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Use efficiency of controlled release fertilizer on the growth of croton and petunia and N loss by leaching

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Thesis presented to obtain the degree of Doctor in Science. Area: Crop Science

Piracicaba
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DEDICATION

I am dedicating this thesis to my parents, Eunice Antonio dos Santos de Oliveira and Manoel Antonio Fernandes de Oliveira, and my husband, Renato Salla Braghin, who have always supported my decisions, and for teaching me to pursue all of my dreams with integrity and purpose.

Thank you very much!

Chega o momento de alcançarmos a vitória maior e é aí que descobrimos o quanto ainda somos pequenos e temos que aprender, pois cada conquista nossa abre as portas para a construção de um novo sonho...

(Autor desconhecido)

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SUMMARY

RESUMO

Eficiência do uso de fertilizantes de liberação controlada no crescimento de cróton e petúnia e perda de N pela lixiviação

O mercado de flores e plantas ornamentais tais como cróton (*Codiaeum variegatum*) e petúnia (*Petunia*×*hybrida* Vilm.-Andr) apresenta-se em constante desenvolvimento tecnológico, caracterizando-se como um dos mais promissores segmentos da horticultura. A adubação, visando o aumento da eficiência do fertilizante e redução de perdas, são temas de estudos em todo o mundo. Assim, foram realizados dois experimentos para avaliar o uso de fertilizantes de liberação controlada (FLC) no crescimento de duas espécies de plantas ornamentais e a perda de nitrogênio por lixiviação. O primeiro experimento teve como objetivo avaliar fontes e doses de FLC e solução nutritiva no crescimento de cróton e a concentração de nitrogênio (N) na solução drenada dos vasos. Os resultados revelaram que a solução nutritiva e as menores concentrações de FLC proporcionaram o maior crescimento das plantas, e as taxas de N perdidas por lixiviação foram superiores para o tratamento com solução. O segundo experimento objetivou comparar estratégias de adubação que proporcionem nutrição adequada durante a fase de produção e do consumidor com menor custo, as quais incluíam FLC e solução nutritiva. Simultaneamente, foram realizados dois experimentos para avaliar a liberação de nitrogênio pelos fertilizantes, sem as plantas, nas condições de cultivo das plantas (estufa) e em câmaras de crescimento sob três temperaturas de incubação. Os resultados mostraram que durante a fase de produção todos os tratamentos resultaram em plantas nos padrões comerciais, e no período que simulou a fase do consumidor as plantas que receberam apenas solução nutritiva durante a fase de produção apresentaram deficiência nutricional, enquanto com os FLC as plantas cresceram vigorosamente, principalmente para os tratamentos com as maiores doses. Os fertilizantes avaliados apresentaram diferença quanto à temperatura na liberação dos nutrientes, sendo maior a taxa de liberação quanto maior a temperatura. De acordo com os resultados o FLC proporcionou o crescimento das plantas na mesma proporção que a solução nutritiva, com uma redução na concentração de N por lixiviação e acréscimo inferior a U$0.065 no custo por planta quando utilizado FLC durante a produção.

Palavras-chave: *Codiaeum variegatum*; *Petunia*×*hybrida* Vilm.-Andr; Nitrogênio; Lixiviação

ABSTRACT

Use efficiency of controlled release fertilizers on the growth of croton and petunia and N loss by leaching

The market of flowers and ornamentals such as croton (*Codiaeum variegatum*) and petunia (*Petunia*×*hybrida* Vilm.-Andr) have been created new technologies to constantly development, as one of the most promising segments of horticulture. Fertilization providing adequate nutrition and less leaching to the environment is the objective of numerous studies around the world. Therefore, two studies were conducted to evaluate the use of controlled release fertilizer (CRF) on the growth of two ornamental species, and N loss by leaching. The first experiment aim to evaluate sources and rates of CRF and water soluble fertilizer (WSF) on croton growth and nitrogen concentration on drained solution. Results showed that treatments with WSF and low rates of CRF provided higher plants growth, and the amount of N leached was higher for WSF treatments. The second experiment objective to compare plant performance and cost for strategies that potentially provide adequate nutrition during both the production and consumer phases for container-grown Petunia plants. In addition, two experiments were conducted to evaluate nutrient release in sand containers inside of the greenhouse and under controlled temperature conditions without plants. Results showed that during production phase all fertilizer treatments produced high quality plants, and during consumer phase, plants grown with WSF only during the production phase were nutrient-deficient, while plants receiving CRFs were still growing vigorously, especially in a high rate. The release rates of all CRF products were temperature-dependent. In conclusion CRF provided plant growth at the same rate that WSF, with less N leaching and extra cost less than U$0.065 per plant with CRF during production.

Keywords: *Codiaeum variegatum*; *Petunia*×*hybrida* Vilm.-Andr; Nitrogen; Leaching

1 INTRODUCTION

1.1 Controlled release fertilizer

The fertilizer industry faces a continuous challenge to improve its products increasing the efficiency of their use, particularly of nitrogenous fertilizers, and to minimize any possible adverse environmental impact. This is done either through improvement of fertilizers already in use, or through development of new specific fertilizer types (MAENE, 1995; TRENKEL et al., 1988). One possible way to improve management of nutrient application is by using controlled-release (CRF) or slow-release fertilizers (SRF), matching nutrient supply with plant demand and maintaining nutrient availability (SHAVIV, 2000).

There has been limited use of slow- and controlled-release fertilizers on many agricultural crops because the relatively higher prices compared to conventional mineral fertilizers. Only since the end of the 1990s have they been used for a wider range of commodity or conventional agricultural crops. This change was made possible through large-scale production and excellent promotion and advisory work (TRENKEL, 2010).

These fertilizers still represent only about 0.15% of the market (TRENKEL, 1997), though is projected at a compound annual growth rate of 6.5% until 2019. In 2013, the estimated use market was valued at $2,061.2 million, and grass and ornaments was the leading application segment in 2014 followed by cereals & oilseeds and fruits & vegetables (MARKETS AND MARKETS, 2014).

The worldwide experiences in agricultural development have proved that rational fertilization is the most efficient and important measure for increasing crop production (XIANG et al., 2008). Controlled-release and ‘stabilized’ fertilizers meet, to a significant extent, requirements for an ideal fertilizer (SHOJI and GANDEZA, 1992), which after granulation are given a protective, water-insoluble coating to control water penetration and thus dissolution rate, nutrient release and duration of release (TRENKEL, 2010). Thus, nutrient release is efficiently controlled or delayed by improving the fertilizer itself, which matches the release time and intensity with the demands of plants for nutrients, providing enhanced nutrient use efficiency (AZEEM et al., 2014).

The release of nutrients depends on the formulation of the coating materials, as polymeric material used by each manufacturer that depends on its chemical and physical properties, further coating thickness and CRF prill shape and diameter (CARSON; OZORES-HAMPTON, 2013). According to Trenkel (2010), there are three main groups of coated/encapsulated fertilizers, based on the following coating materials: sulphur, sulphur plus polymers, and polymeric/polyolefin materials.

There are variables such as humidity and temperature that influence the release of nutrients into the medium. The resin surrounding membrane is dissolved, gradually releasing the nutrients present in the fertilizer and continues according to the temperature and / or with the removal of nutrients from the solution by plant (SGARBI et al., 1999). Therefore, understanding these mechanisms in terms of nutrient availability to the target crop plant is critical to the choosing the proper material and is valid for economic considerations (i.e., maximizing the utilization of added fertilizer) and even more for minimizing fertilizer leaching (HANAFI, 2000).

Three methods categories are used to estimate N release: laboratory; growth chamber or greenhouse; and field methods (CARSON; OZORES-HAMPTON, 2012). Growth chamber and greenhouse methods are used to evaluate or compare how CRFs will act in a particular controlled environment (BROSCHAT; MOORE, 2007; HUETT; GOGEL, 2000). Lastly, field methods are used to measure N release in commercial vegetable field conditions (SIMONNE; HUTCHINSON, 2005).

However, CRF used alone does not provide a complete solution to the problem of nutrient leaching, but it can help address a number of grower needs to apply the right fertilizer, at the right time, rate, and location. Appropriate application methods and CRF types must be calibrate to match crop production (BROSCHAT; KLOCK-MOORE, 2001). Therefore, these studies were undertaken in order to (1) determine appropriate application rates, timing and methods of fertilization among two species of ornamental plants (2) determine nutrient uptake and indices of N-use (3) leaching losses of nitrogen under different types of CRF and WSF (4) an economic analysis of CRFs versus water soluble fertilizer (WSF) to help guide grower fertilizer decisions (Chapter 3).

1.2 *Codiaeum variegatum*

Ornamental plant production represents an important agricultural industry in Brazil with a net wholesale value of R$5.7 billion in 2014 (INSTITUTO BRASILEIRO DE FLORICULTURA - IBRAFLOR, 2015), whereas containerized flowers and plants represent 20% of total market value (JUNQUEIRA; PEETZ, 2013). Among ornamental species, few shrubs are available with as great a variety of beautiful leaf colors and shape as croton, an example of the most common plants that have not been explored.

Native to South Sea Island and the Malaya Peninsula, croton (*Codiaeum variegatum*) is a group of beautifully variegated leafy perennial, tropical woody shrubs or trees with glabrous branches and with multicolored spots to irregular color patches or solid-colored leaves of red, orange, yellow, and green, belonging to the family Euphorbiaceae (GILMAN, 1999; MAZHER et al., 2011). Plants are generally available in many areas within its hardiness range, as one indoor and outdoor plant.

Potted ornamental plants are grown containerized mostly in substrates. Thus, excessive mineral nutrients are supplied to ensure plant growth is not restricted. The negative impacts (i.e., leaching and runoff) of this strategy are more pronounced in containerized crop production where nutrient uptake efficiencies are low because of the relatively inert substrates used as growing medium (OWEN JUNIOR et al, 2008). This management strategy needs to be reconsidered as a result of economic and environmental concerns surrounding current production practices.

Therefore, is required to know nutritional demands of the crop to ensure highest production. Some studies were carried out aiming to evaluate nutrient content on the leaves of croton (POOLE and CONOVER, 1976; CONOVER and POOLE, 1984). Chase e Poole (1989) suggested optimum levels for nitrogen (3,5-5,5%), phosphorus (0,45-0,55%), potassium (3,2-3,7%), sulfur (0,2-0,3%), magnesium (0,4-0,6%), and calcium (1,0-1,5%). Based on tissue nutrient levels, is essential that a fertilizer material provides sufficient nutrients for the initial start followed by a uniform supply that synchronizes well with the nutrient requirement of the crop.

Controlled-release fertilizers, sometimes considered a useful adjunct to a liquid fertilization program for containerized nursery crops, may also be used as the sole source of nutrients. Exclusive use of CRF can greatly reduce the quantities of these nutrients that are leached in runoff water (RATHIER; FRINK, 1989; SHARMA, 1979).

Several studies have reported satisfactory growth of various woody ornamentals in which N, K, and P requirements were met entirely by a preplant application of controlled release fertilizer (POOLE; CONOVER, 1989; SANDROCK et al., 2005; KARAM et al., 2009). Based on a study carried out by El-Aziz et al. (2007), croton plants had higher growth at the lowest level of fertilizer, suggesting the use of lower rates of CRFs.

Due to the wide variety of fertilizers available on the market, optimum formulations, levels, and application strategies differ greatly, affected by species, growing media, and environmental conditions. Thus the purpose of this study was to investigate sources and rates of CRFs on croton production compared with water soluble fertilizer by using quantitative analyses, N uptake and indices of N-use by plants (Chapter 2).

1.3 *Petunia × hybrida* Vilm.-Andr

Petunia (*Petunia hybrida Vilm*.), belonging to the family Solanaceae, is an annual herbaceous with a long flowering period and a wide range of shapes and sizes. Its center of origin and genetic diversity is in South America, and most of commercial materials are hybrids (GARCÍA-ALBARADO et al., 2010). It is popular as bedding ornamental plant for summer home gardens and commercial landscaping projects (ARANCON et al., 2008).

'Supertunia' petunia cultivars were the first in a wave of new vegetatively propagated introductions in the early 1990s when breeding programs began redeveloping multiflora (large flower number on large branched plants) petunia types from wild species and older cultivars (GRIESBACH, 2006). New petunia cultivars with increased genetic variability in terms of stress tolerance, plant vigor, trailing growth, flower size and number, and postproduction durability, could potentially result in variability in fertilizer response.

In intensive horticulture, the management of mineral nutrition is a key factor in determining the ornamental value of the plants. When the plant is growing vegetatively, consideration needs to be given to the form of nutrient applied, the application rate and time of application in order to prevent nutrient deficiencies from limiting growth and quality (ZHANG et al., 2012).

The best fertilization in ornamental plant production depends on the method, the irrigation frequency and local environmental (KANG; IERSEL, 2001). Typical N fertilization recommendations for stock herbaceous ornamental crops are between 150 and 250 mg N L^{-1} applied at each irrigation (DOLE; GIBSON, 2006). Petunia must be grown with a relatively high supply of nutrients to produce marketable plants. During their growing-season, the plants may be irrigated with as much as 150-200 ppm of N. Many growers supplement their liquid feed program with a controlled release fertilizer (CRF) such as Osmocote, and a topdress of CRF applied the week before shipping may improve performance for the retailer and consumer. (HAMRICK, 2003).

Nutrients can be supplied through a combination of preplant dry fertilizers in the substrate, supplemental application of water soluble fertilizer, and/or incorporation of controlled release fertilizers (SANTOS et al., 2011). However, fertilization strategies for Petunia vary widely between commercial growers, resulting in a range of resource efficiencies, suggesting a need to better understand nutrient uptake processes and fertilizer response (SANTOS et al., 2008).

Several studies have been conducted in order to assess petunia nutritional requirement and water soluble fertilizer used as a source of nutrients (ZHANG et al., 2012; SMITH et al., 2004; SANTOS et al., 2011; ALEM et al., 2015), although just some of them tested controlled-release fertilizers (KLOCK-MOORE; BROSCHAT, 2001; CURREY; LOPEZ, 2014).

Recently, there has been interest in the potential of CRF to maintain some residual fertilizer for the consumers, as an opportunity to add value and profitability with a slightly higher sales price by providing the product with a fertilizer load, and thus increasing the post-production of flowers. In this study, fertilizer strategies were compared in Supertunia cultivar to compare plant performance and nutrient release that potentially provide adequate nutrition during both the production and consumer phases for container-grown floricultural plants (Chapter 3).

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2 EFFECTS OF CONTROLLED RELEASE FERTILIZERS ON CROTON GROWTH AND NITROGEN LEACHING

Abstract

The fertilizer management is an essential step in the production process, because it allow the plant to use as much of its productive capacity. Maximum improvement of nutrients use by plants and less loss to the environment were tested aiming to increase productivity with reduced environmental impacts. This study aimed to evaluate different sources and doses of controlled release fertilizer (CRF) on growth, nutrient uptake and efficiency of nutrients use by croton plants. The study was carried out during September, 2013 and February, 2014 in a greenhouse in Piracicaba, SP, Brazil. The experimental design used was the randomized block, with six treatments (two sources of CRF - Osmocote and Basacote, with two doses (1.5 and 3.0 $g \cdot L^{-1}$ of substrate), water soluble fertilizer (WSF) and control) and three replications. Croton plants were grown in plastic pots of 4L, containing substrate prepared with pine bark and doses of fertilizer previously added to the substrate at planting. It was used drip irrigation with clear water and nutrient solution recommended for the culture applied for WSF treatment. Plant growth (number of leaves, leaf area, stem height, root volume, shoot and root dry weight) and total nutrient content in tissues plants were evaluated every 30 days. Electrical conductivity, pH, nitrate, ammonium and total nitrogen concentration were measured in the leached solution. Based on the results CRFs at a low rate provided similar results for most of variables analyzed and plant visual compared to WSF. CRF maintained pH and EC within the recommended range for croton growth and lower nitrogen concentration in the leached solution compared with WSF.

Keywords: Controlled release fertilizer; Nitrogen; Nutrient release; Ornamentals

2.1 Introduction

Croton (*Codiaeum variegatum* L.) is one of the most popular plants grown indoor which belongs to the family *Euphorbiaceae* (GOVAERTS et al., 2000). It is a tropical woody shrub to 4 m high, with simply leaves alternate, blade variously shaped, usually 8-25 cm long, divided to the midrib, or twisted, variously motted with red, purple, and yellow (WHISTLER, 2000). Croton plants have attained a prominent place among foliage plants due to its adaptation to indoor conditions, leaf shape, color range and specimen planting in the shaded landscape (WILSON et al., 2002). Grown as a potted plant, foliage beauty fully depends of potting media and adequate nutrition. Therefore, quantities of soluble fertilizers and/or controlled release fertilizer (CRF) need to be applied in the substrate to planting media.

Fertilizers are added as a source of plant nutrients in the medium. There is usually an improvement in plant growth and quality when appropriate fertilizers are added, increasing fertilizer use efficiency and preventing nutrient losses to the environment. One possible way to improve nutrient and particularly nitrogen use efficiency while reducing the environmental hazards is by using controlled-release fertilizers. Potential advantages of controlling nutrient supply depend mainly on two factors: matching nutrient supply with plant demand and maintaining nutrient availability (SHAVIV, 2001).

CRFs show the follow advantages: reduction of stress and specific toxicity, particularly to seedlings, caused through high ionic concentrations, application of substantially larger fertilizer dressings as compared to conventional soluble fertilizers, and reducing such losses by leaching, nitrification, immobilization and volatilization. Moreover, CRFs can meet the crop nutrient demand for the entire season through a single application, reducing the demand for short-season manual labor (SHAVIV, 2001; TRENKEL, 2010).

Most CRFs used for container ornamentals are derived from polymer-coated fertilizers, in which water soluble fertilizer granules are encapsulated by a polymer. Release rates of nutrients from various coated fertilizers are positively correlated with temperature and moisture status of the substrate (NELSON, 2012; SONNEVELD; VOOGT, 2009), and response to environmental conditions depends on the formulation of the coating materials, as polymeric material specific by each manufacturer (CARSON; OZORES-HAMPTON, 2013).

CRFs are applied commonly before planting in container plant production because of their long-term nutrient release. The use of polymer-coated CRFs in ornamental container markets is most sensitive to the quality of the CRF and to its release properties due to plants growing in confined volumes and under heavy leaching conditions (SHAVIV, 2001; CONOVER; POOLE, 1992; HUETT; MORRIS, 1999). Through proper use of CRFs, both agronomic and environmental benefits may be attained with CRF applications as compared to conventional fertilizers. The first one can optimize the level of nutrient supply, release rate, and leaching fraction in order to maintain high yield and reduce leaching losses (CONOVER; POOLE, 1992).

An effective assessment of the environmental impact of CRFs must be rely on improved knowledge regarding nutrient release characteristics and mechanisms, effects of environmental factors on the release, and plant nutrient demand under different agricultural conditions (SHAVIV, 2001). Many types of CRFs and longevities have been developed to meet the variable nutritional requirements of different plants

(HULME; BUCHHEIT, 2007), which depends on the crop and its production time, total nutrient requirement, specific periods of peak demand (ANDIRU et al., 2013).

The controlled release of nutrients depends on temperature and moisture of soil with the release rate increasing at higher temperatures with greater moisture content. Because N is generally assumed to be the most important nutrient in coated fertilizers, longevities of nutrient coated fertilizers are based primarily on the release rate of N from these materials (BROSCHAT; MOORE, 2007). The type of coating is responsible for the mechanism of release elements from encapsulated fertilizers, which release mechanism is basically a nutrient transfer from the fertilizer–polymer interface to the polymer–soil interface, by diffusion/swelling, degradation of the polymer coating, and fracture or dissolution (SHAVIV, 2001).

Due to physical and chemical properties of substrates and nutrient requirements, it is necessary to calibrate fertilizer sources and rates for different species. Several studies concerning the effect of NPK fertilization to the croton plant have been conducted (KARAM et al., 2009; MOHAMMAD et al., 2004; CONOVER; POOLE, 1983). However, most of these studies were relatively short term. In this study, nutrient release patterns of two types of CRFs were compared to water-soluble fertilizer on croton production and nitrogen leaching.

2.2 Materials and Methods

The experiment was conducted at the University of Sao Paulo, Crop Science Department, in Piracicaba, Sao Paulo State, Brazil, from Sept. 2013 to Feb. 2014. The greenhouse has 192 m^2 of ground area, with screen on the walls, diffusive plastic film cover and thermo-reflective shading screen disposed internally. Greenhouse was controlled by an environmental control system with sensors connected to a datalogger (Campbell CR10), which recorded air temperature (^oC) and relative humidity (%) every hour (Figure 1).

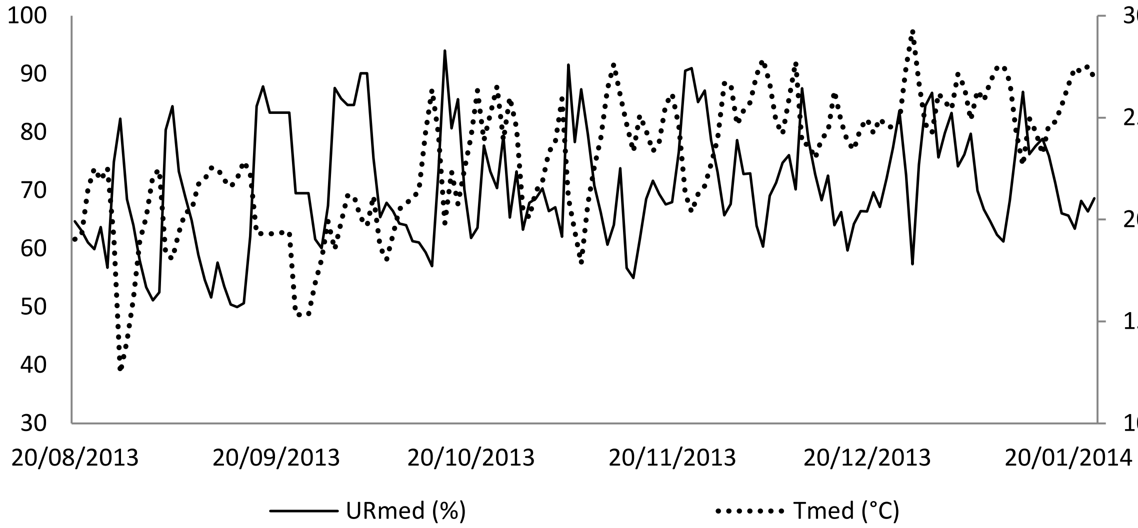

Figure 1 - Daily means of air temperature (^oC) and relative humidity (%) in the greenhouse according to environmental control system data. Lines represent data obtained by averaging environmental measurements each hour

Rooted cuttings of croton 'Petra' from Van Noije Ornamentals were transplanted into 4L containers filled with pine bark (Basaplant Ornamentals, SP, Brazil) that contained a small pre-plant charge, which chemical characteristics are: pH 5.8, nitrogen total 0.55%, phosphorus 0.27%, potassium 0.62%, calcium 0.80%, 0.14% magnesium, 0.14% sulfur. The experiment was a randomized block design with three replicates and five treatments and control. The treatments included two sources of controlled release fertilizer at rates of 1.5 and 3.0 g per liter of substrate, compared to water soluble fertilizer (WSF). Each plot had 14 plants. Fertilizers used were Osmocote Plus 15-09-12 and Basacote 15-08-12, both products with longevity between 5 and 6 months. The following soluble fertilizers were used to prepare 1000 L of solution: calcium nitrate (375 g), potassium nitrate (342.5 g), mono-ammonium phosphate (126.92 g), ammonium nitrate (105.12 g) and magnesium sulfate (61.3 g). The CRFs were incorporated into the substrate with a measured dose per container before planting.

Plants were drip irrigated, using moisture-sensor (Irrigation controler-MRI) based control with starting voltage limit irrigation of 4 kPa. For treatment with WSF, plants received just nutrient solution. Drained solution samples were collected to measure pH, electrical conductivity (EC), nitrate and ammonium concentrations each 10 days, for two randomly selected replicate pots per treatment on each block. The amount of 300 ml of clear water was applied per container to get between 100 and 200 ml of solution that were filtrated through filter paper n°42. Aliquots of 50 ml were kept in tubes with sulfuric acid (1%, v/v) at -10ºC for no more than 60 days until analysis.

The concentrations of NO_3-N and NH_4-N were determined using Flow Injection Analysis System (FIA) (RUZICKA; HANSEN, 1981) by the Center for Nuclear Energy in Agriculture, University of Sao Paulo. Ammonium was analyzed by condutivimetry with sodium hydroxide (SOLÓRZANO, 1969) and nitrate by colorimetry after reaction with sulfanilamide and N-naftil (GINÉ-ROSIAS, 1979).

Every 30 days, two plants per plot were destructively sampled to measure number of leaves, stem height, leaf area (Leaf area meter LI-3100), root volume (BOSA et al., 2003), shoot and root dry weight and tissue nutrient content. Total nutrient content in oven-dried ground plant tissue of croton was analyzed according to Malavolta et al. (1997) methodology. Nutrient uptake was calculated from plant tissue, multiplying the concentration of nutrients by dry weight of shoots, roots and total plant. Plants were harvested 150 DAT, according to the marketing standards set by Veiling system, Holambra, Sao Paulo State.

At the end of the experiment (five months after transplanting), five plants per plot from each treatment was graded visually based on a scale of 1-4, where 1= plants with prominent green color and opaque leaves; 2= plants with multicolor and some dark purple leaves, and low bright; 3 = plants with multicolor leaves, and low bright; and 4 = plants with multicolor leaves and prominent orange shades, and bright.

Data were subject to analysis of variance using Proc GLM in SAS (Version 9.3; SAS Institute, Cary, NC). Means were analyzed using Tukey's honestly significant difference test at α=0.05. Leachate solution measurements (pH, EC, nitrate, ammonium, and nitrogen concentration) were analyzed over the time using ANOVA.

2.3 Results and Discussion

Growth during the production phase: There was interaction between fertilizers and growth periods to the number of leaves (p<0.0001), leaf area (p<0.0001), stem height (p=0.0078), root volume (p=0.048), and shoot dry weight (p=0.0034), with the exception of root dry weight, which was affected only by growth period (Table 1). During growth period croton plants showed statistical difference between treatments after 90 days of transplant. Before that, variables increased just over time. At the end of experiment, significant differences were found among treatments on the vegetative growth (Figure 2).

Table 1 - Mean values of number of leaves, leaf area, stem height, root volume, shoot and root dry weight of croton plants grown in containers affected by different rates and types of fertilizers

Main Factors	Number of leaves	Leaf area cm^2	Stem height cm	Root volume cm^3	Shoot dry weight g	Root dry weight g
Fertilizers (F)						
Control	12.26	584.21	12.31	29.78	5.99	2.71
WSF	16.83	1014.57	15.35	38.71	8.52	3.10
OSM 1.5g	15.23	832.40	12.86	32.07	6.83	2.85
OSM 3.0g	14.97	854.71	12.78	29.31	6.91	2.51
BAS 1.5g	15.03	774.80	13.15	32.50	6.25	2.91
BAS 3.0g	14.03	712.41	11.30	24.83	5.57	2.04
Growth Period (P)						
30	8.25	401.84	8.75	16.97	3.28	1.55
60	11.83	571.30	10.34	29.98	4.50	1.93
90	15.03	770.44	12.51	30.22	6.15	2.63
120	17.03	876.34	14.61	33.78	7.26	3.15
150	21.50	1357.66	18.58	45.05	11.30	4.18
Interaction effects						
F x P [a]	*	**	**	*	*	ns
CV (%)	16.82	22.65	15.37	23.46	19.53	24.92
LSD	2.38	164.68	1.73	5.82	1.01	0.53

[a] ns, *, ** No significant or significant at P≥ 0.05, and 0.01, respectively.

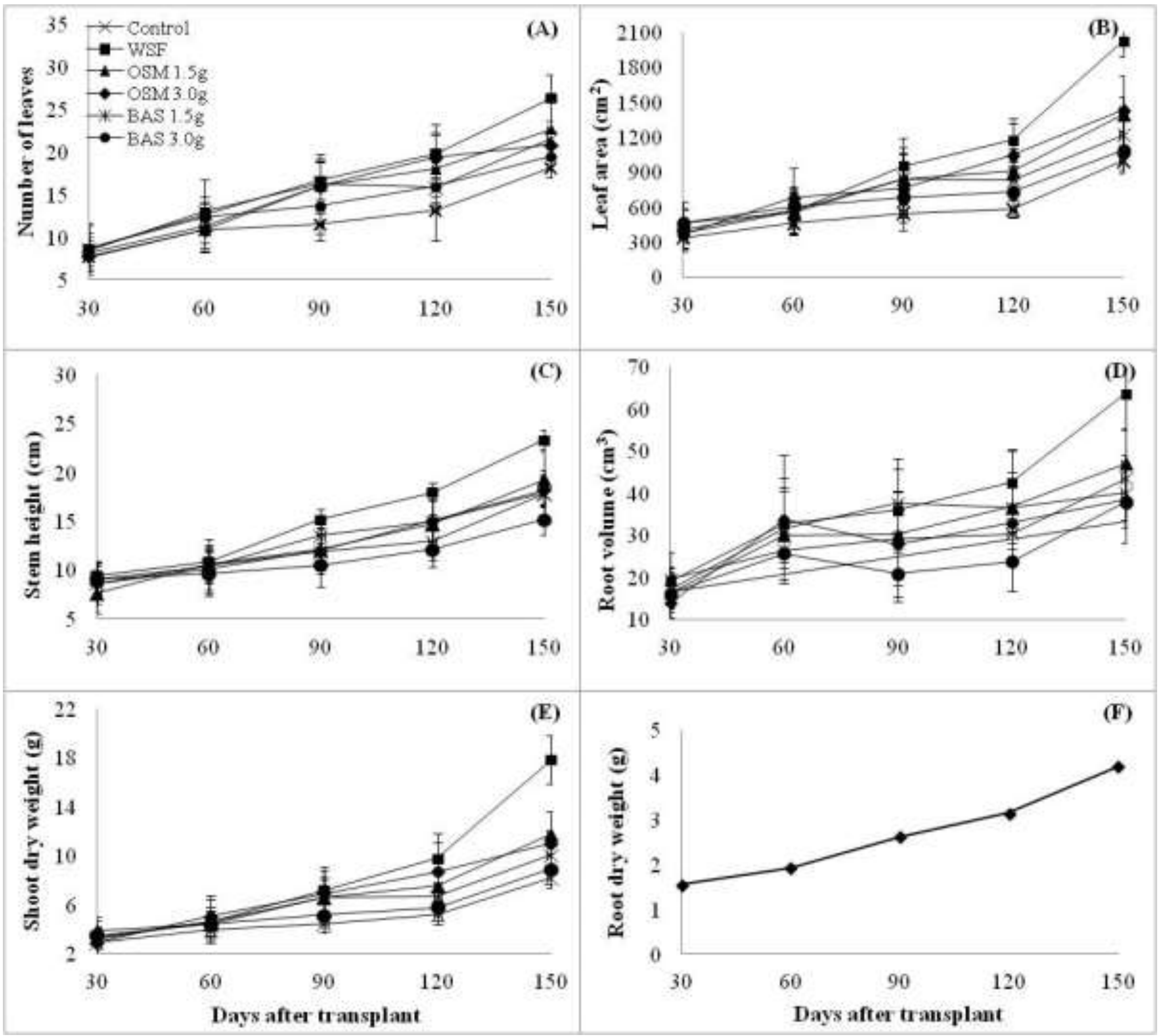

Figure 2 - Effects of different fertilizer treatments on the number of leaves (a), leaf area (b), stem height (c), root volume (d), shoot (e) and root dry weight (f) due to growing period subjected to different fertilizer treatments

The highest values for number of leaves and leaf area occurred with WSF and low rate of OSM compared to the other treatments and control. It was observed that leaf size was 18.7% and 73% higher with WSF than Osmocote and control, respectively. Stem height and shoot dry weight were higher for plants receiving WSF, OSM, and low rate of BAS, compared with high rate of BAS and control. The highest root volume occurred for treatment with WSF, which resulted in larger roots compared to other treatments. Root dry weight was statistically different just over time, whereas weight increased 4.18 g by the end of growth period (Table 1). In comparison to soluble fertilizer, the CRFs showed similar results on the croton growth even at rates up to 3 g L^{-1}. It implies advantages for CRFs placed in the substrate compared to WSF because CRFs reduced the impact of nitrogen leaching. One possible explanation for the growth response observed in this study may be related to the source of N applied and fertilization management. The nutrients from WSF are readily available and applied with high frequency to the ornamental plants produced in pots. For CRFs, the nutrient releases depend on the fertilizer characteristics, rate of application and environment conditions as temperature and soil humidity (SGARBI et al., 1999; SHAVIV, 2007; SONMEVELD; VOOGT, 2009; NELSON, 2012).

According to plant visual grades, the best treatments were WSF (note 4) and Basacote (note 4) fertilizer at low rate (1.5 g/pot), where plants showed multicolor leaves with prominent orange shades and bright leaves (Figure 3). Plants treated with higher level of Basacote (note 3) or Osmocote (note 2) had multicolor and some dark purple leaves, but low bright. Similar results were found for Raese et al. (2007), which have shown that increasing N rates resulted in darker green color of leaves. Plants without fertilization showed opaque and prominent green color leaves (note 1), and did not have uniform shape. In commercial foliage plant production, the ratings of 2 and 3 are generally considered to be of good quality by consumers for croton with leaf variegation.

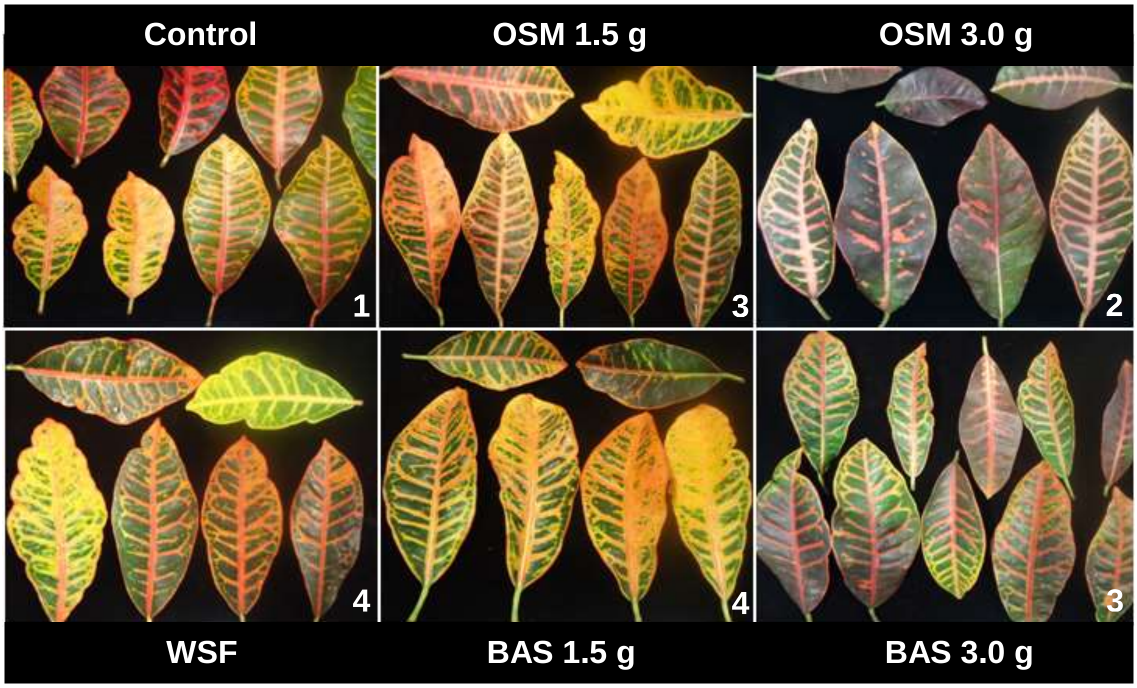

Figure 3 - Effects of different fertilizer treatments on color leaves at the end of growing period subjected to different fertilizer treatments. White number of each photo represent graded visually scale notes.

Nutrient levels: The treatments with high rates of CRFs and WSF provided highest N concentrations compared to low rates and control (Table 2). The shoot N concentrations increased 17 and 28% for OSM and BAS, respectively, when increasing the CRF fertilization from 1.5g$\cdot$L^{-1} to 3.0g$\cdot$L^{-1}. As well as the shoots, the root N concentrations increased 22.4% for WSF, 24% for OSM, and 26% for BAS when fertilized with high rate compared with low rates and without fertilizer (control). Nutrient concentration in leaf tissue of croton plants did not show differential responses to P, K, Ca, Mg, and S concentration during the five-month evaluation period, which averages were 3.9, 4.85, 14.8, 5.6, and 2.1 g$\cdot$kg^{-1}, respectively. The values obtained for P, Ca, Mg and S in the shoots were in accordance with concentrations recommended by Mills and Jones Jr. (1996), which suggested sufficiency range of nutrients in mature leaves of croton. However, N and K concentrations were lower than the values obtained for these authors, although nutrient deficiencies were not observed in the leaves. Interestingly, P and K concentrations increased with WSF in the roots, while Mg concentration in the roots decreased with WSF as compared to the other treatments and control. Studies show that high concentrations of one of them (K and Mg) inhibits absorption of another, whereas this antagonism is more intense from K relative to Mg (Epstein and Bloom, 2006). The Ca concentrations were not affected by types and rates of fertilizers in the roots as in the shoots. However, calcium was absorbed in higher quantities by the plants compared with other nutrients, both in the shoots and roots, due to the high requirement of this element by plants of the family euphorbiaceae, as described in other research’s (LAVIOLA; DIAS, 2008; AUGUSTO et al., 2003). Sulfur was higher for OSM and BAS in high rates, which differ from the treatments with WSF and control.

There was interaction between the treatments and growth period for N, P, K, Ca, Mg, and S uptakes in the shoots (Table 3). Except to N, the other nutrient uptakes did not change with treatments until 60 DAT (Figure 4). For N uptake, WSF and high rate of CRFs were similar between them and higher than control. At 90 DAT, N uptake was higher for WSF than BAS and control. However, for the other nutrients, the results differed between treatments. For N and K uptakes, at 120 DAT, WSF was similar high rate of OSM and higher than other treatments and control. P uptake was higher with WSF than to the other treatments and control. Ca, Mg and S uptake showed similar results than N and K, but the highest treatments did not differ than low rate of OSM. At 150 DAT, WSF increased the nutrient uptakes as compared to the other treatments, except to Ca. Ca uptake was higher with WSF and high rate of OSM as compared to BAS and control.

Table 2 - Average of nutrient concentrations in croton plants during the growth period affected by different rates and types of fertilizers

Treatments	Concentration of nutrients on the plants ($g\ kg^{-1}$) [a]											
	N		P		K		Ca		Mg		S	
	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
Control	8.26 d	6.10 c	3.70 a	2.14 b	4.63 a	4.50 b	13.25 a	12.78 a	5.24 a	8.40 a	1.82 a	2.14 b
WSF	13.61 ab	8.77 ab	4.71 a	3.02 a	5.04 a	6.39 a	14.69 a	11.72 a	5.40 a	6.42 b	2.12 a	2.16 b
OSM 1.5g	11.34 bc	7.14 bc	3.58 a	1.57 b	4.87 a	5.07 b	14.77 a	15.41 a	5.81 a	7.58 ab	2.03 a	2.23 ab
OSM 3.0g	13.30 abc	8.87 ab	4.00 a	1.77 b	4.70 a	5.00 b	15.82 a	14.64 a	5.84 a	7.27 ab	2.28 a	2.59 a
BAS 1.5g	11.18 c	7.17 bc	3.15 a	1.77 b	4.93 a	5.15 b	14.69 a	14.38 a	5.59 a	7.63 ab	1.97 a	2.45 ab
BAS 3.0g	14.31 a	9.04 a	4.28 a	1.72 b	4.92 a	4.98 b	15.63 a	12.34 a	6.05 a	7.15 ab	2.36 a	2.60 a
Test F	**	**	ns	**	ns	*	ns	ns	ns	ns	ns	ns
CV (%)	6.94	7.89	16.37	12.54	4.59	7.29	6.82	10.89	8.98	7.29	12.81	6.23
LSD	2.36	0.98	1.81	0.40	0.63	0.60	2.87	2.33	1.44	0.85	0.76	0.23

[a] Values represent the average of six replications.
[b] ns, *, ** No significant or significant at P≥ 0.05, and 0.01, respectively.

Table 3 - Uptake of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) uptake by shoot and root of croton plants grown in containers affected by different levels and types of fertilizers

Main Factors	N			P			K			Ca			Mg			S		
	Shoot	Root	Total	Shoot	Root	Total	Shoot	Root	Total	Shoot	Root	Total	Shoot	Root	Total	Shoot	Root	Total
Fertilizers (F)	mg plant^{-1}																	
Control	42.94	15.91	65.34	19.88	5.20	28.70	24.31	11.23	40.43	71.15	35.35	119.76	27.76	22.96	55.56	9.49	5.39	16.46
WSF	125.16	27.06	152.21	40.42	9.42	49.85	44.56	19.88	64.44	131.56	36.90	168.47	46.08	19.22	65.31	18.68	6.39	25.08
OSM 1.5g	80.08	20.03	100.12	24.56	3.79	28.36	34.32	13.82	48.15	106.29	45.47	151.77	40.91	21.96	62.87	13.98	5.98	19.97
OSM 3.0g	92.94	21.09	114.07	28.03	3.79	31.83	33.53	12.26	45.79	110.86	38.04	148.90	40.56	18.92	59.48	15.19	5.74	20.97
BAS 1.5g	72.87	20.83	93.71	19.58	4.82	24.40	31.18	14.42	45.60	95.19	43.33	138.52	36.05	22.50	58.56	12.58	6.51	19.41
BAS 3.0g	82.59	18.20	100.80	24.31	3.31	27.62	27.56	9.78	37.34	88.06	24.75	112.81	34.11	14.33	48.44	13.02	4.93	17.96
Growth Period (P)																		
30	29.85	12.78	42.63	10.59	4.17	14.76	13.10	8.64	21.75	40.66	19.13	59.79	16.62	10.58	27.20	6.73	4.38	11.12
60	54.24	14.98	69.22	16.74	4.41	21.15	22.45	10.75	33.20	62.23	27.37	89.60	24.64	15.08	39.72	8.84	5.06	13.84
90	78.12	20.55	98.67	26.23	4.58	30.81	31.48	14.80	46.28	95.71	34.92	130.63	35.51	19.74	55.25	13.16	6.07	19.59
120	97.44	22.71	125.55	31.96	5.23	40.21	37.96	15.13	57.16	116.47	45.35	172.87	43.56	23.83	71.43	15.67	6.17	23.15
150	154.21	31.59	185.80	45.12	6.90	52.02	57.91	18.49	76.40	187.53	59.77	247.30	67.57	30.68	98.25	24.72	7.44	32.17
Interaction effects																		
F x P [a]	**	*	**	**	**	**	**	**	**	**	ns	**	**	ns	ns	**	ns	**
CV (%)	14.08	16.74	17.24	25.07	28.21	29.76	15.82	20.95	22.95	14.90	24.97	23.16	19.27	19.53	20.98	19.47	20.20	20.94
LSD	21.07	2.43	15.64	11.44	1.24	13.83	8.68	2.38	9.66	19.00	11.86	25.21	9.34	4.65	9.26	3.88	0.85	2.96

[a] ns, *, ** No significant or significant at p≥ 0.05, and 0.01, respectively

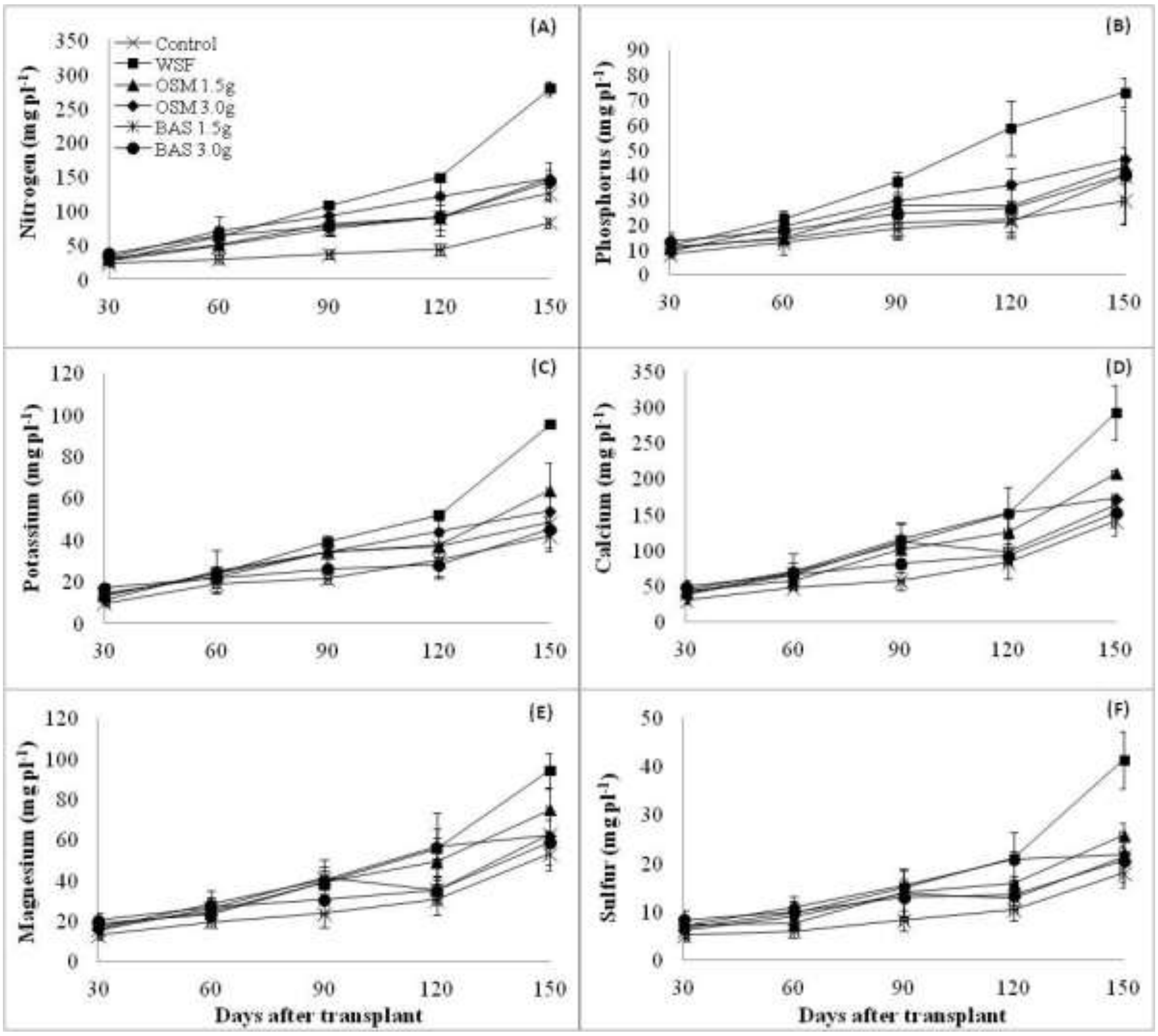

Figure 4 - Effects of different fertilizer treatments on nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur uptake on the shoots due to growing period subjected to different fertilizer treatments

Nutrient uptakes in the roots were affected by treatments and growth period after 60 DAT for P, 90 DAT for N, K, Mg and S, and 120 DAT for Ca (Table 3). N uptake at 120 DAT was higher with WSF as compared to BAS at high rate and control, and did not differ of OSM and low rate of BAS (Figure 5). At the end of growth period, N uptake was higher with WSF than other treatments. P and K uptakes, from 120 DAT, were higher with WSF than CRF and control. Treatments did not affect Ca absorption during growth period, except BAS at high rate from 120 DAT to 150 DAT. Mg was higher with CRFs than without fertilizer, while CRF treatments resulted in lower S uptake at the same period compared with WSF.

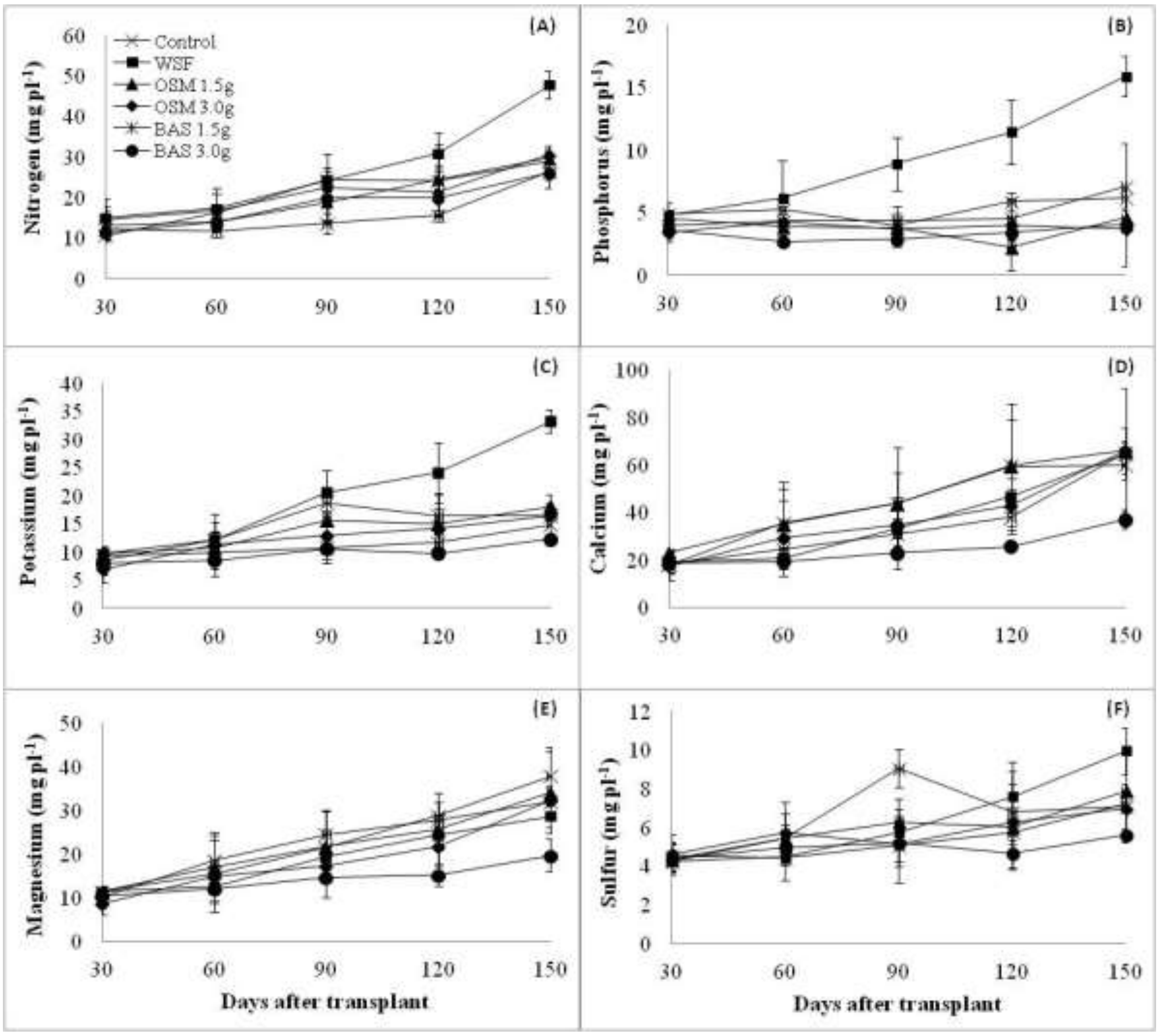

Figure 5 - Effects of different fertilizer treatments on nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur uptake on the roots due to growing period subjected to different fertilizer treatments

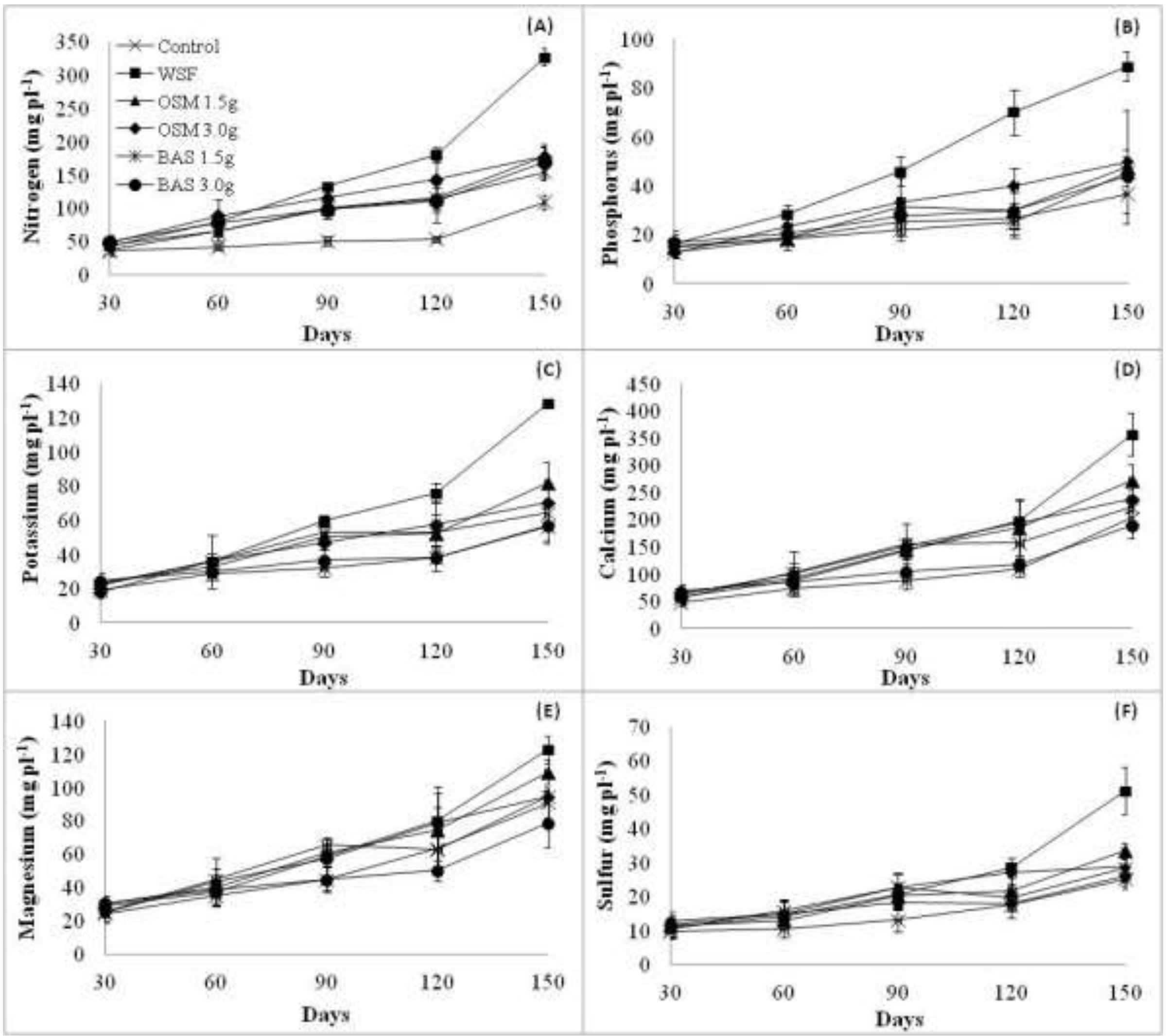

Figure 6 - Effects of different fertilizer treatments on the nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur uptake on the plants due to growing period subjected to different fertilizer treatments

The nutrient uptakes (mg plant-1) by plants follow the order: Ca > N > Mg > K > P > S (Figure 6). The distributions of nutrients among shoots and roots were 82.2%/17.8% (N), 87.2%/12.8% (P), 75.9%/24.0% (K), 47.3%/52.6% (Ca), 68.4%/31.5% (Mg), and 76.3%/23.7% (S). According to these results, the highest proportions between shoots and roots were reached by P, N, K, S, Mg and Ca. In this experiment, maximum biomass on the shoots and roots parameters was observed in low CRFs rates and WSF, whereas in general, highest nutrients uptake was in WSF and higher rates of CRFs. Reduced growth observed in plants grown in CRF at high rates is consistent with other ornamentals reported by Cabrera (2003) and Karam et al. (2004). They attributed it in part to an increased salinity of the growing medium with high fertilizer rate, although the plants have not shown symptoms of toxicity, except for the leaves with dark purple color and low bright (Figure 3). The plants that have absorbed in larger quantities the fertilizer applied at high rates of CRFs probably complies with luxury absorption described by Malavolta (2006), which describes a possible absorption after the critical level of the crop and above the level of toxicity.

Nutrient release: Leached solution from the containers collected each 10 days was significantly affected by fertilizer treatments for substrate pH and EC (Figure 7). Substrate-pH level for WSF was lower than substrate-pH for all other treatments. Most pH levels were in the range of 5.5 and 7.0, and the lowest substrate-pH occurred was 3.82 at 135 days for WSF, which did not affect plant production as showed on figure 2. The CRFs substrate-EC kept between 0.5-2.0 dS m^{-1}. Recommended levels of EC when using the PourThru technique for container-grown plants in pine bark substrate fertilized with only a CRF should range from 0.2 to 0.5 dSm^{-1} (SOUTHERN NURSERY ASSOCIATION, 2007), which is lower than obtained in this experiment. The WSF treatment was also significantly higher than with other treatments. From 75 DAT to the end of the study, leached EC gradually increased to 4.26 S m^{-1}, that was above the EC levels recommended, because high leachate EC levels is consider detrimental to the health for wood ornamentals.

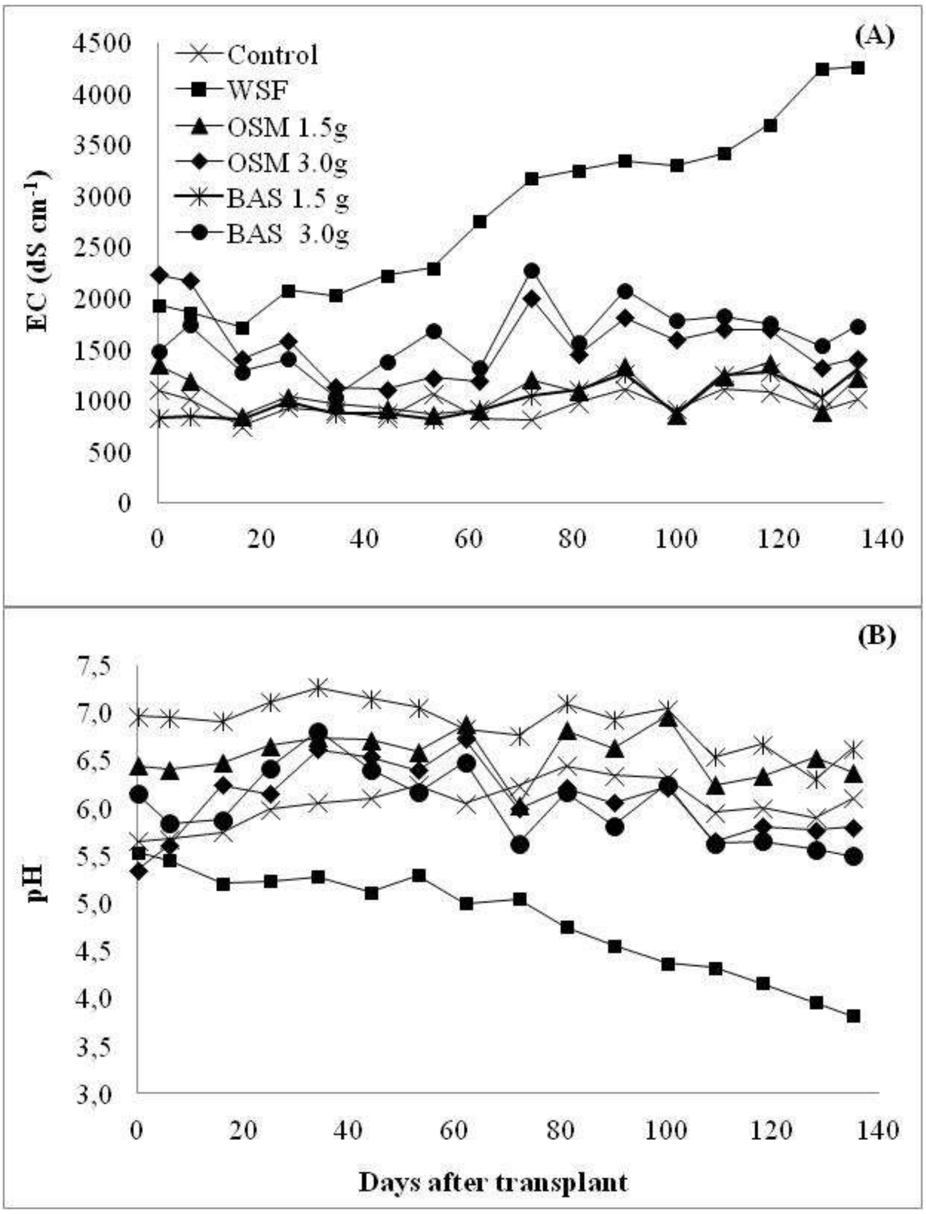

Figure 7 - Electrical conductivity (EC) and pH values of drained solution from container due to growing period subjected to different fertilizer treatments

Nitrogen leaching response in all fertilizer treatments studied is shown in figure 8. A greater proportion of N in the leached solution was in nitrate form, regardless of the fertilizer. NO_3^- losses were significantly higher with WSF (1121.82 mg L^{-1}) compared to the other treatments, which loss was lower than 200 mg L^{-1} throughout the entire period. For all CRFs, leachate NO_3-N was highest during the first 20 days, than decreased less than 100 mg L^{-1} for the remainder of the experimental period. Other differences in leachate nitrate concentrations were found during the last half of the study, increasing after 70 DAT for high rates of OSM and BAS. Like NO_3^-, most of the NH_4-N losses were produced at the beginning of the experiment (before 20 DAT), although all treatments leached only small amounts over the experimental period. CRFs in a high rate leached higher amount of NH_4-N compared with low rates, WSF, and control. More specifically, at the beginning of the experiment, OSM released 125.97 mg L^{-1} and BAS 75.22 mg L^{-1}, compared with WSF (35.47 mgL^{-1}). The results are in agreement with those reported by Fernández-Escobar et al. (2004) and Newman et al. (2006), which reported NH_4-N values near to zero, much lower than nitrate form in the leached solution.

Total cumulative N leaching per pot was highest with WSF, followed by OSM and BAS in a high rate, although CRFs regardless of rates did not produced significantly N losses (Figure 9). Nitrate losses for WSF was 76.95% of the total applied, whereas CRFs leached no more than 10%. Throughout the experiment, as expected, measured N release from the control treatment was close to zero. NH_4^+ represented just 5% of total nitrogen collected from the containers. Therefore, nitrogen lost from the leachate solution was primarily in the nitrate form.

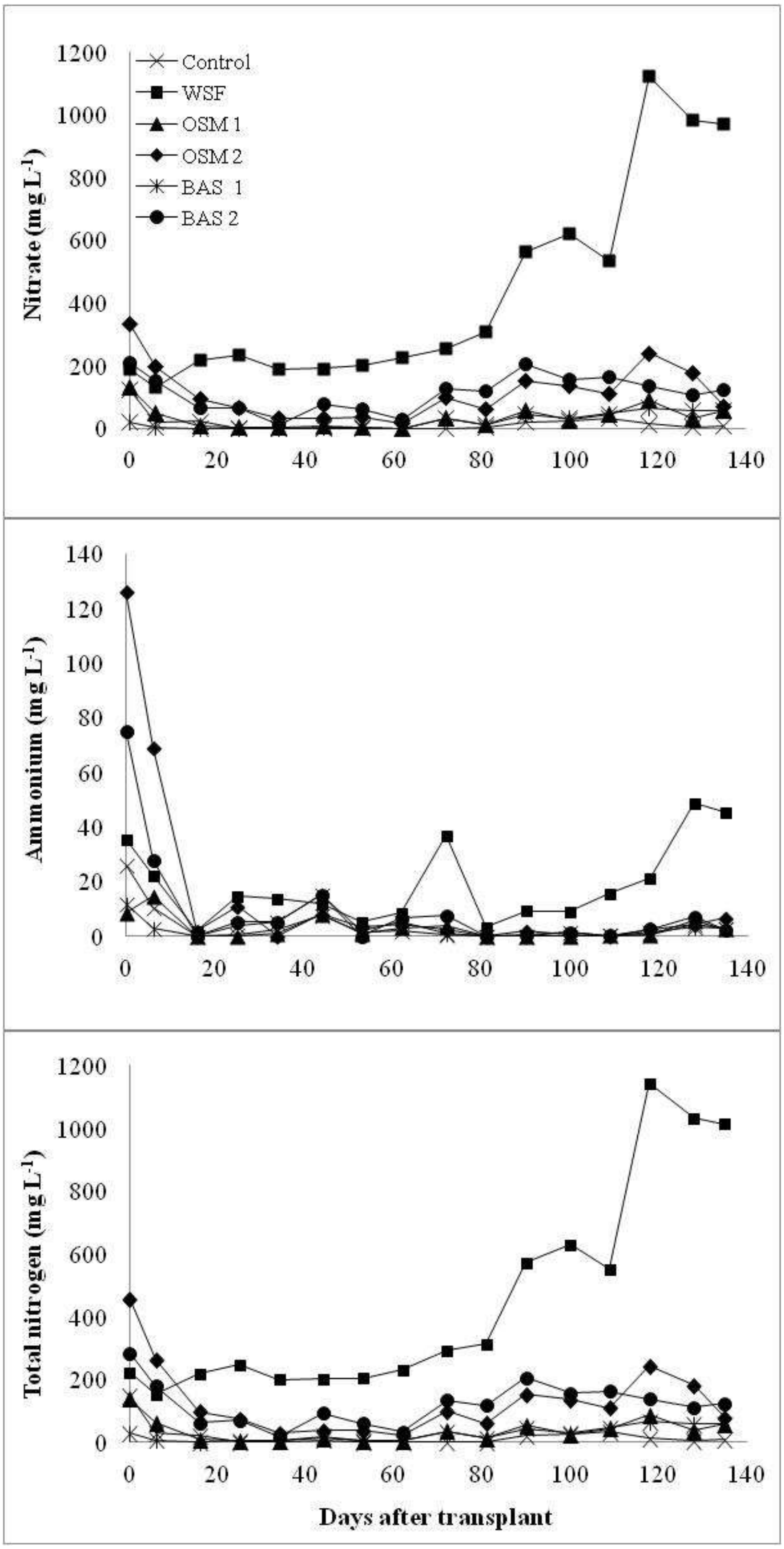

Figure 8 - Amounts of nitrate, ammonium and total nitrogen leached from containers due to growing period subjected to different fertilizer treatments

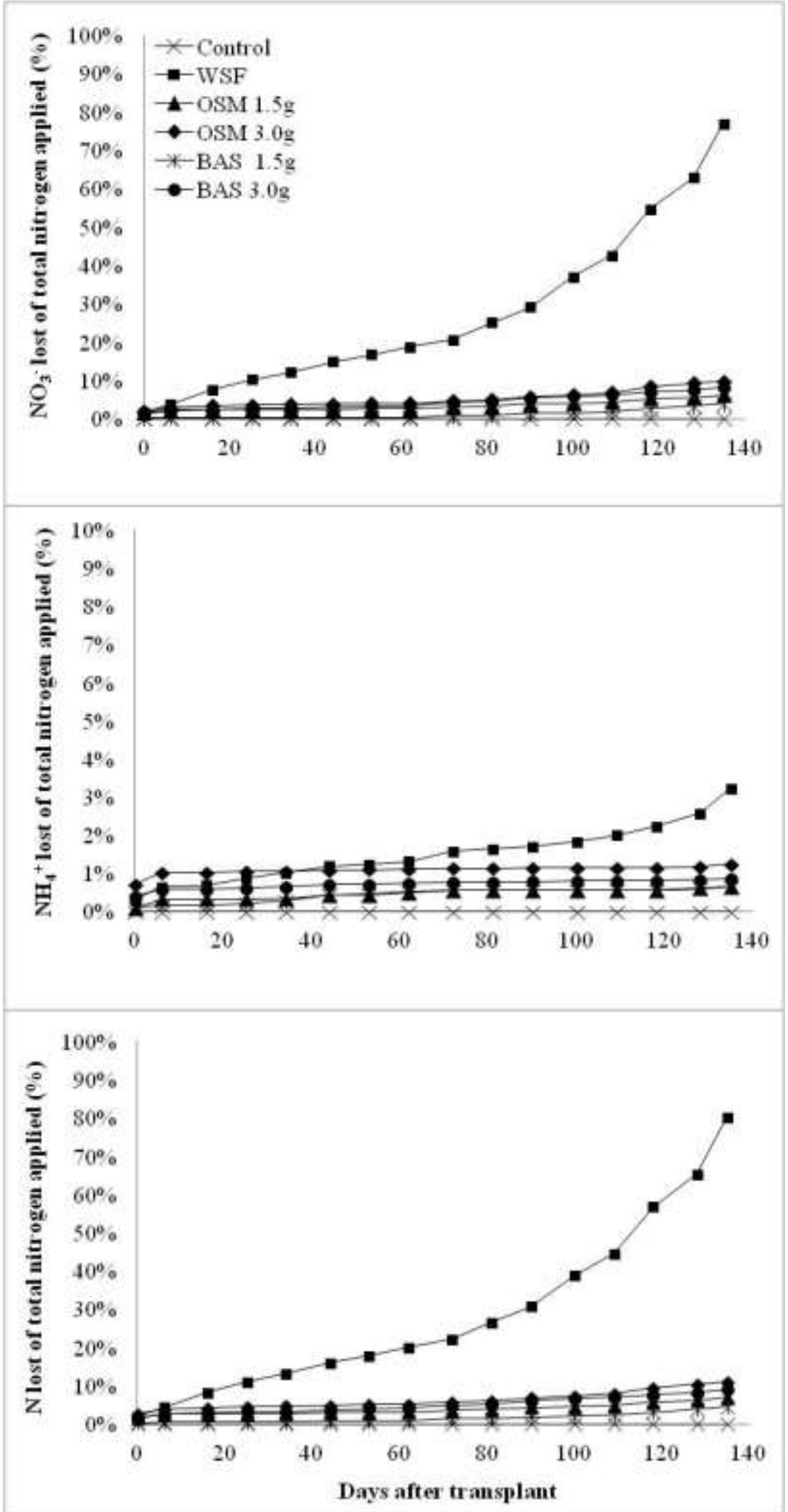

Figure 9 - Percentage ratio of nitrate (a), ammonium (b) and total nitrogen (c) leached accumulated from containers and nitrogen applied per treatment due to growing period subjected to different fertilizer treatments

2.4 Conclusions

Controlled release fertilizer showed to be as effective as WSF for growth of croton during the study period. Osmocote and WSF provided similar results for most of variables analyzed during the growth period, while Basacote used as a source of nutrients resulted in better plant visual together WSF. Controlled release fertilizers applied at a low rate provided better results for growth.

The use of controlled release fertilizer maintained pH and EC within the optimum range for croton growth compared with WSF, and CRF resulted in significantly lower nitrogen concentration in the leached solution compared with WSF, reducing such losses by leaching.

Thus, both controlled release fertilizers tested would be recommended for croton production. Other CRF products can be tested for longer periods of evaluation, in order to keep the plants for a longer period in the greenhouse for sale.

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3 STRATEGIES TO PROVIDE FERTILIZER FOR BOTH PRODUCTION AND CONSUMER PHASES OF PETUNIA

Abstract

The effects of fertilization management strategies using soluble fertilizers and controlled release fertilizers (CRFs) were studied on biomass of petunia (*Petunia* × *hybrida*), and N leaching. Strategies included a Dual Coated Technology (DCT) controlled release fertilizer (CRF) with a second coating that delayed initial nutrient release, compared with Osmocote (OSM) (a conventional single-coated CRF), and water soluble fertilizer (WSF). Rooted cuttings of petunia were grown for 42 days in 2.84 L containers (the “production phase”) with WSF only, a low rate of combined WSF and OSM, or low and high label rates of WSF and OSM top-dressed (WSF+OSM TD), WSF and DCT (WSF+DCT), OSM, or a commercial blend of OSM and DCT (OSM + DCT). By the end of production phase after 42 days, all fertilizer strategies tested produced horticulturally acceptable plants in terms of chlorophyll index and number of flowers. In a subsequent "consumer phase", plants were maintained in containers or were transplanted into a landscape and irrigated with clear water for 98 days. Plant performance (number of flowers, SPAD chlorophyll index, dry weight, and tissue nitrogen level) was greater during the consumer phase in treatments with high rates of CRF compare with WSF only, or lower rates of CRF. Based on nutrient release in a sand substrate without plants at 10, 21 or 32 ^{o}C, the DCT had delayed nutrient release compared with single-coated CRF. The release rates of all CRF products, and the duration of the delay in release from DCT were temperature-dependent. These results emphasize the importance of considering temperature on the longevity of product. A partial budget found that the lowest cost treatment was WSF only at $0.02/container. Comparing at high rates, using WSF+DCT ($0.085) was more expensive than incorporated OSM ($0.05), and had a similar cost to WSF+OSM TD ($0.084). The greatly improved consumer performance for plants with residual fertilizer compared with WSF provides an opportunity to add value and profitability with a slightly higher sales price. Several fertilizer strategies are available depending on material and labor cost and availability, and preferred crop management style.

Keywords: Controlled release fertilizer; Nitrogen; Nutrient release; *Petunia* × *hybrid*; Temperature

3.1 Introduction

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

Both growth chamber and greenhouse methods have been used to compare how CRFs will act in a particular controlled environment (BROSCHAT; MOORE, 2007; CARSON; OZORES-HAMPTON, 2012). Field methods are also used to measure nitrogen (N) release in commercial vegetable soil conditions (BIRRENKOTT et al., 2005; SIMONNE; HUTCHINSON, 2005). The CRF response profile under controlled laboratory conditions can be combined with substrate extraction methods in the field to quantify release characteristics of CRFs for different crops and locations (BIRRENKOTT et al., 2005).

A range of fertilizer strategies are available to provide nutrients during production and consumer phases. Containers may be produced with WSF and then top-dressed with CRF prior to sale. A CRF may alternatively be incorporated or top-dressed at planting with a longevity that exceeds the production time, so that residual nutrient reserves remain for the consumer. A technology termed Dual Coated Technology (DCT, Protect™, Everris, The Netherlands) has a second outer coating over an Osmocote Exact ™ CRF prill, which according to the manufacturer delays the initial nutrient release for 1.5 to 2 months depending on temperature. For the purposes of clarity in this article, we will use OSM to refer to a single-coated technology (Osmocote™), to differentiate from DCT. A blended product of OSM and DCT (Hi-End™) will be referred to as OSM+DCT, and both OSM and DCT will be referred to as types of CRF.

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

3.2 Materials and Methods

3.2.1 Greenhouse Fertilizer Experiment (petunia)

A greenhouse fertilizer experiment was conducted at the University of Florida, Environmental Horticulture Research Complex in Gainesville, FL, from 16 Sept. 2014 to 5 Feb. 2015. During the production phase from 16 Sept. 2014 to 29 Oct. 2014, greenhouse daily light integral (DLI) averaged (± SD) 15.7 ± 5.1 $mol \cdot m^{-2} \cdot d^{-1}$ and daily air temperature averaged (± SD) 24.1 ± 2.2 ^{o}C. This production period was followed by 98 d from 30 Oct. 2014 to 5 Feb. 2015, as the “consumer period” in either the same greenhouse (DLI (± SD) of 12.5 ± 5.7 $mol \cdot m^{-2} \cdot d^{-1}$ and 21.3 ± 1.1 ^{o}C) or following transplanting into a drip-irrigated landscape bed (DLI (± SD) of 21.9 ± 8.2 $mol \cdot m^{-2} \cdot d^{-1}$ and 17.0 ± 5.8 ^{o}C). In the landscape, plants were spaced at 0.5 m along the bed, and were drip-irrigated using 500 $L \cdot h^{-1}$ per 100 m drip tape during for 60 min approximately every two days depending on rainfall. A total of 19.6 cm of rain fell the consumer phase. Plants in the landscape were covered with spun-bound polyethylene cloth on nights when frosts occurred (19 Nov. and 20 Nov.2014 and 8 Jan.2015), with a minimum air temperature of 0 ^{o}C (32 ºF).

Unrooted cuttings of petunia ‘Supertunia Vista Bubblegum’ from Innovaplant Costa Rica were transplanted into 25 mm diameter paper-wrapped pots (Ellepots; Blackmore, Apopka, FL) with 70% peat/30% perlite mix (Fafard 1P Mix; Sun Gro Horticulture, Agawa, MA) on 28 Aug. 2014. After cuttings were well-rooted (16 Sept. 2014), they were transplanted into 2.84 L containers (trade 1-gal containers; Growers solution, Cookeville, TN) filled with 80% peat moss, perlite and vermiculite substrate (Fafard 2 Mix; Sun Gro Horticulture, Agawam, MA) that contained a low concentration of water-soluble fertilizer as a pre-plant nutrient charge (initial electrical conductivity (EC) 600 $\mu S.cm^{-1}$, pH 6.3 using the saturated medium extract method (WARNCKE, 1986). The bottom of each container was lined with nylon mesh to avoid substrate being lost through drainage holes.

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

Table 1 - Fertilization treatments applied to petunia 'Supertunia Vista Bubblegum' over a 42 days crop cycle for the greenhouse plant growth experiment. OSM refers to 15N-3.93P-9.96K Osmocote Plus™, DCT refers to 14N-3.49P-9.13K Protect™ dual-coated, OSM+DCT refers to a blend of 15N-3.93P-9.96K Osmocote Exact™ and DCT (Hi-End™), and WSF refers to 15N-2.18P-12.45K (Peters Excel 15-5-15) water soluble fertilizer

Treatment Code	**Incorporated pre-plant**	**Fertilizer during the production phase (42 days)**	**Fertilizer during the consumer phase (98 days)**
(1) WSF	None	WSF (200 $mg \cdot L^{-1}$ N)	None
(2) WSF+OSM	OSM (2.37 kg/m^3)	WSF (100 $mg \cdot L^{-1}$ N)	None
(3) WSF+OSM TD Low	None	WSF (200 $mg \cdot L^{-1}$ N)	OSM TD(3.56 kg/m^3)
(4) WSF+OSM TD High	None	WSF (200 $mg \cdot L^{-1}$ N)	OSM TD(5.93 kg/m^3)
(5) OSM Low	OSM (3.56 kg/m^3)	None	None
(6) OSM High	OSM (5.93 kg/m^3)	None	None
(7) WSF + DCT Low	DCT (3.81 kg/m^3)	WSF (200 $mg \cdot L^{-1}$ N)	None
(8) WSF + DCT High	DCT (6.35 kg/m^3)	WSF (200 $mg \cdot L^{-1}$ N)	None
(9) OSM+DCT Low	OSM+DCT(3.56kg/m^3)	None	None
(10) OSM+DCT High	OSM+DCT(5.93kg/m^3)	None	None

Between 0 to 42 d, plants were irrigated with one of three solutions: clear water (treatments 5, 6, 9, and 10), 100 $mg \cdot L^{-1}$ of nitrogen (N) (treatment 2) from 15 N-2.2 P-12.5 K (Peters Excel 15-5-15, Everris, North America), or 200 $mg \cdot L^{-1}$ N from 15N-2.18P-12.45K (treatments 1, 3, 4, 7, and 8). For treatments with incorporated CRF, a measured dose of the fertilizer per container was mixed into the substrate before planting, at 534 and 890 $mg \cdot L^{-1}$ N of substrate for the low or high rate treatments. Controlled release fertilizers used were DCT 14N-3.5P-9.1K (Dual coated technology; Everris, CA Geldermalsen, The Netherlands), OSM 15N-3.9P-9.9K (Osmocote Plus; Everris, North America) and OSM+DCT 15N-3.93P-9.96K (Osmocote Exact Hi-End; Everris, CA Geldermalsen, The Netherlands), with longevity between 5 and 6 months for the three products.

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

The pour-through method (WHIPKER et al., 2011) was used for non-destructive pH and EC measurements at days 0, 7, 14, 21, and 28 and then every 15 d from day 28 onward, for two randomly selected replicate pots per treatment on each of the three benches. For nitrate and ammonium analysis of leachate using semi-automated and automated colorimetry by the University of Florida Analytical Research Laboratory (Gainesville, FL), two replicate containers per bench were combined into a composite sample, resulting in three replicates for leachate analysis per treatment combination per measurement date.

At day 0, 150 rooted liners were destructively sampled to measure initial dry weight and tissue nutrient content. At day 42, six plants each treatment were destructively sampled for N level in tissue and total plant dry weight (shoot and roots combined). For N analysis of combined shoot and root tissue by Quality Analytical Laboratories (Panama City, FL), the two replicate containers per bench were combined into a composite sample, resulting in three replicates per treatment combination. At day 42, the number of flowers (all open or closed buds showing pink petal color) were counted, and chlorophyll index was measured on five fully expanded leaves per plant with a Minolta SPAD meter on all 18 replicates per fertilizer treatment.

To simulate a consumer phase in either containers or the landscape after day 42, six plants per treatment remained in the 2.84 L containers, and six plants were transplanted into the landscape in a sandy soil for an additional 98 d. No additional fertilizer was applied except for CRF in top-dress treatments (3) and (4). The landscape soil was tested before planting with a Mehlich III P and K soil extraction and deionized water to extract NH4/NO3 from the soil (Quality Analytical

Laboratories, Panama City, FL) and showed no detected N, high P (487.8 ppm) and K (219.1 ppm) (MYLAVARAPU et al., 2014), pH 6.32, and an EC of 0.20 $\mu S \cdot cm^{-1}$. All plants in both locations were irrigated with clear tap water. Every 15 d after transplanting, chlorophyll index was non-destructively measured on all plants. Flowers were counted every 15 d from day 70 onwards. During the consumer phase, plants were drip-irrigated in the landscape, or in the greenhouse were manually watered using a hose (with zero leaching using collection saucers under each container). For the container-grown plants only, pour-through leachate samples were collected from each container every 15 d.

At day 140, the 12 plants in containers or the landscape were destructively sampled for tissue dry weight and nutrient content, chlorophyll analysis, and number of flowers. Nitrogen uptake efficiency was calculated from leaf tissue. Total N content in oven-dried ground plant tissue samples was determined by potassium persulfate / sodium hydroxide digestion and analyzed with a Lachat Quik-Chem flow injection NO3 analyzer by Quality Analytical Laboratories.

3.2.2 Nitrogen Release from CRF in the Greenhouse Fertilizer Experiment (Sand Containers, No Plants)

Based on protocols from Birrenkott et al. (2005), a leachate collection unit (LCU) was assembled by placing a standard nursery container inside a 15.2 cm diameter hole cut into the lid of 7.6 L black poly bucket (Plasticas Inc. Dallas, TX). An injection-molded 2.3 L nursery container (Classic 300S; Nursery Supplies, Inc., Chambersburg, PA) was inserted into the collection bucket lid and slid into position so that about 2.5 cm of the bottom of the nursery container protruded through the lid, with all drain holes beneath the collection bucket lid. The nursery container was plastic welded to the lid of the collection bucket using a 0.4 cm diameter HDPE plastic welding rod and a plastic welding gun. The container was welded on both the top and bottom sides of the lid. A circular disk (15.2 cm diameter x 2.5 cm height) cut from porous spun-bound polyester fabric was placed in the bottom of the nursery container to cover the drain holes, filter the leachate solution and retain the hydrochloric acid (HCl)-washed sand substrate.

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

3.2.3 Growth Chamber Experiment

Plastic columns measuring 40 cm in height (filled with substrate to the 25-cm line) and 5 cm internal diameter were mounted vertically into growth chambers. Columns were filled with 0.5 L of HCl-washed sand, fitted with mesh in the end and sealed to retain moisture. The experiment included three fertilizer source treatments, three growth chamber incubation temperatures (10, 21 and 32 °C), and 14 sampling dates (1, 2, 4, 7, 14, 28, 42, 56, 70, 84, 98, 112, 126, and 147 d), with six replicate columns for each fertilizer treatment randomized within each temperature environment.

For each experimental unit, fertilizer was added at a rate of 5.93 $g \cdot L^{-1}$ of OSM, 5.93 $g \cdot L^{-1}$ of OSM+DCT (Hi-End), or 6.36 $g \cdot L^{-1}$ for DCT to provide 890 mg N per L of substrate. Granular fertilizer was weighed and hand-mixed into the sand of each column. A beaker containing 40 of 0.2M sulfuric acid was placed in each growth chamber for ammonia gas entrapment to trap ammonia (NH_3) that volatilizes from the soil.

Experimental conditions and leachate sampling from the sand columns were based on published protocols (CABRERA, 1997; CARSON; OZORES-HAMPTON, 2012; FAN; LI, 2010). Columns remained saturated with water up to the upper level of the sand. At each sampling date, all columns were removed from the growth chamber and 1.25 L of deionized water was added to each column (substrate/extraction solution ratio of 1:2.5). Leachate from each container was captured in polyethylene beakers and filtered through Whatman N^o.42 filter paper. Each replicate column was measured separately for pH, EC and leachate volume. Pairs of replicate columns were combined for nitrogen analysis and stored with sulfuric acid (1%, v/v) at 4 °C for no more than 15 d before analysis at the UF/IFAS Analytical Services Laboratories. Air temperature was measured in the three controlled climate conditions using dataloggers.

3.2.4 Statistical Analysis

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

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

$$R = (H_{init} * H_{final}) /((H_{init}^N + (H_{final}^N - H_{init}^N) * e^{-K*t})^{(1/N)}) \qquad (1)$$

After plotting the rate parameter *K* in equation (1) for each fertilizer, *K* increased with temperature in an approximately linear fashion. Therefore K was calculated from the column temperature *T*, *K* was replaced with a linear function *a* + *bT*, and PROC NLIN was used to estimate *N*, *a*, and *b* in eq. (2) separately for each fertilizer:

$$R = (H_{init} * H_{final}) /((H_{init}^{N} + (H_{final}^{N} - H_{init}^{N}) * e^{-1*(a+bT)*t})^{(1/N)}) \qquad (2)$$

The empirically fitted curves from equation (2) could therefore be used to describe the observed nutrient release at *t* days within the temperature range from 10 to 32 ^{o}C for each fertilizer based on the three parameters, *N*, *a*, and *b* and the temperature *T*.

3.2.5 Economic Analysis

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

The price of WSF was based on Peters Excel 15-5-15™ (15N-2.18P-12.45K, 2014 catalog cost from BWI, Apopka, FL) at $31.20 per 25 lb bag. The amount of N from the WSF applied to the containers was calculated on a pot-by-pot basis (Mattson, 2010). To use this method it was necessary to consider the cost and weight per bag, percentage of N, the volume of water applied per container (5.4 L), and the applied concentration of fertilizer (0, 100 or 200 $mg \cdot L^{-1}$ N). These assumptions were used to calculate the WSF cost per container from eq. (3), (4) and (5).

Cost per g of N = (cost per bag ($) /(weight per bag (g) * % N per bag) (3)

N applied (g) = ((volume of water applied (L) * concentration of fertilizer ($mg \cdot L^{-1}$ N))/1000) (4)

Total cost per container WSF = (grams of N applied /cost per gram of N) (5)

3.3 Results and Discussion

Growth during the production phase: Fertilizer treatments affected total dry weight (p=0.0028), SPAD chlorophyll index (p=0.0019), and number of flowers (p<0.0001) at day 42, with least-square treatment means shown in Table 2. The highest dry weight occurred with the high rate of incorporated OSM (treatment 6), which resulted in more growth than with the low rate of OSM+DCT (treatment 9) or the WSF only treatment (combined 1, 3 and 4). SPAD chlorophyll index was higher for plants receiving the low rate of incorporated OSM (treatment 5) compared with the low rate of WSF+DCT (treatment 7). The highest number of flowers occurred with the low and high rates of incorporated OSM (treatments 5 and 6). Overall, OSM incorporated at low or high rates (treatments 5 and 6) resulted in high levels of growth and quality indices across all variables (dry weight, SPAD chlorophyll index, and number of flowers). However, at day 42 all plants appeared horticulturally acceptable as saleable flowering products, in terms of multiple open blooms with dark green foliage covering the container surface, regardless of fertilizer strategy (Figure 1A).

Table 2 - Summary analysis of variance table showing the effects of fertilizer treatments on plant growth and nutrition in containers at the end of the production phase (42 days)

Treatments	Total dry weight (g/plant)	SPAD chlorophyll Index	Flowers (no./plant)	pH	Electrical conductivity ($\mu S \cdot cm^{-1}$)	Substrate-N ($mg\ L^{-1}$)	Tissue N (%)
(1, 3, and 4) WSF	11.4 b [z]	37.8 ab	11.3 c	6.62 a	1668 d	27.4 c	4.6 ab
(2) WSF+OSM	14.3 ab	37.7 ab	14.4 bc	6.34 bc	2308 c	72.0 b	4.9 ab
(5) OSM Low	14.7 ab	41.8 a	29.5 a	6.32 bc	2301 c	86.0 b	3.1 c
(6) OSM High	17.5 a	41.3 ab	20.8 ab	6.12 d	3224 a	142.1 a	4.7 ab
(7) WSF+DCT Low	13.8 ab	37.3 b	9.3 c	6.35 b	2535 bc	69.3 b	5.2 ab
(8) WSF+DCT High	13.7 ab	39.1 ab	12.8 bc	6.30 bc	2869 ab	99.1 b	5.3 a
(9) OSM+DCT Low	10.0 b	38.0 ab	9.6 c	6.38 b	2210 c	83.3 b	3.0 c
(10) OSM+DCT High	15.7 ab	40.4 ab	18.7 b	6.20 cd	3141 a	144.2 a	3.8 bc

[z] Least-square means were compared using Tukey's HSD at the α=0.05 level.

Figure 1 - Photographs of representative plants grown with the different fertilizer treatments detailed in Table 1. (A) Photograph taken at the end of the production phase (42 days after planting); (B) 42 days in the consumer phase (84 days after planting) or (C) 98 days in the consumer phase (140 days after planting). White arrows on the left of each photo represent the container height of 16.5 cm to provide a comparative scale, because photos were taken an increasing distance away from the plants as time progressed

Nutrient levels during the production phase: Fertilizer treatments affected substrate-pH (p<0.0001), substrate-EC (p=<0.0001), substrate-N (p=<0.0001), and tissue-N (p<0.0001), with least-square treatment means shown in Table 2. Substrate-pH level for WSF only (combined treatments 1, 3 and 4) was higher than substrate-pH for all other treatments. The lowest pH levels occurred with the high rate of OSM (treatment 6) and OSM+DCT (treatment 10). Substrate-EC with the WSF only treatment (combined treatments 1, 3 and 4) was also significantly lower than with other treatments. The highest substrate-EC occurred with the high rate of OSM (treatment 6) and OSM+DCT (treatment 10). The observed trend whereby high pH treatments tended to have a low EC is consistent with cation exchange of fertilizer cations with protons on the peat substrate (FISHER et al., 2014). Most pH levels were slightly higher than recommended for petunia [5.4 to 6.2 (FISHER, 2003)] during the production phase, although there were no visual signs of iron deficiency (Figure 1A) or large differences in SPAD chlorophyll level (Table 2). The recommended range for EC using the pour-through method of 2600 to 4600 $\mu S \cdot cm^{-1}$ for most established plants (WHIPKER et al., 2003) was above the EC levels observed in treatments except for the high rates of OSM (treatment 6), WSF+DCT (treatment 8), or OSM+DCT (treatment 10). The average substrate-N content during the production phase (Table 2) was highest with the high rate of incorporated OSM (treatment 6) or OSM+DCT (treatment 10), and was lowest with the WSF only treatments (1, 3 and 4). The low rate of OSM (treatment 5) and OSM+DCT (treatment 9) resulted in 3.1% and 3.0% tissue-N, respectively, which was lower than the range recommended by Mills and Jones (1996) for petunia of 3.85-7.60%.

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

Table 3 - Summary analysis of variance (ANOVA) table showing the effects of fertilizer treatments on plant growth and tissue-N after 98 days in the consumer phase (140 days after planting) for the containers continued in the greenhouse or transplanted to the landscape

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

[z] Least-square means were compared using Tukey’s HSD at the α=0.05 level. The ANOVA for each variable was run separately by environment (greenhouse or landscape).

At the end of the consumer phase, fertilizer treatments affected the SPAD chlorophyll index (Table 3). In the greenhouse (p<0.0001), treatments with either a high rate of incorporated OSM (treatment 6) or OSM+DCT (treatment 10), or both low or high rates of WSF+DCT (treatments 7 and 8) or WSF+OSM TD (treatments 3 and 4) resulted in the highest SPAD. In the landscape (p=0.0012) the highest SPAD occurred with incorporated OSM (treatments 5 and 6) and WSF+OSM TD (treatments 3 and 4) in both low and high rates. In the greenhouse, SPAD decreased throughout the consumer phase, particularly for the plants with WSF only in treatment 1 that had no CRF (Figure 2A and B). In the landscape (Fig. 2C and D), SPAD leveled out or increased during the second half of the consumer phase. However, plants dropped leaves in response to cold temperatures in January to February 2015 and SPAD measurements were therefore made on intact leaves that were growing under cool conditions, justifying the increase in SPAD values.

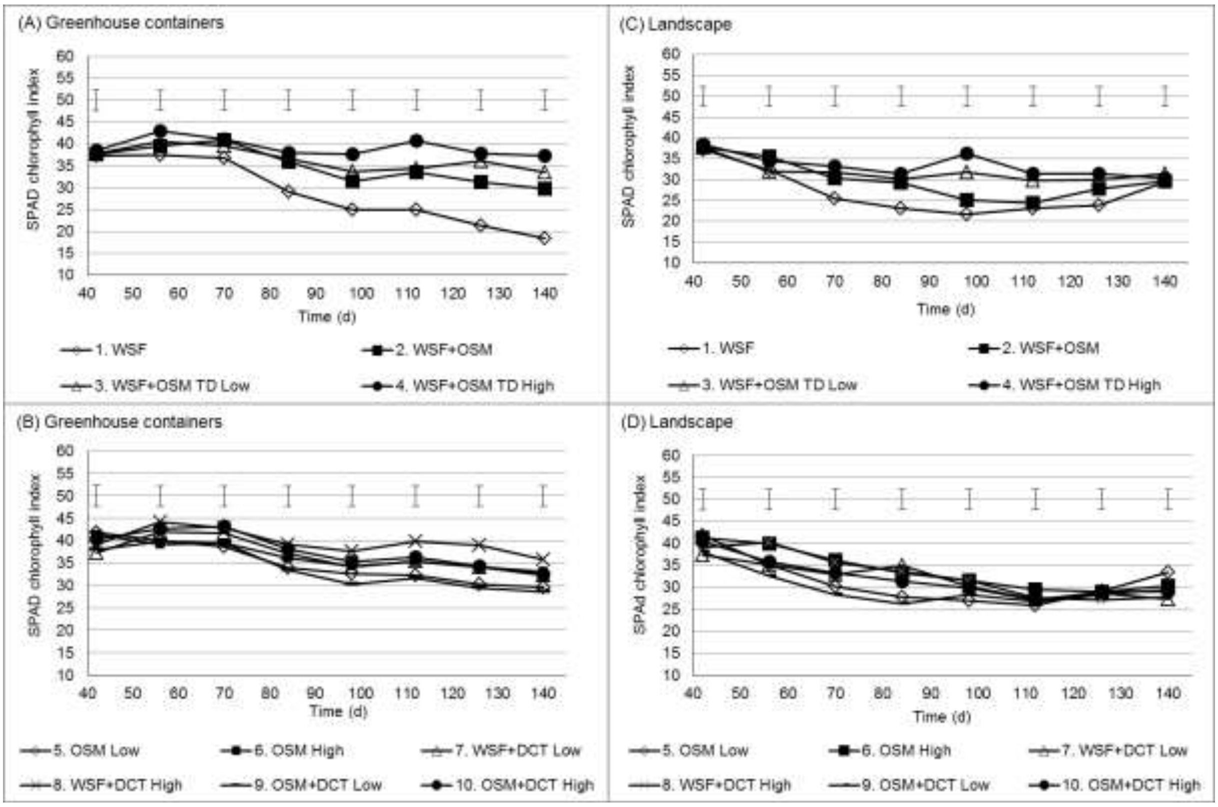

Figure 2 - Effect of controlled release fertilizer (CRF) and water soluble fertilizer (WSF) treatments on SPAD chlorophyll index during the consumer phase in greenhouse containers (A and B) or a landscape planting (C and D) beginning at day 42

The number of flowers at the end of the consumer phase (p=0.0074, Table 3) was higher for WSF+OSM TD high rate (treatment 4) than the low rate of incorporated OSM (treatment 5) or OSM+DCT (treatment 9) in the greenhouse. In the landscape (p=0.0040), plants fertilized with the high rate of WSF+DCT (treatment 8) had a higher number of flowers than WSF (treatment 1), WSF+OSM (treatment 2), low rate of incorporated OSM (treatment 5) or OSM+DCT (treatment 9) (Table 3). By the end of the consumer phase, there were no flowers on the WSF only plants in the field. The number of flowers peaked at 70 d. after transplant (28 d. in the greenhouse or landscape), and decreased after this period. The number of flowers remained higher for plants in the greenhouse compared with plants in the landscape (Figure 3).

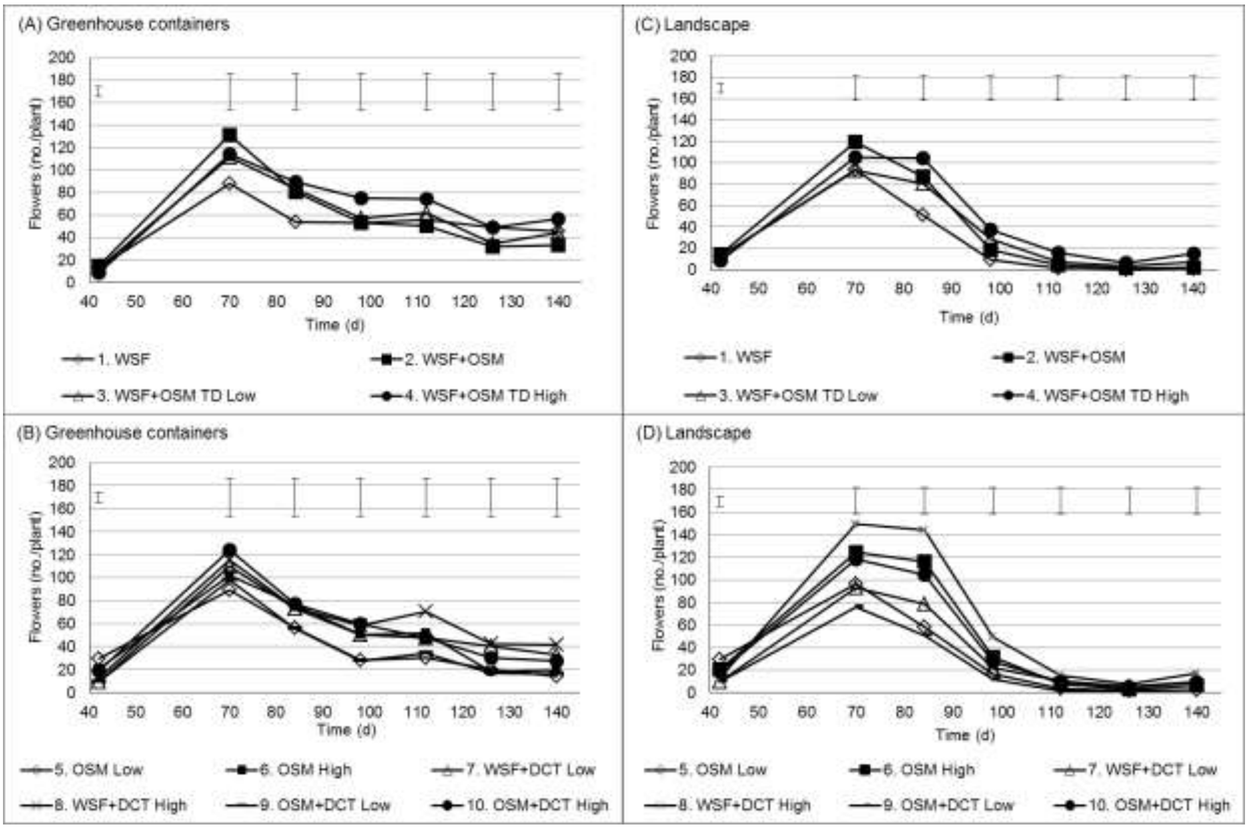

Figure 3 - Effect of controlled release fertilizer (CRF) and water soluble fertilizer (WSF) treatments on number of flower count per plant during the consumer phase in greenhouse containers (A and B) or a landscape planting (C and D) beginning at day 42

At the end of the consumer phase (140 d.), tissue-N concentration (Table 3) was lower than the recommended range of 3.85-7.60% (MILLS; JONES, 1996) for all treatments. There were differences between fertilizer treatments in tissue-N in both the greenhouse (p=0.01) and the landscape (p=0.002). Tissue-N was lowest in the

WSF only treatment (1) in both environments. Tissue-N in the greenhouse-grown plants was significantly lower in WSF treatment 1 than with high rates of WSF+OSM TD (treatment 4) or WSF+DCT (treatment 8). In the landscape, tissue-N in the WSF treatment 1 was lower than either WSF+OSM TD treatments (3 and 4), or the high rate of incorporated OSM (treatment 6).

Nutrient release in the Greenhouse Without Plants: Nutrient release over time differed between CRF treatments in the sand-containing LCUs without plants or WSF in the greenhouse (Figure 4). Throughout the experiment, as expected, measured N release from the washed sand control was close to zero. During the production phase (up to 42 d., OSM, and OSM+DCT had similar release curves. However, initial release from DCT was close to zero for the first 15 d., and then had a similar release rate with other CRF products, as represented by the parallel gradients of curves in figure 4. From day 63 onward, the OSM+DCT product had a faster release rate than OSM or OSM TD. Faster release of OSM+DCT than OSM alone was not expected. However, polymers may differ between the OSM product that was formulated in the US, compared with the OSM+DCT product manufactured in Europe. By day 42, at the end of the production phase, OSM, and OSM+DCT had released between 42.0 to 44.1% of applied N. In contrast, DCT had released only half this level (21.0%), which would result in greater potential release during the consumer phase. At the end of the consumer phase, 82.1% of OSM, 91.2% of OSM+DCT, and 65.9% of DCT were released. Throughout the LCU experiment, OSM TD had a similar release rate to the incorporated OSM. In the petunia experiment, however, OSM was not top-dressed until 42 d. and the top-dressed LCU data were therefore out of phase with the planted petunia experiment. By the end of the consumer phase at 140 d., lower concentration of nutrients would therefore have been released from OSM TD applied at petunia at 42 d., compared with incorporated OSM applied at day 0.

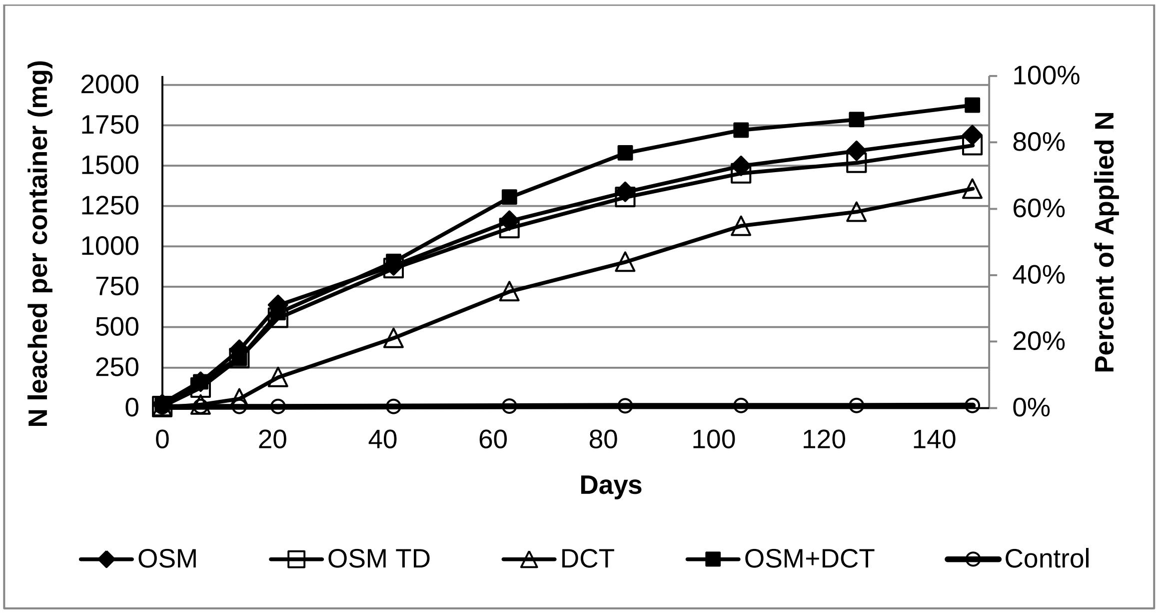

Figure 4 - Effect of fertilizers applied to each LCU (sand container without plants with clear water only) for greenhouse fertilizer experiment without plants with five treatments, representing a control (no fertilizer), or the high rates of incorporated Osmocote (OSM), Dual-coated controlled release fertilizer (DCT), OSM+DCT (blend of Osmocote Exact™ and DCT), and OSM top-dressed on total cumulative nitrogen released (mg) and the percent nitrogen (N) released out of the cumulative N applied

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

Based on the Richards function, the OSM product released 50% N after 88, 47, or 32 d at 10, 21, or 32 ^{o}C, respectively. The release rate for OSM+DCT required 111, 49, or 31 d for 50% release at 10, 21, or 32 ^{o}C. The DCT product had a slower initial release rate, with 100 or 62 d required for 50% release of N at 21 or 32 ^{o}C. Only 36% of N was released from DCT at 10 ºC after 182 d. The Richards function estimated 251 d would be required for DCT to release 50% of nutrients at 10 ºC (although this was far longer than the tested conditions).

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

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

Economic Analysis. The lowest cost treatment was WSF only (treatment 1) at $0.02/container (Table 4). Many greenhouse growers produce plants using WSF rather than CRF because of lower production cost and the flexibility of being able to vary applied nutrient concentration during crop growth.

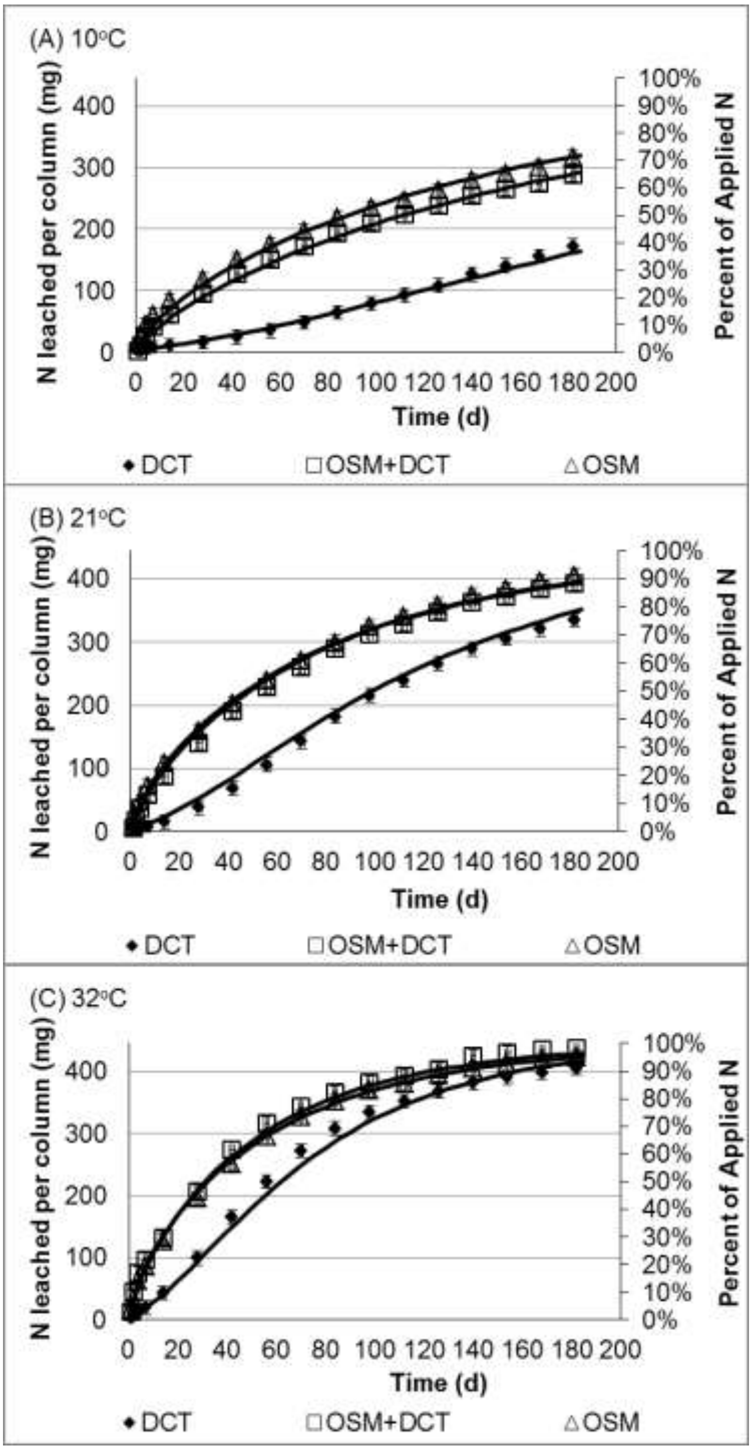

Figure 5 - Effect of controlled release fertilizers on total cumulative nitrogen released (mg per column) and the percent of nitrogen (N) released/N applied in three growth chamber incubation temperatures (10, 21 and 32 °C). Curves represent the Richards function fitted separately by fertilizer, including the temperature function in equation (2)

Table 4 - Production cost per container ($ per plant) of petunia 'Supertunia Vista Bubblegum' fertilizer in 2.84 L containers for the tested controlled release fertilizer (CRF) and water soluble fertilizer (WSF) strategies. The labor cost of applying fertilizer was only considered for treatments with top-dressed CRF, because labor cost to prepare WSF or apply CRF before planting would be minor. Cost estimates only consider the production phase, because during the consumer phase only clear water was applied

	(1) WSF	(2) WSF + OSM	(3) WSF + OSM TD Low	(4) WSF + OSM TD High	(5) OSM Low	(6) OSM High	(7) WSF + DCT Low	(8) WSF + DCT High	(9) OSM + DCT Low	(10) OSM + DCT High
CRF Costs										
Cost per 50 lb bag (US$)		$83.7	$83.75	$83.75	$83.75	$83.75	$100.5	$100.5	$92.13	$92.13
Cost per gram		$0.004	$0.004	$0.004	$0.004	$0.004	$0.004	$0.004	$0.004	$0.004
CRF weight (g/container)		5.5	8.2	13.7	8.2	13.7	8.8	14.7	8.2	13.7
Material cost per container		$0.02	$0.030	$0.051	$0.030	$0.051	$0.039	$0.065	$0.033	$0.056
Labor cost per container (top-dressed)[z]			$0.013	$0.013						
Cost per container of CRF (material, labor)		$0.02	$0.044	$0.064	$0.030	$0.051	$0.039	$0.065	$0.033	$0.056
WSF Costs										
Concentration of fertilizer ($mg \cdot L^{-1}$ N)	200	100	200	200			200	200		
N applied (g)	1.08	0.54	1.08	1.08			1.08	1.08		
Total cost per container WSF (materials)[y]	$0.02	$0.01	$0.020	$0.020			$0.020	$0.020		
CRF cost	$0.00	$0.02	$0.044	$0.064	$0.030	$0.051	$0.039	$0.065	$0.033	$0.056
WSF cost	$0.02	$0.01	$0.020	$0.020	$0.000	$0.000	$0.020	$0.020	$0.000	$0.000
Total cost per container	**$0.02**	**$0.03**	**$0.064**	**$0.084**	**$0.030**	**$0.051**	**$0.059**	**$0.085**	**$0.033**	**$0.056**
Additional cost beyond WSF only	**$0.00**	**$0.01**	**$0.044**	**$0.064**	**$0.010**	**$0.031**	**$0.039**	**$0.065**	**$0.013**	**$0.036**

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

[y] WSF cost assumes $31.20 per 11.3-kg bag with 15% N, giving a cost per gram of N equal to $0.018.

Using incorporated OSM (treatments 5 and 6) increased cost by $0.010 to $0.031 per container at the low or high experimental rates, respectively, compared with WSF only. However, based on results from the petunia experiment, improved plant performance with residual fertilizer from CRF has potential to be promoted in product marketing. A slight increase in sales price could easily pay for the added cost of CRF compared with WSF only.

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

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

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

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

3.4 Conclusions

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

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

Plants grown with WSF only during the production phase, without residual fertilizer, were severely nutrient-deficient (as quantified by chlorophyll index and flower number) after 42 d in the consumer phase (day 84, Figures 2 and 3). In contrast, any plants receiving CRF were still growing vigorously after 42 d in the consumer phase, especially when OSM (incorporated or top-dressed) or DCT were applied at a high rate.

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

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

An economic analysis indicated the cost per trade 1-gallon (2.84 L) container ranged from $0.020 per container with WSF only, to $0.051 with incorporated OSM,

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

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