 kg·m$^{-3}$. Flower cover of 8-9M and 12-14M was greater than the other treatments. Flowers from fertilizer rates of 6.8 (3-4M), 10.2 and 13.6 kg·m$^{-3}$ (3-4M, 5-6M and 8-9M) appeared to have white patchy and soggy centers and margins.

At a 1.4 kg·m$^{-3}$ CRF application rate, consumers preferred the WSF plants over the CRF treated plants (Table 3.4). At this same rate, 3-4M plants received a higher rating than 12-14M. When CRF were applied at 10.2 kg·m$^{-3}$, consumer ratings for 3-4M and 5-6M were higher than WSF plants. The 8-9M and 12-14M longevity treatments at rates of 13.6 kg·m$^{-3}$ received a higher score than the other treatments.

3.4. Discussion

CRF of different longevities release nutrients at different rates. Our results from Experiments I and II demonstrated that shorter longevity CRF produced maximum dry weight at lower rates than fertilizers with longer longevities. This was consistent with the recommended rates of the fertilizer where the optimal rate for longer longevity CRF was higher than the rate for shorter longevities. The longevity of a CRF can be affected by cultural practices, growing environment, and substrate temperature (Hulme and Buchheit, 2007; Scotts, 2005). CRF with shorter longevities are expected to have a greater nutrient release rates than those with longer longevities. Our results were consistent with these expectations: plants grown with 3-4M CRF reached the maximum predicted dry weight with a lower application rate than the 12-14M which reached the maximum predicted dry
weight at a much higher rate (Table 3.2).

Plants grown at a CRF rate of 1.4 kg·m$^{-3}$ (Experiment I and II) and 3.4 kg·m$^{-3}$ (Experiment I) had smaller leaf canopy covers than WSF plants, probably due to lack of sufficient nutrients for plant growth. The WSF plants had adequate fertilizer for the entire production period while CRF plants lacked fertilizer at some point at the lowest rates, resulting in stunted plants with many flowers. Flower cover of CRF plants was greater at 1.4 kg·m$^{-3}$ than WSF (3-4M Experiment I and all CRF longevities in Experiment II except 12-14M) probably due to nutrient stress, which decreased plant size disproportionately from flower cover. Stunting of plants grown with low fertilizer rates (1.4 kg·m$^{-3}$) in our work was similar to results presented by Parks et al., (2007). They grew six species of *Proteacea* with different rates of Osmocote CRF and found that plants grown with fertilizer rates of 1.25 kg·m$^{-3}$ were stunted.

On the other hand, plants fertilized with shorter longevity (3-4M and 5-6M) and higher rates of either 10.2 (Experiments I and II) or 13.6 kg·m$^{-3}$ (Experiment II) had smaller leaf canopy and flower cover than the other treatments probably due to excess nutrients. Plants grown with excess nutrients may take longer to mature perhaps due to salt stress and time to adapt to high salt levels (Haver and Schuch, 1996). Plants grown with high fertilizer supplies are reported to have large leaves and dark green succulent leaves. These plants might be sensitive to damage during shipping and retailing (Nell et al., 1994). Our results were similar to those of Haver and Schuch (1996) who found that
*Impatiens hawkeri* ‘Illusion’ (New Guinea impatiens) grown with either low or high (3.3 or 9.9g/container; equivalent to 4.5 kg·m^{-3} or 13.5 kg·m^{-3} respectively) CRF rates had marketable quality but lacked the stature and fullness of plants grown with 8.9 kg·m^{-3}, which in this case was a medium rate. Our CRF plants grown with a medium rate (6.8 kg·m^{-3}) had similar dry weight, leaf canopy cover and flower cover than the WSF treated plants because the CRF plants had adequate fertilizer for their production.

Consumers preferred WSF over CRF grown at a rate of 1.4 kg·m^{-3} (Experiment II) and 13.6 kg·m^{-3} (Experiment I except 12-14M) because of the differences in plant size (leaf canopy cover) and flower cover. The CRF plants were either stunted (1.4 kg·m^{-3}) or showing some signs of flower burn. There was no difference in consumer preference between WSF and CRF plants grown with 6.8 kg·m^{-3} (Experiment II) because these plants were similar in canopy cover, dry weight, and flower number. Consumer evaluation is a useful addition to dry weight data because they represent a measure of aesthetic quality of the product that drives purchasing decisions. Consumer preference of bedding plants can be influenced by uniformity, compactness, stress tolerance, flower coverage and diseases incidence (Borch et. al., 1998). Bedding plants with green leaves, more flowers and flower buds, large but compact plants and good overall appearance of the plants can be more appealing during purchase (Nell et al, 1994).

Plants in Experiment II had greater dry weight, leaf canopy cover and flower cover than plants in Experiment I due to differences in light levels. Plants in Experiment I were
grown during the late fall and winter (DLI of 6.5 mol·day$^{-1}$) while those in Experiment II were grown later during later summer and early fall (DLI of 18.2 mol·day$^{-1}$). Higher light integral provided plants with more photosynthetic activity leading to increase in growth and or assimilate accumulation (Drüge, 2000).

3.5. Conclusion

CRF rate of 6.8 kg·m$^{-3}$ produced plants of similar dry weight, leaf canopy and flower cover as well as consumer preference than those of WSF. Although plants grown with CRF at a rate of 3.4 kg·m$^{-3}$ had slight differences in shoot dry weight, leaf canopy cover, and flower canopy cover (except Experiment I), the consumers were not able to detect those differences and gave all plants the same rating.

3.6. Literature Cited


Cabrera, R.I. 1997. Comparative evaluation of nitrogen release patterns from controlled-


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Where $X=$ CRF rate and $y=$ shoot dry weight

Table 3.1. Regression equations and coefficient of determination ($R^2$) for shoot dry weight as a function of fertilizer application rates of plants from Experiment I. Plants were grown with CRF of 3-4, 5-6, 8-9, and 12-14 month longevity incorporated at rates of 1.4, 3.4, 6.8, 10.2, and 13.6 kg·m$^{-3}$. 
Table 3.2. Predicted maximum shoot dry weight (g) and respective fertilizer rate during Experiment I and II. Plants were grown with CRF of 3-4, 5-6, 8-9, and 12-14 month longevity incorporated at rates of 1.4, 3.4, 6.8, 10.2, and 13.6 kg·m⁻³ (equivalent of 1, 2.5, 5, 7.5, and 10 g/container respectively).

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<td>7.5</td>
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<td>5.7</td>
<td>8.0</td>
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<tr>
<td>12-14M</td>
<td>4.1</td>
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Table 3.3. Shoot dry weight (g), leaf canopy cover (cm$^2$) and flower cover (cm$^2$) of plants from Experiment I. Plants were grown with CRF of 3-4, 5-6, 8-9, and 12-14 month longevity incorporated at rates of 1.4, 3.4, 6.8, 10.2, or 13.6 kg·m$^{-3}$, and 150 mg·L$^{-1}$ N WSF applied as same volume of water as for CRF (WSF1) or using a hose (Control). Values are means of 6 replications. Means with the same letter in a column are not significantly different.

<table>
<thead>
<tr>
<th>Fertilizer rate</th>
<th>1.4 kg·m$^3$</th>
<th>3.4 kg·m$^3$</th>
<th>6.8 kg·m$^3$</th>
<th>10.2 kg·m$^3$</th>
<th>136 kg·m$^3$</th>
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<td>Leaf Canopy Cover (cm$^2$)</td>
<td>Flower Cover (Cm$^2$)</td>
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<tr>
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<tr>
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<td>590$^{ab}$</td>
<td>123$^a$</td>
<td>123$^a$</td>
<td>ns</td>
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<tr>
<td>12-14M</td>
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<td>664$^a$</td>
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<tr>
<td>WSF1</td>
<td>2.90$^c$</td>
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<td>ns</td>
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<tr>
<td>Control</td>
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<td>***</td>
<td>**</td>
<td>*</td>
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</table>

ns, *, **, or *** nonsignificant or significant at p < 0.05, 0.001 or 0.0001 respectively.
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<th>Fertilizer rate</th>
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<th>3.4 kg·m⁻³</th>
<th>6.8 kg·m⁻³</th>
<th>10.2 kg·m⁻³</th>
<th>136 kg·m⁻³</th>
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<td><strong>Treatments</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>3-4M</td>
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<td>3.67a</td>
<td>3.20f</td>
<td>2.66c</td>
<td>2.60b</td>
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<td>5-6M</td>
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<td>3.49bc</td>
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<tr>
<td>8-9M</td>
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<td>3.70a</td>
<td>3.85a</td>
<td>3.48b</td>
<td>2.55b</td>
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<td>3.74ba</td>
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<td>3.83ba</td>
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<td>3.67ba</td>
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<td><strong>Significance</strong></td>
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<td>ns</td>
<td>***</td>
<td>***</td>
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</tbody>
</table>

**Consumer Rating Experiment II**

| 3-4M           | 2.65b      | 3.51a      | 3.15a      | 3.71a      | 2.87c      |
| 5-6M           | 2.29bc     | 3.50a      | 3.41a      | 3.78a      | 3.37b      |
| 8-9M           | 2.27bc     | 3.06a      | 3.51a      | 3.64ba     | 4.39a      |
| 12-14M         | 2.19c      | 3.10a      | 3.62a      | 3.42ba     | 4.16a      |
| WSF1           | 3.26a      | 3.26a      | 3.26a      | 3.26b      | 3.26bc     |
| Control        | 3.26a      | 3.26a      | 3.26a      | 3.26b      | 3.26bc     |
| **Significance** | ***         | ns         | ns         | **         | ***         |

ns, *, **, or *** nonsignificant or significant at p < 0.05, 0.001 or 0.0001 respectively

Table 3.4. Consumer ratings during Experiment I and II of plants grown with CRF of 3-4, 5-6, 8-9, and 12-14 month longevity incorporated at rates of 1.4, 3.4, 6.8, 10.2, and 13.6 kg·m⁻³, and WSF applied as same volume of water as for CRF (WSF1) or using a hose (Control). Values are means of 40 (Experiment I) or 35 (Experiment II) ratings. Means with the same letter within a column are not significantly different (p ≤ 0.05).
<table>
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<th>Regression</th>
<th>$R^2$</th>
<th>Regression Equation</th>
<th>p</th>
</tr>
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<td>3-4M</td>
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<td></td>
<td>Quadratic</td>
<td>0.65</td>
<td>$y = 1.58 + 1.96x - 0.17x^2$</td>
<td>&lt;0.0001</td>
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<tr>
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<td>Linear</td>
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<td>0.0247</td>
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<tr>
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<td>$y = 3.51 + 0.49x$</td>
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<tr>
<td></td>
<td>Quadratic</td>
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<td>12-14M</td>
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<tr>
<td></td>
<td>Quadratic</td>
<td>0.93</td>
<td>$y = 0.68 + 1.82x - 0.12x^2$</td>
<td>&lt;0.0001</td>
</tr>
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Where X= CRF rate and y= shoot dry weight

Table 3.5. Regression equations and coefficient of determination ($R^2$) for shoot dry weight as a function of fertilizer application rates of plants from Experiment II. Plants were grown with CRF of 3-4, 5-6, 8-9, and 12-14 month longevity incorporated at rates of 1.4, 3.4, 6.8, 10.2, and 13.6 kg·m$^{-3}$. 

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Table 3.6. Shoot dry weight (g), leaf canopy cover (cm$^2$) and flower cover (cm$^2$) of plants from Experiment II. Plants were grown with CRF of 3-4, 5-6, 8-9, and 12-14 month longevity incorporated at rates of 1.4, 3.4, 6.8, 10.2, or 13.6 kg·m$^{-3}$, and 150 mg·L$^{-1}$ N WSF applied as same volume of water as for CRF (WSF1) or using a hose (Control). Values are means of 6 replications. Means with the same letter in a column are not significantly different.
Figure 3.1. Variation of shoot dry weight (g) with increasing fertilizer concentration for Experiment I. Plants were grown with CRF of (A) 3-4M longevity, (B) 5-6M longevity, (C) 8-9M longevity, and (D) 12-14M longevity. The best fit of regression was a quadratic model at p \leq 0.05. The CRF were incorporated at rates of 1.4, 3.4, 6.8, 10.2, and 13.6 kg·m⁻³ (equivalent of 1, 2.5, 5, 7.5, and 10 g/container respectively).
Figure 3.2. Variation of shoot dry weight (g) with increasing fertilizer concentration for Experiment II. Plants were grown with CRF of (A) 3-4M longevity, (B) 5-6M longevity, (C) 8-9M longevity, and (D) 12-14M longevity. The best fit of regression was a quadratic model at $p \leq 0.05$. The CRF were incorporated at rates of 1.4, 3.4, 6.8, 10.2, and 13.6 kg·m$^{-3}$ (equivalent of 1, 2.5, 5, 7.5, and 10 g/container respectively).
Chapter 4: EFFECTS OF CONTROLLED RELEASE FERTILIZER ON THE
GREENHOUSE AND GARDEN PERFORMANCE OF IMPATIENS WALLERIANA

4.1. Introduction

Nutrient management during production can greatly affect postproduction quality of plants (Chiari, et al., 1999; Nell et al., 1997). Nitrogen is the macronutrient that has the most influence on plant growth (Marschner, 2006; Drüge, 2000). According to Brueck (2008), Druege, (2001) and Drüge (2000), nitrogen determines carbon allocation, uptake and availability of other nutrients, and most influences on the pH in the root zone during plant production. An equal Ammonium-nitrogen:nitrate-nitrogen ratio potentially favors postharvest behaviors of plants through higher cytokinin delivery by the root systems (Drüge, 2000). However, high ammonium based fertilizer can cause toxicity, carbohydrate deficiency, and high ethylene production thus decreasing postproduction life of plants (Drüge, 2000; Druege, 2001).

While high applications of fertilizer accelerate vegetative growth, reduced flowering and or salt damage, low levels of fertilizer can lead to stunted plants, early flowering, leaf and flower senescence (Armitage and Kaczperski, 1994; Drüge, 2000). Fertilizer practices
throughout production cycle can affect the aesthetic value of plants during postproduction through exhibition of unfavorable physiological conditions. Growers harden off or tone crops during the final phase of production to prepare them for different environment. Toning plants through reduced fertilizer applications during the final stage of production results in increased shelf life during shipping, retail or consumer environments (Armitage, 1993; Jones, 2002; Nelson, 1999). Beach et. al., (2009) found that reducing fertilizer rate 2 weeks before harvest can prolong shelf life of some vegetable annuals.

The use of controlled-release fertilizer (CRF) for floricultural production can add value to floricultural postproduction quality by decreasing chlorosis and increasing vegetative growth (Chiari, et al., 1999). Haver and Schuch (1996) studied the production and post-production performance of Impatiens hawkeri (New Guinea Impatiens) cultivars grown with CRF and no leaching. They found that plants responded favorably to CRF in a lathhouse during the post-production phase. Although they studied the effects of CRF, this experimental setup simulated environmental conditions similar to a retail nursery. According to Chiari et al., (1999), in their study of resin coated fertilizer (RCF) to improve postproduction performance of impatiens in hanging baskets found that RCF use increased plant growth and duration of flower production. Despite all the research conducted with CRF, no information regarding the effect of CRF, applied at the beginning of the crop cycle, on garden performance of plants was found in the literature.
The objective of this study was to evaluate the effect of CRF applied at the beginning of the crop cycle on the garden performance of impatiens (*Impatiens walleriana* Hook. f. ‘Xtreme Scarlet’). Plant quality, shoot dry weight, flower number, flower dry weight, and leaf greenness were evaluated in the greenhouse and field phase of the experiment.

4.2. Materials and Methods

The growing substrate consisted of 3:1 ratio of Canadian sphagnum peat moss (Sunshine Peat Moss, SunGro Horticulture, Bellevue, Wash):perlite (Therm-O-Rock East inc, New Eagle, PA). Carbonated lime at 3 kg·m⁻³ was added to correct the pH to 5.8 - 6.4. This substrate was hydrated by adding 11.2 mL of Aqua-Gro (Scotts Company, Marysville, Ohio) in 1 L of water. Up to 5L of water was added to reach 30% to 50% container capacity moisture content (Argo & Biernbaum, 1996). The substrate (95 L) was then placed in a 100 L plastic container and left to equilibrate for 24 hours. Before potting the plants, substrate EC and pH were measured using a 1:2 dilution method with an Accumet Model AP85 pH/Conductivity meter (Fisher Scientific, Pittsburgh, PA). Initial substrate pH was 6.2, which is within the required range. Initial EC was 0.66 dS·m⁻¹.

Osmocote Plus 16-9-12 CRF of two different longevities and Peters Professional WSF 20-10-20 (The Scotts Company, Marysville, OH) were used in these experiments. CRF were incorporated at a rate of 6.8 kg·m⁻³ (5 g/container) while the WSF was applied at 150 mg·L⁻¹ N. The treatments consisted of a) CRF of 5-6 month longevity (5-6M), b)
CRF of 8-9 month longevity (8-9M), c) A combination of 3.4 kg·m$^{-3}$ each of 5-6M and 8-9M, d) WSF applied with a hose, which is a common method used by growers (Control), and e) WSF irrigated with the same volume of water as the CRF treatments were irrigated with a WSF solution (WSF1). One plug of ‘Xtreme Scarlet’ impatiens from Green Circle growers was transplanted in 12.7 cm diameter by 9 cm height plastic container filled with growing substrate. Plants were grown in the greenhouse and later transferred to the field.

Treatments were arranged in a randomized complete block design with six blocks (each representing a replication). About 300 plants were grown in the greenhouse (5 treatments by 10 plants/treatments by 6 blocks). Data were analyzed using mixed models with SAS version 9.1 (SAS Institute, Cary, NC). Blocks were considered random effects while fertilizer treatments were considered fixed effects. Effects were considered to be significant if $p \leq 0.05, 0.001$ or 0.0001. The statistical model used was:

$$\text{Dry weight} = \text{Overall mean} + \text{Fertilizer effects} + \text{Block effects} + \text{error term}$$

Plants from the two experiments were grown in the Howlett greenhouse and later transplanted to the Waterman Horticulture Research Farm, both located at The Ohio State University (Columbus, OH).

(a) Experiment I plants were grown for 54 days in the greenhouse with average temperatures of 18/24°C (low/high) and average daily light integral (DLI) of 12.4 mol·day$^{-1}$. Plants in the field were grown for 73 days with average temperature of
19/29 (low/high) and DLI of 38.3 mol·day\(^{-1}\).

(b) **Experiment II** was a repetition of Experiment I. However, plants in the greenhouse were grown for 37 days with average temperatures of 18/22°C (low/high) and average daily light integral of 15.6 mol·day\(^{-1}\). Plants in the field were grown for 75 days with average temperature of 19/29 (low/high) and DLI of 18.8 mol·day\(^{-1}\).

Plants were grown in a double layer acrylic greenhouse and irrigated or fertigated as needed depending on plant size and environmental conditions. Fully opened flowers were harvested every three to four days. These flowers were counted and dried in an air forced oven (GS Blue M Electric) at 55°C for 72 h. The dry weights of the flowers were measured. At the end of the greenhouse phase, plants were rated on a scale of 1 - 5 where: 5 is excellent (healthy plants with uniform and vigorous growth); 4 is good (uniform and healthy plants with less vigor); 3 is average (healthy, less vigorous and uniform plants); 2 is fair (healthy, non-uniform plants with less vigor) and 1 is poor (neither uniform nor vigorous or dead plants). Plant quality in this experiment was defined as visual appeal of plants.

Two plants per treatment per block were randomly sub-sampled for shoot dry weight determinations. Above the substrate plant parts were harvested, placed in separate bags and dried in an forced-air oven at 55°C for 72 h. Plant tissue was ground (Thomas
Scientific grinder, Swedesboro), passed through a mesh screen and digested in a microwave digester (MARS Express, CEM Corp) using a modified USEPA method 3051 for analysis of P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn in the plant tissue (USDA-ARS laboratory facility). N was measured with a combustion analyzer (model 2400, Perkin Elmer). Six plants per treatment from the remaining plants were transplanted in the field.

A 9.1 m x 27.4 m plot at The Ohio State University Waterman Horticulture Research Farm (Columbus, OH) was ploughed and an irrigation system that sprinkled one inch of water per hour was installed. Six blocks of 5.8 m² (0.91 m x 6.4 m) each were marked in the field and located 3 m apart. A black shade cloth of 55% shade was placed over each block and supported at a height of 1.2 m by steel pipe frame (Figure 4.1a). Photosynthetic photon flux densities inside and outside the structure were measured during a sunny and a cloudy day to determine the actual shade percent of the cloth: 52% shade. Soil samples were randomly taken inside the blocks at a depth of 20 cm. The soil samples were dried at 55 °C for 72 h, ground and stored at room temperature for nutrient analysis. The soil in both experiments was of a moderate fertility.

Plants from each treatment and block combination in the greenhouse phase were kept in the same block in the field. However, these plants were randomly reassigned within the blocks before planting in the field. Each block consisted of 30 plants (6 plant per treatment x 5 treatments) randomly arranged in two rows of three plants per treatment at
0.3 m apart (Figure 4.1b). Irrigation was supplied as needed (by sprinklers). No fertilizer was supplied to the plants in the field in order to evaluate the postproduction effect of the fertilizers applied during production.

Fully opened flowers were harvested every 3-4 days for 53 or 51 days after field planting (Experiment I and II respectively). Flowers were counted, dried and dry weights measured. After that period, plants were allowed to flower for an additional 14 days before consumer evaluations were conducted by a group of 38 people in Experiment I and 35 people in Experiment II. Each panel consisted of a mix of growers, master gardeners, faculty, staff, and students. The evaluations were conducted over a period of 7 days and a scale of 1 to 5 was used. A rating of 5 meant the consumer liked the plants very much, while a 1 meant they disliked the plants.

Every two weeks during Experiment I, a visual assessment of nutrient deficiencies/leaf greenness was performed on all plants immediately after flower harvesting. In Experiment II, leaf greenness was estimated at the end of the field phase using a chlorophyll content meter (Model SPAD-502, Minolta, Japan). Four measurements from randomly selected recently fully expanded leaves on the upper canopy of each plant were obtained (Romero et al., 2006). At 73 days (Experiment I) or 75 days (Experiment II) after planting, above ground plant parts were harvested and dry weight determined. The dry tissue was ground and stored at room temperature for nutrient analysis as before.
4.3. Results

4.3.1. Experiment I

4.3.1.1. Greenhouse phase

WSF plants were taller (Figure 4.2) than 5-6M, 8-9M and Blend plants during the greenhouse phase. WSF1 plants had a significantly higher shoot dry weight compared to Blend and 5-6M CRF plants (Figure 4.3). The 5-6M plants had smaller shoot dry weight compared to WSF and 8-9M CRF treatments. Plants grown with 5-6M produced the fewest flowers (Figure 4.4). WSF1 and 8-9M treated plants had the largest single flower dry weight (Figure 4.5). There was a significant difference in shoot tissue content of P, K, Ca, and Mn between fertilizer treatments (Table 4.1). Overall, plants fertigated with WSF had greater P and K concentration but less Mn in the shoot tissue compared to CRF plants.

4.3.1.2. Field phase

In general, plant quality deteriorated over time. At the beginning of the field phase, less than 25% of the leaves from 8-9M and Blend plants were chlorotic (Figure 4.6). WSF and 5-6M CRF plants were greener (p ≤ 0.001) than 8-9M and Blend. At 28 days after field planting, WSF plants became more chlorotic than CRF plants (p ≤ 0.0001). This trend continued until the end of the experiment (55 days after field planting). At the end
of the field phase, CRF plants were visually more compact and shorter than the fertigated plants (similar to greenhouse phase; data not shown). There were significant differences only in tissue Ca, Mg and Zn concentrations (Table 4.1). Both treatments receiving WSF had lower concentrations of Ca, Mg and Zn than the other treatments. Plants in the field had similar shoot dry weight (Figure 4.7), single flower dry weight (Figure 4.8), and consumer rating (Table 4.2). WSF treated plants produced 23% - 28% more flowers than CRF plants (Figure 4.9).

4.3.2. Experiment II

4.3.2.1. Greenhouse phase

At the end of the greenhouse phase, all plants were visually similar and there were no signs of chlorosis. Quantification of nutrient deficiency symptoms was therefore considered unnecessary. Blend and 5-6M treated plants had about 22% greater shoot dry weight than WSF plants (Figure 4.3). The 8-9M treated plants had significantly greater shoot dry weight than Control. There were no differences in single flower dry weight among all treatments (Figure 4.4). Single flower dry weight was the same for all the treatments (Figure 4.5). WSF plants had higher tissue N, P and K level than the other three treatments (Table 4.1).
4.3.2.2. Field phase

CRF plants had 33% - 45% greater shoot dry weight than WSF plants (Figure 4.7) and they produced 25% more total flowers than WSF plants (Figure 4.9). At the end of the experiment, CRF plants were visually more compact with more flowers than the WSF plants, which had few branches with less leaves and flowers (Figure 4.10). SPAD readings of leaves from WSF1 treated plants were about 34% lower than CRF plants (Figure 4.11; \( p \leq 0.0001 \)). As time progressed, plant quality across all treatments decreased, with WSF plants becoming more chlorotic than other treatments. Plants grown with 5-6M had higher SPAD readings than fertigated plants. CRF plants had higher tissue N concentration compared to fertigated plants (Table 4.1). Consumer ratings for CRF treated plants were about 42% higher than WSF plant rating (Table 4.2).

4.4. Discussion

During the greenhouse production phase of Experiment I, WSF1 and Control treated plants were taller than 5-6M, 8-9M and Blend treated plants probably because they had higher phosphorus and potassium levels in their tissues (Table 4.1). In our experiments, all plants had more than the optimum range (0.2 - 0.5% for most crops) of tissue phosphorus (Nelson, 1999). High amounts of phosphorus in plant tissue have been associated with plant stretching, and research has shown that impatiens grown with low phosphorus were more compact than those grown with high phosphorus (Borch et al.,
Differences in shoot dry weight between the 5-6M and the 8-9M treated plants grown in the greenhouse during Experiment I (Figure 4.3), could be attributed to more nutrient leaching from the 5-6M treatment earlier in the season when plants were smaller and had limited nutrient requirements (Craig et al., 2003). Several studies have demonstrated non-uniform nutrient loss from CRF (Cox, 1993; Hershey and Paul, 1982; Rathier and Frink, 1989) and the largest losses occur during the early stage of the production cycle (Haver and Schuch, 1996; Simonne and Hutchinson, 2005).

Shoot dry weight of plants during the greenhouse phase of Experiment I were 18% - 56% greater than in Experiment II perhaps due to differences in duration of production phase. Growth per day of plants from Experiment I and II was similar except for WSF. Plants in Experiment II were larger in size because they were grown for a longer period of time (17 days) than plants in Experiment I. Longer growing period provided plants with more photosynthetic activity leading to increase in growth and or assimilate accumulation (Drüge, 2000).

Plants grown with the 5-6M treatment in Experiment I performed well in the field as plants from the other treatments in spite of being the smallest (by up to 31% less dry weight) in the greenhouse phase (Figure 4.7). In general, CRF plants in Experiment II
produced greater shoot dry weights in the field than WSF plants possibly because of more nutrient availability. WSF plants may have exhausted the nutrients accumulated in the root zone during greenhouse production. It is quite possible, on the hand, that CRF continued to release nutrients in the field. Plants in Experiment I had greater shoot dry weight in the field than the plants in Experiment II probably because plants in Experiment II were smaller (greenhouse shoot dry weight) at the time of field transplant.

The initial reduction in plant quality during field production (0 - 17 days after field planting) could be attributed to plant acclimation in the field. When plants are moved from greenhouse to retail outlets or landscapes, they suffer stress due to the difference in environmental conditions from those in the production areas (Armitage, 1993). Since plants received no fertilizer during the field production, mature leaves were chlorotic because they lacked nitrogen for plant growth (Marschner, 2006; Warncke and Krauskopf, 1983).

Flower production of bedding plants can be affected by availability of nutrients for plant growth. Nell, et al. (1994) found that plants that received continuous fertilization in the landscape produced more flowers. In our experiment, CRF plants produced more flowers in Experiment II probably because CRF granules continued to release nutrients in the field. Flower number can be advantageous during consumer preference evaluations due to added aesthetic value to the plant. At the time of purchase, plants with more flowers are
more appealing, and consumers are more likely to purchase them.

At the end of the field experiment, all plants appeared to have some chlorosis, although the intensity varied between treatments. CRF plants were greener than WSF1 plants in Experiment II (Figure 4.11) most likely because of differences in tissue nitrogen content (Table 4.1). Nell et al., (1997, 1994) reported that of all production factors, mineral nutrition is the number one factor affecting postproduction longevity and quality of flowering potted plants. Insufficient fertilizer application produces small plants with many flowers. The SPAD readings indicated some differences in leaf greenness, which were not as clear as the pictures/visual appearance of the plants because SPAD readings were taken from recently fully expanded leaves. In a future work, SPAD readings should be taken from leaves at the top, middle and bottom of the plant.

4.5. Conclusion

Our results indicated that nutrients accumulated from WSF in the root zone during greenhouse production might not be sufficient for plant growth during the entire garden production phase. As shown in Experiment II, CRF use during production of bedding plants has the potential to enhance garden performance. Plants placed in the garden may grow without the need for customers to fertilize them immediately. If results of Experiment II can be validated in future works, retailers can market this as a value added product that will require less care in the landscape. The carry over effect of the CRF may
be sufficient for the first month of garden performance, but extended period of garden production will require addition of a fertilizer to grow green and vigorous plants throughout the summer. However, we do not know how plants will perform when they go from the greenhouse to a garden center environment before going to the garden. Future work can be carried out to investigate plant performance from greenhouse to a garden center and then to the field.

4.6. Literature Cited


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Table 4.1. Shoot tissue nutrient content of plants grown in the greenhouse and field during Experiments I and II. Impatiens plants were grown with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m⁻³ each of 5-6M and 8-9M) applied 6.8 kg·m⁻³. WSF plants were grown with a 150 mg·L⁻¹ N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1). Values are means of six replications. Soil Field I and Soil Field II are the nutrient contents of the field soil where plants in Experiment I and Experiment II were grown respectively.
Table 4.2. Consumer ratings of plants at the end of the field phase for Experiment I and II. Impatiens plants were grown with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m$^{-3}$ each of 5-6M and 8-9M) applied 6.8 kg·m$^{-3}$. WSF plants were grown with a 150 mg·L$^{-1}$N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1). Values are means of six replications from average of 38 or 35 evaluations (Experiments I and II, p=0.086 and p ≤ 0.0001 respectively).
Figure 4.1. Field experimental setup (a) cages were constructed (East-West orientation) with steel pipes and a shade cloth placed on top of them to provide shade (b). Six plants of ‘Xtreme Scarlet’ impatiens were planted at 0.31m apart. Impatiens plants were grown with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m^{-3} each of 5-6M and 8-9M) applied 6.8 kg·m^{-3}. WSF plants were grown with a 150 mg·L^{-1}N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1).
Figure 4.2. Plant height (cm) at the end of the greenhouse phase of Experiment I. Impatiens plants were grown with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m⁻³ each of 5-6M and 8-9M) applied 6.8 kg·m⁻³. WSF plants were grown with a 150 mg·L⁻¹N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1). Values are means of six replications. Error bars represent the standard error of the mean. Means with same letter are not significantly different (p ≤ 0.0001)
Figure 4.3. Shoot dry weight (g) at the end of greenhouse phase of Experiments I and II. Impatiens plants were grown with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m⁻³ each of 5-6M and 8-9M) applied 6.8 kg·m⁻³. WSF plants were grown with a 150 mg·L⁻¹ N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1). Values are means of six replications. Error bars represent the standard error of the mean. Means with same letter are not significantly different (p ≤ 0.0001 for Experiment I and p≤0.0053 for Experiment II).
Figure 4.4. Total flower number during the greenhouse phase of Experiment I and Experiment II. Impatiens plants were grown with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m$^{-3}$ each of 5-6M and 8-9M) applied 6.8 kg·m$^{-3}$. WSF plants were grown with a 150 mg·L$^{-1}$N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1). Values are means of six replications. Error bars represent the standard error of the mean. Means with same letter are not significantly different ($p \leq 0.0001$ for Experiment I and $p \leq 0.0001$ for Experiment II respectively.)
Figure 4.5. Average single flower dry weight (g) during greenhouse phase of Experiment I and Experiment II. Impatiens plants were grown with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m⁻³ each of 5-6M and 8-9M) applied 6.8 kg·m⁻³. WSF plants were grown with a 150 mg·L⁻¹ N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1). Values are means of six replications. Error bars represent the standard error of the mean. Means with same letter are not significantly different (p ≤0.0121 for Experiment I and p ≤ 0.0001 for Experiment II respectively)
Figure 4.6. Variation of leaf greenness rating of ‘Xtreme Scarlet’ impatiens during field phase of Experiment I. Plants were grown with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m⁻³ each of 5-6M and 8-9M) applied 6.8 kg·m⁻³. WSF plants were grown with a 150 mg·L⁻¹N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1). Plants were rated on scale of 1-5 after open flowers were harvested. Values are means of six replications. Error bars represent the least significant difference.
Figure 4.7. Shoot dry weight (g) during field phase of Experiments I and II. Impatiens plants were grown with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m\(^{-3}\) each of 5-6M and 8-9M) applied 6.8 kg·m\(^{-3}\). WSF plants were grown with a 150 mg·L\(^{-1}\)N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1). Values are means of six replications. Error bars represent the standard error of the mean. Means with same letter are not significantly different (p = 0.254 for Experiment I and p<0.0001 for Experiment II).
Figure 4.8. Average single flower dry weight (g) of one single flower during field phase of Experiment I and Experiment II. Impatiens plants were grown with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m⁻³ each of 5-6M and 8-9M) applied 6.8 kg·m⁻³. WSF plants were grown with a 150 mg·L⁻¹N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1). Values are means of six replications. Error bars represent the standard error of the mean. Means with same letter are not significantly different (p ≤0.0121 for Experiment I and p ≤ 0.0001 for Experiment II respectively).
Figure 4.9. Total flower number during field phase of Experiment I and Experiment II. Impatiens plants were grown with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m⁻³ each of 5-6M and 8-9M) applied 6.8 kg·m⁻³. WSF plants were grown with a 150 mg·L⁻¹N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1). Values are means of six replications. Error bars represent the standard error of the mean. Means with same letter are not significantly different (p ≤ 0.0001).
Impatiens plants were grown in the greenhouse with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m⁻³ each of 5-6M and 8-9M) applied 6.8 kg·m⁻³. WSF plants were grown with a 150 mg·L⁻¹N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1). No fertilizer was applied to the plants during the field phase. (a) Plants grown with CRF in the field, compact, bigger in size, vigorous and less chlorotic (b) Plants grown with WSF in the field, smaller, less compact, more chlorotic and less vigorous.

Figure 4.10. ‘Xtreme Scarlet’ impatiens plant at the end of the field experiment.
Figure 4.11. SPAD readings. Impatiens plants were grown with Osmocote 16-9-12 of 5-6M, 8-9M longevity and a Blend (a combination of 3.4 kg·m⁻³ each of 5-6M and 8-9M) applied 6.8 kg·m⁻³. WSF plants were grown with a 150 mg·L⁻¹ N solution of 20-10-20 Peter’s Professional WSF applied with a hose (Control), or at the same volume of water as the one applied to CRF treatments (WSF1). Values are means of six replications (each replication is an average of four measurements per plant). Error bar is the standard error of the mean (SE). Means with same letter are not significantly different (p ≤ 0.0001).
Chapter 5 : GENERAL CONCLUSIONS

Using controlled-release fertilizer (CRF) for the production of impatiens resulted in plants of similar quality as Peter’s Professional water-soluble fertilizer (WSF). Bottom placement of CRF resulted in lower nutrient use efficiency and produced smaller plants. We have show in this short-term study, that if WSF is delivered through a system that minimizes water losses, less nutrients will be lost than when a 5-6M longevity CRF is used. However, if plants are irrigated using a hose, about 33% of irrigation water or nutrient will be lost outside the container. The amount of water/nutrient lost increases as distance between containers increase due to increase in plant size. CRF are more efficient than WSF when a hose irrigation system is sued.

CRF rates of 3.4 - 6.8 Kg·m⁻³ produced good quality plants and their aesthetic value was similar although there were differences in dry weight, leaf and flower canopy cover. Lower rates of CRF produced plants of less quality than WSF. CRF of different longevities can be used to grow impatiens of acceptable market quality. However, CRF of different longevities cannot be applied at the same rate. When selecting CRF for production, it is advisable to use release rates depending on the time of production.
From the results of our postproduction studies, growing plants with CRF can benefit the consumer due to the carry over effect. However, evidence of chlorosis at the end of our experiment suggests that the carry over effect of the CRF may be sufficient for only the first four weeks. Therefore, CRF use does not totally eliminate the need for fertilization in the landscape by the gardener.

When choosing CRF for production of short-term plants like annuals in the greenhouse, careful selection of CRF formulation will benefit the grower. From our results, the 8-9M CRF formulation resulted in lower N, P and Fe losses, increased shoot dry weight, high canopy and flower cover of plants. It also increased the aesthetic value of plants, which, is a major decision-making factor influencing consumer preference.
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APPENDIX: CRF USED FOR EXPERIMENT IN THIS THESIS

The CRF used in this research were Osmocote Plus products (The Scotts Company, Marysville, Ohio) of varying longevities. Osmocote Plus 16-9-12 (16N-4P-10K) of 5-6M and 8-9M longevity formulations were used in experiments that examined the effects of CRF placement on the growth of impatiens and nutrient leaching and the effects of CRF on the garden performance of impatiens. On other hand, Osmocote Plus of 15-9-12 of 3-4, 5-6, 8-9 and 12-14 month longevities were also used in an experiment to investigate the effects of CRF longevity on the growth and quality of impatiens plants. The CRF formulations contained different amounts of coated slow-release of N, P and Fe (Table 1). We were particularly interested in N, P and Fe content in the leachates because these nutrients are potential pollutants. The recommended medium rates by the manufacturer for incorporation of the CRF formulations ranged between 3.6 - 12 Kg·m⁻³ (Figure 1) and that for topdressing of plants grown in plastic container of 12.7 cm diameter by 9cm height (5” containers) is 6.8 - 15 Kg·m⁻³.
Figure A.1. Product sheet Osmocote Plus 16-9-12 of five to six month longevity used.
**Figure A.2.** Product sheet Osmocote Plus 16-9-12 of eight to nine month longevity used.
Figure A.3. Product sheet Osmocote Plus 15-9-12 of three to four month longevity used.
Figure A.4. Product sheet Osmocote Plus 15-9-12 of five to six month longevity used.
Figure A.5. Product sheet Osmocote Plus 15-9-12 of eight to nine month longevity used.
Figure A.6. Product sheet Osmocote Plus 15-9-12 of 12-14 month longevity used.
Figure A.7. Product sheet Peters Professional Water Soluble Fertilizer 20-1-20 formulation used.