NUTRIENT RELEASE PATTERNS OF CONTROLLED RELEASE FERTILIZERS USED IN THE ORNAMENTAL HORTICULTURE INDUSTRY OF SOUTH FLORIDA

By

HENRIQUE MAYER

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2010

To my family: Ingrid, Patricia, Gabriela, and Melanie

ACKNOWLEDGMENTS

I would like to give my sincere gratitude and appreciation to Dr. Yuncong Li and Dr. Xiaohui Fan for their guidance, problem solving, good comments, and inspiration. Achieving this degree would not have been possible without their support. I would also like to thank the other members of my supervisory committee, Dr. George Fitzpatrick, Dr. Samira Daroub, Dr. Rafael Muñoz-Carpena, Dr. Qingren Wang, and Dr. Kati W. Migliaccio whose knowledge and comments contributed significantly to this research project. Further, my special thanks go to Yu Guigin, Laura Rosado, Sikavas Na-Lampang, Gudong Liu, Daniel Irick, Nick Kiggundu, Gaelan Jones, and all the personnel of the Tropical Research and Education Center Soil and Water laboratory for their friendly assistance through laboratory analysis and field tasks for my research. Thanks also go to BWI, Harrell's, and Kerry Bromeliads for providing materials for this research. Finally, I would like to thank all the members of my family, especially my wife, for their constant support and help during these long years.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

NUTRIENT RELEASE PATTERNS OF CONTROLLED RELEASE FERTILIZERS USED IN THE ORNAMENTAL HORTICULTURE INDUSTRY OF SOUTH FLORIDA

By

Henrique Mayer

August 2010

Chair: Yuncong Li
Major: Soil and Water Science

Use of controlled release fertilizer (CRF) is one of the Best Management Practices (BMPs) utilized by the ornamental horticulture industry in South Florida to improve nutrient use efficiency (NUE) and reduce detrimental environmental effects. CRF manufacturers generally claim nutrient release will last for a specific period of time (4, 6, 9, or 12 months). The prevalence of relatively high temperatures throughout the year, a typical feature of South Florida climatic conditions, could result in faster nitrogen (N) release rates than those stated by CRF manufacturers and published in their application guidelines. In Florida, no official laboratory method exists that can verify the N release rates provided on CRF product labels. A laboratory study was conducted to investigate the effect of temperature on the N release patterns of five polymer-coated fertilizers (Nutricote® 18-6-8 Type 140, Multicote® 4 Extra 15-7-15 +1.2 Mg, Kingenta® 20-8-10 six months, Osmocote® Plus 15-9-12 3-4 months, and Harrell's® Polyon 16-6-11 5-6 months). A long term fertilizer incubation method (180 days), in water at 25° Celsius (C), was employed to attain polynomial equations of N release as a function of time. A short term or quick extraction method (168 hours or 7 days), in water at 100°C, has also been developed to assess N release under accelerated laboratory conditions using a Constant Temperature Extractor (CTE). A nitrogen release prediction equation was developed, using

regression analysis, for each of the CRFs with high accuracy (R^2>0.97). Results suggested that all CRFs tested have shorter N release longevities than the label claimed. High correlation (R^2>0.97) values indicate N release patterns can be predicted accurately at 25°C. The quick laboratory method (100°C) shows a high correlation to 25°C methods and can be used to predict N releases from CRFs within a few days. In order to evaluate N uptake by plants, liners of *Ficus elastica* 'Robusta' were grown in a greenhouse in 3.8 L containers with Premier Promix BX / Mycorise Pro 3.8 potting media for 180 days. Plant biomass and N uptake were measured every 30 days. All tested fertilizers increased plant biomass compared to the control treatment which did not receive supplemental nutrition. *F. elastica* leaf N concentrations ranged from 1.2% at the mature stage (150 days after planting (DAP)) to 3.4% at the juvenile stage (30 DAP). The ranges of N concentrations were 0.8-1.5 for both stems and roots. The highest nitrogen use efficiency (NUE) came from F5 (an alkyd resin-based product) treatment with 40% while the lowest was from F6 (a Polyon® material) treatment with 31%. Plant biomass and N uptakes were highly correlated to N release from CRFs measured at 25°C (r>0.94). This study indicated that CRFs hold great promise to improve plant growth and NUE but additional research on characterization, plant response, environmental effects, and economics is needed.

CHAPTER 1
INTRODUCTION

Florida nursery and landscape plant industries include a wide range of businesses, including field nurseries, greenhouses, shadehouses, landscape design, installation and maintenance service, lawn and garden stores, retail establishments and others. The 2005 Florida Nursery Growers and Landscape Association (FNGLA) and University of Florida (UF) study showed that the State of Florida produces the second largest nursery crop in the United States (US) after California (Hodges and Haydu, 2005). Total annual sales of this industry totaled $15 billion with nurseries, landscape, and garden and retail centers accounting for $3, $5 and $7 billion, respectively. Cumulatively, these businesses generate more than 320,000 job opportunities. Nursery crops, along with fruits, vegetables, and forestry productions, are one of the largest agricultural commodity groups in Florida. There are 7,952 registered nurseries in the state, which represent 24,000 hectares (ha) of container production and 10,000 ha of field production. Almost half of the production facilities are located within 2 kilometers (km) of an urban center. The close proximity to urban centers can result in undesired off-site effects. Miami-Dade, Palm Beach, Orange, and Hillsborough counties are the top four counties for employment impact and sales related to the nursery industry. Use of fertilizers, pesticides, and other inputs also are very high in these counties.

Excessive use of fertilizers presents potential problems especially with container-grown plants because roots are confined to small volumes, and the storage capacity of growth media for nutrients and water are limited. Frequent irrigation and fertilization are necessary to maintain the soil moisture and nutrient level, which may enhance leaching and runoff losses (Oertli, 1980). Therefore, it is very important to select a proper fertilizer type, rate, and application technique in order to match the plant's nutrient and growth requirements as precisely as possible (Trenkel, 1997).

In an effort to improve water quality and prevent groundwater contamination the Florida Department of Agriculture and Consumer Service (FDACS) created the Best Management Practices (BMP) program for container plant production in 1994. Fertilization management is very important for plant production and the use of controlled release fertilizer (CRF) is now recommended in the BMP document (Sartain and Kruse, 2001).

The Florida Department of Environmental Protection (DEP) created the Green-Industry Best Management Practices for Protection of Water Resources **(**GI-BMP) for the professional landscaper in 2001. The program encourages the use of fertilizers with a minimum of 50% nitrogen (N) as a slow release. Today some cities like Naples, Fort Myers, Port Charlotte, and Orlando are enforcing the program. The goal is to make the program mandatory in all of Florida by 2014 (UF, 2009).

CRFs have the potential to synchronize nutrient release patterns with crop demand. This will optimize nutrient uptake efficiency and increase plant biomass while reducing nutrient losses to the environment. CRFs product labels usually include a claim quantifying the nutrient release rate (e.g. 3, 6, 9 and 12 months). Verification of the nutrient release pattern is critical for evaluation of the effectiveness of these fertilizers; however, there are no official laboratory methods that can verify such claims. The main factor that controls the nutrient release rate from CRFs is the temperature (Oertli and Lunt, 1962; Broschat and Moore, 2007). Climatic conditions of South Florida, specifically the relatively high temperature throughout most of the year, can result in the longevity of CRFs to be lower than the manufacturer label claims. Furthermore, it is important to determine the longevity of the CRFs because they are becoming increasingly more popular in South Florida. Approximately 60% of the big- and middle- size nurseries in Miami-Dade County use CRFs, which account for approximately 7% to 20% of the total farming related business expenses, excluding labor (Clarence Chamorro, unpublished data, 2010).

The objectives of this study were to (1) establish N release curves of selected CRFs using a standard water extraction method (6 months) at 25° Celsius (C), (2) develop a quick laboratory method (one that would require less than 7 days) for N release patterns from CRFs at 100°C, (3) build a relationship between the laboratory incubation method and the weight loss method within a greenhouse, and (4) evaluate the relationship between N release patterns of five CRFs and biomass and N uptake of *Ficus elastica* 'Robusta' grown in a greenhouse.

CHAPTER 2
LITERATURE REVIEW

History of Slow Release Fertilizers and Controlled Release Fertilizers

Slow release fertilizers (SRFs) and controlled release fertilizer (CRFs) have been available since the 1950s, although most of the advances in the development of these products were made in the 1980s and 1990s. The first CRF sources to become commercially available were strictly nitrogen (N). CRF technology has expanded to include potassium (K), phosphorus (P), and other nutrients including micronutrients. SRF/CRF employs several mechanisms to reduce the amount of nutrient available from the fertilizer at any one time (Obreza et al., 2006). Elemental sulfur (S) is commonly used as a coating material because it is inexpensive and has a low melting point (Trenkel, 1997). Molten sulfur could be sprayed over the prills of urea creating sulfur-coated urea (SCU). The product was first produced commercially by the Tennessee Valley Authority (TVA) for almost 40 years (Trenkel, 1997). In order to seal cracks in the coating and reduce microbial degradation, a layer of wax sealant is applied to SCU. At the end, attapulgite, a type of clay, is added as a conditioner. One disadvantage of the product is that the release rate is not uniform because the coating has cracks as imperfections (Shaviv, 2001). On average, one third of the product is released too fast ("burst"), and about one third is released too slow ("lock-off") (Shaviv, 2001). To have more control over the N release from the SCU, an additional layer of resin was added. The final product is called polymer sulfur-coated urea (PSCU). Although the product has better properties than SCU, PSCU still has a burst and tailing effect on plants (Shaviv, 2001).

Another type of resin coating is an alkyd-type called osmocote (Scotts-Sierra Horticultural Products, Marysville, OH), which was introduced in California in 1967. The resin consists of a copolymer of dicyclopentadiene with a glycerol ester (Sartain et al., 2001). Manufacturers can control the nutrient release rate by varying the coating thickness or composition of the CRFs. This technology could be applied to a large variety of fertilizer like N-P-K, urea, and others. Normally, the coating weight varies from 10% to 20% of the total weight.

The osmocote market has mainly been limited to high value plants such as commercial ornamental nurseries, greenhouses, citrus and strawberry production. Another type of coating is based on a polyurethane-like coating. It is obtained by reacting poly-isocyanates with polyols on the surface of the fertilizer and forming an attrition-resistant CRF. This technology is called Reacted Layer Coated Fertilizer (RLCF). The RLCF can be applied to many prilled materials. It has the advantage to accomplish good control over the nutrient release pattern and rate. Some commonly marked products with this technology are: Polyon (Pursell Technologies, Sylacauga, AL), Plantacote (Aglukon GmbH, Dusseldorf, Germany), and Multicote (Haifa Chemical, Haifa, Israel) (Trenkel, 1997; Shaviv, 2001).

Other technology for coating granular fertilizers is through utilization of thermoplastic resins as coating substances. The coatings are dissolved in fast-drying chlorinated hydrocarbon solvent. Because the thermoplastic polymers used are highly impermeable in water, to obtain the desired diffusion characteristics ethylene-vinyl acetate and surfactants must be added as a release controlling agents. The release pattern is controlled by the level of release-controlling agents. Release rates can also be altered by blending talc into the coating. The coating could be applied to many granular and prilled fertilizers (Sartain and Kruse, 2001). Some commonly marketed products are Meister products (Chisso – Asahi Fertilizer Corp., Tokyo, Japan), and Nutricote (Chisso – Asahi Fertilizer Corp., Tokyo, Japan).

Definitions and Types of Slow Release Fertilizers and Controlled Release Fertilizers

The Association of American Plant Food Control Officials (AAPFCO) define SRFs and CRFs as fertilizers as products that contain a plant nutrient in a form which; a) after application, the plant uptake is delayed, or b) longer availability of the products compared with other quick release fertilizers such as urea (AAPFCO, 1995). The main difference between CRF and SRF is that in the CRF, the factors affecting the rate, pattern, and duration of release are well known and controllable, while in the case of SRFs, the pattern, rate, and duration of release are not well controlled. Release characteristics are affected by conditions such as manipulation, storage, and transportation. Soil moisture content and biological activity also could have an effect (Shaviv, 2001). The Comité Européen de Normalisation proposed that for a fertilizer to be described as SRF it needs to follow three criteria under 25° Celsius (C); (i) less than 15% of the nutrients release in 24 hours, (ii) less than 75% release in 28 days, and (iii) at least about 75% release by the stated release time (Trenkel, 1997).

CRFs and SRFs can be classified into four types; (i) materials with low solubility with organic-N compounds that can be biologically or chemically decomposed, e.g. urea-formaldehyde, and isobutyledene-diurea (IBDU), (ii) low-solubility, inorganic compounds such as partially acidulated phosphate rock (PAPR) and metal ammonium phosphates, (iii) water soluble or relatively water soluble materials that gradually decompose and release the plant nutrients (e.g. guanylurea salts), and (iv) fertilizers in which the release is controlled by a physical barrier. The barrier can be further divided into three groups; a) organic polymer coated fertilizer (PCF) such as osmocote, polyon, multicote, nutricote, which are widely used in container nursery plant production (Husby et al., 2003), b) inorganic such as sulfur- or mineral-based coatings materials (e.g. SCU), and c) fertilizers with a combined coating of Polymer/ Sulfur-Coating (e.g. PSCF, PSCU) (Shaviv, 2005; Trenkel, 1997).

PCFs represent the fastest growing segment of controlled release fertilizer technology because of their improved flexibility in nutrient release patterns compared with other CRF products and the flexibility in controlling the release of other nutrients in addition to N (Sartain, 1999). Several technologies have been produced depending on the coating material and coating process. Some examples of coating technologies are polyurethane-based, like Reactive Layers Coating (RLC, Pursell) or Polyon®, Multicote® (Haifa Chemicals Inc.), polyolefin-based, like Meister®, and Nutricote® (Chisso); alkyd resin-based like Osmocote® (Scotts). In general, the coating material represents 3% to 4% of the total weight of the finished product in the case of reactive layer coating (RLC) technology and 15% in the case of conventional coating polymers (Trenkel, 1997).

Advantages of Controlled Release Fertilizer

Increase Nitrogen Use Efficiency

For container nursery growers, maintaining continuous optimum nutrient level is very important for rapid production of quality plants. Growers use slow release fertilizers to make sure that mineral nutrients do not restrict plant growth. Fertilizer nutrient recovery is defined as the total nutrient absorbed by the plant as a percentage of total nutrient supplied by that fertilizer for a given time (Craig, et al., 2003). The use of CRF can improve nitrogen use efficiency (NUE) while reducing environmental hazard. This is mainly because CRF can couple nutrient delivery with plant demand by having a pattern of supply congruent to plant growth.

Less Leaching and Runoff

In most cases, due to the microbial activity mineral N is likely to be oxidized to nitrate. Due to the high water solubility of nitrate, relatively high quantities of the applied N may potentially be leached and cause surface and ground water contamination. This happens more often in nurseries that use soilless growing substrates that are irrigated more than once a day (Foster et al., 1983). In the United States (US), nitrate concentration standards in potable water have been set at 10 milligrams of nitrogen per liter (mg N/L). Any technology or nutrient management system that reduces the detrimental effect of nitrogen is desirable (Shaviv, 2001). Due to the gradual release of nutrients, CRFs can significantly reduce possible leaching of nitrate between applications and plant uptake. Less leaching and volatilization decrease the risk of environmental pollution (Oertli, 1980; Trenkel, 1997).

Less Ammonia Volatilization and Nitrous Oxide Emissions

In calcareous and alkaline soils of South Florida, surface applied products like ammonium and urea fertilizers are potential sources of ammonia (NH_3) volatilization. The emission can cause damage to vegetation or may be oxidized into nitric acid and form acid rain when coupled with sulfuric acid (Shaviv, 2001). CRFs reduce volatilization losses of ammonia since only a small fraction of the total application is present in a readily available form at any one moment. Reduction in volatilization losses decreases the risk of environmental pollution (Oertli, 1980; Trenkel, 1997).

Use of standard N fertilizers in agriculture effects traces gas emission, particularly nitrous oxide (N_2O) and nitrogen monoxide (NO). Soil microbial processes, temperature, soil water content, and mineral-N content control N trace gas emission. During the process of nitrification and de-nitrification, only a small fraction of ammonium is converted to NO, N_2O, and N_2. Emission of N_2O is the main concern for causing ozone depletion, atmospheric “holes” and global warming (Shaviv, 2001). CRFs contribute to reduce gas emissions (N_2O) due to the slow release of N.

Less Toxicity and Salt Content

It is important for a grower to understand how a particular fertilizer works and to know its designed release rate before applying it. For greenhouse and nursery crops, controlled release fertilizers are typically incorporated into the growing media or top dressed after planting (Obreza and Sartain, 2010). Because of the slow dissolution of nutrients, CRFs reduce the toxicity to plants, particularly to seedlings. Due to less toxicity and salt content, substantially larger amounts of CRFs can be applied less frequently as compared to conventional soluble fertilizers.

Low Labor Cost

Plant nutrient management is intensive when producing high value horticultural crops that demand high fertilizer inputs. Controlled release fertilizers can meet the crop nutrient demand for the entire season through a single application. Saving on labor cost constitutes the main benefit for CRF use. Decreased application frequency results in saving in labor cost, time and energy. The utilization of CRF could be increased because they provide good qualities like increased nutrient efficiency, maintained yields, and reduction of nutrient pollution (Shaviv, 2001).

Disadvantages of Controlled Release Fertilizers

Lack of Standardized Methods

As Trenkel (1997) mention there are no standardized methods for reliable determination of nutrient release pattern available yet. There appear to be a lack of correlation between data from the laboratory which are available to the consumer and actual data collected from the field Lack of standardized methods for determination of nutrient release patterns is a huge disadvantage of the CRF because it is difficult to assure compliance with the label claims by the manufacturers. Existence of an appropriate methodology to evaluate a wide range of materials will allow regulators and producers monitor more efficiently, and faster CRF nutrient release patterns (Cabrera, 1997; Sartain et al., 2004).

Accumulation of Salts

Another disadvantage is the possibility that nutrient release from CRF may continue during the non-cropped season and result in leaching losses or accumulation of toxic levels of salts (Oertli, 1980). A study by Meadows and Fuller (1983) revealed that the release curve of the product could be too short to meet the plants demands for nutrients. The nutrient release periods of several CRFs were shorter than those claimed by their manufacturers. The release of the S-coating may occur too fast (burst), causing damage to the crop and to the environment compared with non-coated water soluble fertilizers. While if the coating is too closely applied, it could cause the nutrients contained in the granules to not be released quickly (lock-off) (Lamont et al., 1987; Trenkel, 1997; Shaviv, 2001; Rosen et al., 2006). In some cases, S-coated fertilizers may increase the acidity of the soil, and the coating agents may decompose very slowly leaving undesired residues of synthetic materials in the soil.

High Cost

The greatest disadvantage for CRF is the high manufacturing cost as compared with conventional fertilizers, which may be as much as three to ten times higher than the corresponding standard fertilizer products. The higher production costs are due to the expensive coating material, equipment and energy cost. The coating process requires a more complicated technical process. The higher cost limits the CRF use to high value crops such as ornamentals, vegetables, rice, fruits, and turf (Trenkel, 1997; Simonne et al., 2005).

Consumption of Controlled Release Fertilizers

Globally

Use of CRF is growing faster than soluble materials although CRF use represents only 3% to 4% of the total fertilizer used. The US and Canada account for about 66% of the total amount used. All European countries and Japan consume the rest at the same proportion. In Japan, almost all CRFs are used for vegetables, rice, and fruits. In Canada, US, and Europe, the situation is different. Ninety percent of the total consumption is used in golf courses, nurseries, lawn and landscape. Only 10% is used for food production such as vegetables, strawberries, melons, citrus, and other fruits. However, the increase use of CRF in food production is more important than in non-food markets. Approximately 75% of the fertilizers used for food crops are coated CRFs with an annual average increase rate of 10% in the use of polymer coated fertilizers (PCFs). The supply of fertilizers from 1983 to 1996 grew 76% in the US, and 257% in Japan during the same period (Trenkel, 1997). For 1996, Trenkel (1997) estimated the total amount of SRF/CRF consumed worldwide at 562,000 tons (Table 2-1). In Japan from 1985 to 1994, the consumption increased by 470%. Polymer-coated N-P-K products have become the most important fertilizer used in Japanese agriculture. The annual growth rate in Europe from 1980 to 1996 is only 1% (Trenkel, 1997).

United States

In the US, the production of SRFs and CRFs increased by 76% from 1983 to 1996 (Trenkel, 1997). During the last 15 years, the consumption of CRFs has increased more than any other type (about 10% per year). Nursery production and greenhouses, landscape, golf courses, and home yards are the main users (Landels, 1994; Trenkel, 1997).

Florida

Table 2-2 illustrates the historical consumption of fertilizer in Florida from 1998 to 2006. The farm category includes fertilizers for citrus growers, cattle ranchers, farmers, vegetable growers, and others. The non-farm category includes fertilizers for lawn turf, golf-athletic field, garden, container and greenhouse nurseries. The majority of SRF and CRF used in Florida is within the container and greenhouse nursery category. The non-farm category has increased from 1998 to 2006 from 10% to 27% of the total. On the other hand, the farm portion showed a decrease from 90% to 75%. These data reflect the enormous growth of the SRF and CRF market consumption in Florida. South Florida (south of Lake Okeechobee) has the biggest growth in the state (non published, Gary Bird, 2010)

Factors Affecting Consumption of Controlled Release Fertilizers Release

Temperature

CRFs nutrient release is mainly affected by temperature (Oertli and Lunt, 1962; Lamont et al., 1987; Kochba et al., 1990; Huett et al., 2000; Husby et al., 2003). Ingram (1981) found that the temperatures within black plastic nursery containers in Florida increased from 21°C to 40°C or more when exposed to the sun. Increase in temperature significantly increases nutrient release (e.g. an increase in temperature from 10°C to 20°C almost doubled the initial rate). Oertli and Lunt (1962) speculated that properties of the coating materials could possibly change with temperature because the release rate increased greater than expected from a simple diffusion mechanism. Husby et al. (2003) studied the nutrient release patterns of three PCFs placed in sand-filled columns under different temperatures. When temperature increased from 20°C to 40°C, they found an increase of nutrient release. When the temperature decreased from 40°C to 20°C, the nutrient release rate decreased. They suggested that the changes in the daily nursery container temperature may have rapid effects on container nutrient level and nutrient release longevity of CRFs. Ahmed et al. (1963) showed in a study that nutrient release rate was directly related to temperature. Kochba et al. (1990) determined in a soil incubation study that the change of nutrient release rate with temperature is expected to be an exponential function since vapor pressure is exponential function of temperature. Cabrera (1997) studied the N leaching patterns of different CRFs in containers under greenhouse conditions. It was found that some CRFs exhibited N leaching patterns that closely followed changes in average daily ambient temperature over the season. Lamont et al. (1987) investigated the nutrient release rate of CRFs in beakers with distilled water at temperatures between 5°C and 45°C. It was found that the nutrient release rate was affected by both incubation temperature and time. Generally, as temperature increased, nutrient release rate also increased. After a high initial release rate, nutrient release decreased with time. They also found that high temperatures during the first month following planting can cause salt problems to the crop due the high nutrient release; conversely, low temperatures could cause nutrient deficiency due to the slow nutrient release.

Other Factors

Nutrient release is mainly dependent on the soil temperature and moisture permeability of fertilizer polymer coating. It is not appreciably affected by other factors such as pH, cation exchange, salt, texture, biological activity, and redox (Trenkel, 1997; Sartain and Kruse, 2001). The moisture permeability can be controlled by the manufacturer by varying the coating material, but the soil temperature is still variable. Oertli and Lunt (1962) found that the release rate was independent of pH, as well as microbial activity. Thickness of the coating has a direct effect on the release rate. Heavily coated fertilizer formulations have low release rates and lightly coated ones have higher release rates. They also found that nitrate and ammonia were released more rapidly than potassium and phosphate under comparable environmental conditions. Cabrera (1997) found a decrease of nutrient release rates when the product is applied as a top-dressing instead of incorporated. The release rate from CRFs can also be affected by composition of the coating and the fertilizer N source being coated (Sartain and Kruse, 2001).

Lunt and Oertli (1962) found that moisture levels exceeding the range of permanent wilting percentage to field capacity in a loam soil did not significantly affect the rate of nutrient transfer through the membrane of coated fertilizers mixed in the soil. Kochba et al. (1990) hypothesized that in the nutrient release rate the substrate vapor pressure is the rate limiting step, since lowering the substrate moisture level within range of field capacity does not have a marked effect on the substrate vapor pressure.

Predicting Nutrient Release

Effective utilization and proper management of nutrient application require tools for predicting the nutrient release under various soil and environmental conditions. Efforts have been made in the past to predict and measure the nutrient release pattern from CRF using different models and techniques. Most of the models assume that the nutrient release from CRFs is either controlled by the rate of water vapor that penetrate through the coating or by the rate of solute diffusion from the fertilizer (Shaviv, 2001). Because CRF release pattern is most affected by temperature and not significantly affected by soil properties, it is possible to predict the nutrient release.

Mechanism of Nutrient Release

The mechanism of nutrient release from CRF was described by Shaviv (2001) as water in the form of vapor passes through the coating and then the vapor condenses and dissolves the fertilizer core inducing an increase in the internal pressure. At this point, two events can occur. The coating can break and the entire content of the granule is released immediately. Goertz (1995) called this sequence the “failure mechanism” or “catastrophic release”. It is more typical in the inorganic type of coating such as S, which are fragile and non-elastic coatings. If the coating resists the internal pressure, the fertilizer could be released either by diffusion forced by a concentration gradient across the coating, by mass flow driven by a pressure gradient, or by a combination of the two. This is called the “diffusion mechanism” and is more characteristic in PCFs with polyurethane, polyolefin, and alkyd resin coatings. The main characteristic of the diffusion mechanism is the gradual fertilizer release which has a sigmoidal shape when plotted. However, different properties in a group of granules could cause a different release pattern when compared with an individual granule (Shaviv, 2001; 2005). Shaviv (2001) reported that nutrient release consists of three stages: (1) the initial stages or “lag period” during which almost no release is observed, (2) the constant release stage, and (3) the last or mature stage where a gradual reduction of release rate occurs. Oertli and Lunt (1962) used several elution and leaching experiments and observed that the mechanism controlling the nutrient release is the diffusion of salts out of the fertilizer prills.

Traditional Field and Laboratory Methods for Nitrogen Release

Sartain et al. (2004) used several soil incubation methodologies at room temperature to measure N release from CRFs. Initially they worked with a mixture of sand, organic matter, soil, and CRFs inside plastic bags. The media within the plastic bags was leached, and the leachate was analyzed for N. The initial results of these experiments were variable because the N recovery was very poor due to high ammonia volatilization. They subsequently introduced an ammonium trap and the plastic bags were replaced with jars. After leaching the media, only 60% to 80% of the N was recovered. The poor recovery was due to a fixation of ammonium N by the organic matter. They eliminated the organic matter from the incubation media using only sand. Finally, they introduced the lysimeter technique to characterize nutrient release from CRFs under standard soil, temperature, and moisture conditions. After 270 days, leachates were collected and N was analyzed. Medina et al. (2008) conducted a one year experiment with CRFs in mesh bags under citrus trees in ambient temperature and moist conditions. Medina et al. (2009) working with SRFs and combinations of slow-release/water soluble fertilizers in the laboratory developed a regression model that allows prediction of the N release from the SRFs in a short period of time. They worked in the laboratory with a mixture of sand and soil with the N source inside a lysimeter and used an extraction solution under different temperatures.

The nutrient release profile of most commercial SRF materials can be generated by accelerating their natural release mechanism in a laboratory setting. Various increasingly aggressive solvent extraction procedures were performed, such as a jacketed chromatography column (Sartain et al., 2004). This procedure provided the ability to maintain temperature and allow a flexible continuous extraction flow scheme. Extraction solutions used were water and 0.2% citric acid both at 25°C and 65°C.

It appears that the accelerated laboratory extraction procedure could successfully predict the N release rate of slow-release N sources. This procedure will allow manufacturers to increase quality control of SRF and CRF products and regulators to make judgments of SRF and CRF efficiency. However, it has proven to be more difficult to estimate N release curves for some types of SRF materials, as well as mixtures of slow release and soluble release materials. More data is needed to establish reproducible predictive equations (Medina et al., 2009)

Regulations and Registration

During the last few decades, several unique technologies have been developed to characterize the release properties of SRF materials. These technologies are product-specific and based on the regulation and analysis of each material. However, with the constant introduction of new SRF products, an individualized approach to regulation is inadequate to verify manufacturer claims regarding material performance. The use of several technologies to evaluate nutrient release properties also creates consumer confusion regarding choices when purchasing SRFs and lack of protection against ineffective products. An SRF and CRF task force was established in 1994 by the AAPFCO to address issues regarding the effective regulation and analysis of SRF materials. Soil incubation methodology and short-term laboratory nutrient extraction methods have been developed to overcome these regulatory issues (Sartain et al., 2004). Regardless of this important market, no universally established legislation exists yet in the US nor in Western Europe or Israel to protect the consumer. Only Japan has introduced required test methods. However, in the future, more legislation and regulation will be needed as the use of CRFs become more popular (AAPFCO, 1995)

Until more appropriate methods are developed, the Association of Analytical Chemists International (AOACI) method 970.04 (15th Edition) is used to confirm the coated slow-release rate and occluded slow-release nutrients whose slow-release characteristics depend on particle size. AOACI method 945.01 (15th Edition) shall be used to determine the water insoluble part when working with inorganic N materials (AAPFCO, 1995)

These methods only utilize a 2 hour time frame and do not standardize temperature. They are also hampered by examining what is not released over time instead of measuring what is released. Analytical methodology to measure nutrient release rates is essential to lessening the affect of regulatory inconsistencies (Sartain et al., 2004).

Federal Level

In the US, each state regulates its own agricultural policies, including fertilizers. However, if state policy does not meet or exceed the federal regulation, the Federal Environmental Protection Agency (EPA) could impose their policies. The slow release materials have been marketed using many differing names, claims or descriptions for the higher efficiencies of their products. All of these materials have been referred to as a single class of materials called ‘Enhanced Efficiency’ by the AAPFCO. Within the ‘Enhanced Efficiency’ class of materials there are two broad categories: inhibitor materials and slow release materials. The last one is described as materials that delay their nutrient availability for plant uptake relative to a reference soluble material. Historically nitrogen has been the focus of most slow release technology and products developed (Sartain et al., 2004).

State Level

The Florida Department of Agriculture and Consumer Service (FDACS) Bureau of Compliance Monitoring, under the Fertilizer Section, is charged with the enforcement and administration of Florida's Commercial Fertilizer Law, Chapter 576, F.S., and Chapter 5E-1, Florida Administrative Code (F.A.C) (http://www.doacs.state.fl.us/ onestop/aes/fertilizer.html). Any company that intends to market fertilizer in Florida needs to be licensed with FDACS. They will be required to pay an inspection fee of $1.00 per ton for mixed fertilizer, and $0.50 per ton if the fertilizer contains N or phosphate. Specialty fertilizer sold in packages of less than 49 pounds for home and garden use also are required to comply with the Fertilizer Law.

Chapter 5E-1.003 of the Florida Commercial Fertilizer Law defines slow or controlled release fertilizer as “a fertilizer containing a plant nutrient in a form which delays its availability for plant uptake and use after application, or which extends its availability to the plant significantly longer than a reference "rapidly available nutrient fertilizer," such as ammonium nitrate or urea, ammonium phosphate, or potassium chloride”. When one or more slow or controlled release nutrients are claimed or advertised, the list of source materials shall be shown as a footnote and shall be expressed as percent of the actual nutrient. No claim or advertisement shall be made, if the slow or control release nutrient is less than 15% of the total guarantee analysis (Sartain, 1980). In order to train and educate the consumer about the better use of fertilizers, to encourage and promote the proper use of fertilizers, and to improve standards regarding nonagricultural fertilizers, the Florida Legislature created the Consumer Fertilizer Task Force. The University of Florida Institute of Food and Agricultural Sciences (IFAS) has one representative on this task force (Florida Commercial Law, 2009).

Table 2-1. World consumption in metric tons (MT) of manufactured slow release fertilizers and controlled release fertilizers

Region	**1983 (MT)**	**%**	**1996 (MT)**	**%**
US	202,000	62	356,000	64
Western Europe	76,000	24	87,000	15
Japan	44,000	14	119,000	21
Total	322,000	100	562,000	100

Note: Adapted from Trenkel, M. A. 1997. Controlled release and stabilized fertilizers in agriculture. International Fertilizer Industry Assn., Paris.

Table 2-2. Historical total fertilizer consumption in tons (T) in Florida

Year	**Total (T)**	**Farm (T)**	**%**	**Non-Farm (T)**	**%**
1998/99	1,698,000	1,524,000	90	174,000	10
1999/00	2,200,000	1,985,000	90	214,000	10
2000/01	2,178,000	1,760,000	81	417,000	19
2001/02	2,110,000	1,768,000	84	342,000	16
2002/03	2,129,000	1,785,000	84	344,000	16
2003/04	2,038,000	1,614,000	79	424,000	21
2004/05	2,022,000	1,471,000	73	551,000	27
2005/06	1,992,000	1,496,000	75	495,000	25

Note: Adapted from Florida Department of Agriculture and Consumer Service (FDACS), Bureau of Compliance Monitoring. (2004). Archive fertilizer tonnage data.

CHAPTER 3
NITROGEN RELEASE RATES FROM CONTROLLED RELEASE FERTILIZERS PREDICTED BY DIFFERENT METHODS.

Introduction

Controlled release fertilizers (CRFs) are widely used for the production of nursery plants in South Florida. CRFs have the ability to release nutrients that can optimally match the pattern and duration of nutrients uptake by crops, which may reduce nutrients loss and improve nutrients efficiency (Gandeza et al., 1991; Shaviv, 2001). The duration of nutrient release can vary and depends on type and ratio of materials coated on the nutrients (Gandeza et al., 1991). The rate of nutrients release from CRFs is dependent on temperature and is less affected by other factors such as pH and moisture content of the growing medium (Lamont et al., 1987; Fan et al., 2010). The pattern and duration of nutrients release from CRFs are the important factors which are considered by consumers when they choose the type of CRFs to apply to particular crops.

In recent years, several technologies have been developed to characterize the release properties of CRFs materials (Medina et al., 2009). However, there is not one universal standard method for determining the pattern and duration of nutrients release from CRFs (Dai et al., 2008). Trenkel (1997) indicated that dissolving in pure water followed by incubation at 25° Celsius (C) is a traditional method to measure the release characteristics and the number of days required for 75% release of nutrients was considered as the release duration of CRFs. Since pure water dissolving incubation at 25°C may require several months to get one release curve for a CRF product, some researchers have investigated the accelerated laboratory extraction methodology by increasing incubation temperature (Sartain et al., 2004; Dai et al., 2008; Medina et al., 2009; Wang et al., 2009). Medina et al. (2009) predicted constants for a model that characterizes nutrient release as a function of time from long term incubation method. Also, they estimate nutrient release rates under a short period of time and established release constants that were useful in the prediction of the CRF longevity. Dai et al. (2008) predicted the release patterns of CRFs by use of both the cumulative nutrient release equation at 80°C and regression equation of release time needed for some cumulative release rates between 25°C and 80°C. The highest incubation temperatures used in the two experiments were 60°C and 80°C, respectively, and the prediction of nutrient release from CRFs still took longer than 1-3 months. Increasing testing temperature could reduce the time needed for prediction of release rates. At the current time, there is no published study on predicting nutrient release rates using incubation method at 100°C with a short period of time.

Laboratory incubation methods provide the release pattern information under constant temperature condition. However, temperature varies in greenhouse and field situations. Although many types of CRFs are available to crop producers, there is a lack of knowledge about nitrogen (N) release patterns under field conditions (Wilson et al., 2009). Trenkel (1997) pointed out that there was a lack of correlation between laboratory and field measurement. There is no standard method to test N release characteristics in the field. To test N release rate from CRFs in the field, the most common technique is to enclose an amount of CRF into a nylon mesh bag and bury it in the field. These mesh bags are removed over time to estimate N loss (Wilson et al., 2009). Medina et al. (2008) used this weight loss method to determine N release from CRFs used in citrus production. Wilson et al. (2009) determined N release from CRFs in potato fields using the weight loss method. Their research indicated this method can be reliably used as a substitute for chemical analysis to determine N release characteristics of CRFs (Wilson et al., 2009; Medina et al., 2008).

The objectives of this study were to (1) verify an accelerated test procedure at 100°C for prediction of nutrient release at 25°C from CRFs and (2) determine the relationship between the laboratory incubation method and weight loss method in greenhouse.

Materials and Methods

Five CRF products used in this study were obtained from local fertilizer distributors and their basic properties are listed in Table 3-1. All nitrogen was derived from ammonium nitrate, (AN), ammonium phosphate (AP), and potassium nitrate (PN). There was no urea in the ingredients. The release claimed in the label varies from 90 days (F3) to 180 days (F6). Nitrogen release from these products was determined in water over 180 days at 25°C and 7 days (168 hours) at 100°C.

Determination of Release Pattern and Duration from Controlled Release Fertilizers in Water at 25°C

Ten grams (g) of each CRF were weighed, transferred into a nylon bag and then placed in a plastic bottle containing 250 milliliters (mL) of deionized (DI) water (Figure 3-4). All bottles were incubated at 25°C. Each treatment was replicated three times. The samples were collected at 1, 3, 7, 14, 30, 60, 90, 120, 150, and 180 days after incubation began. At each sampling time, all water in the bottles was collected and then 250 mL of new, fresh deionized water was added.

Determination of Release Pattern and Duration from Controlled Release Fertilizers in Water at 100°C

Ten grams of the control release fertilizer was weighed into a small (5 centimeter (cm) x 3 cm) stainless steel wire mesh container. The container was placed in a tight incubation chamber (250 mL) which was located in a water bath of a constant temperature extractor (Model HKQT assembled at Shangdong Agricultural Universiy, Taian, China) (Figure 3-5). The wire mesh container was submerged into 250 mL of deionized water in the incubation chamber. The incubation chamber was preheated to 100°C. The extractions (250 mL) were collected at each sampling time. These times were at approximately 1, 3, 5, 7, 10, 24, 30, 36, 48, 54, 60, 72, 96, 144 and 168 hours following incubation initiation for analysis of N release from CRFs. After each sampling time, all extracted water that was in the incubation chamber was collected and another 250 mL of DI water was added for the subsequent extraction. Cumulative percent of N release as a function of time were plotted to generate the N release curve for the CRFs (Figure 3-9).

Determination of Nutrients Release by a Weight Loss Method

A pot experiment in a greenhouse was conducted at the University of Florida Tropical Research and Education Center (TREC), Homestead, FL in 2009. Three grams of a CRF were weighted into a nylon mesh bag; each fertilizer treatment has 24 replicate bags (Figure 3-6). All bags were buried 5 cm below the soil surface in the pots without plants. All these pots were irrigated in the same rate as the pots growing nursery plants, which was 0.25 liter (L) per container every day. The sampling time was at 3, 7, 30, 60, 90, 120, 150, and 180 days after the bags were buried in pots. Three replicate mesh bags were retrieved at each sampling time. Each mesh bag was placed in a paper bag and then air dried. CRF prills in the bag were removed by hand and then weighed. Based on the amount of weight loss from the CRFs in the bag, the N release rate was estimated with the assumption that N release will be equivalent to the loss of weight of the prills.

Regression Analysis of the Release Times at 25°C and at 100°C

The regression analysis between the release time at 25°C and the time at 100°C for the same CRF was analyzed. A factor quadratic and logarithmic equation were developed, where h represented the hour and d represented the days needed for cumulative release rate of 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% at 100°C and at 25°C. The regression equations were developed by using SAS (v9.1; SAS Institute Inc., Cary NC) and Microsoft Office Excel version 2003 (Microsoft Corp., USA).

Results and Discussion

Cumulative data from five CRFs (F1, F3, F4, F5, and F6; see Table 3-1 for specific characteristics for each CRF) indicated N release rates varied with the type of fertilizers (Figure 3-1). At 2 weeks incubation, F5 and F3 released quickly. The cumulative percentage of N release for the two CRFs was 29.6%. F6 and F1 released moderately, which accounted for about 12% of N released during this time period. F4 released slowly; only 3.5% of N was released. From 2 weeks to 60 days, 93.3% of N in F3 was released. The release rates from F5, F1 and F4 were similar (about 71% of N release); the lowest N release was from F6 at 59.2%. After 90 days incubation, more than 91% of N release was observed from F5, F3, F1 and F4. F3 released 99.8% of applied N, which means F3 had a 3 month release period. After 120 days of incubation, N release from F5, F1 and F4 was close to 100%. These three CRFs had 4 month release period. After 180 days incubation, cumulative N released from F6 reached 98.7%. F6 had a 6 month release period, which was the longest among the five CRFs.

Cumulative N release rates from 5 CRFs and incubation time at 25°C could be adequately described by a quadratic equation in the general form:

$$y = a+bd+cd^2 \qquad (3\text{-}1)$$

where y is the cumulative N released at any day (d), and a, b, and c are constants (Table 3-2). The correlation coefficient R^2 was greater than 0.97 for all of the CRF products and showed a significant correlation between the days of incubation and cumulative N release rate. Regression equation and the coefficient of determination (R^2) for each of the CRFs are listed in Table 3-2.

Assuming that y = 100, and solving the equation:

$$100 = a+bd+cd^2 \qquad (3\text{-}2)$$

the value of d was obtained. The value is the duration (days) in which the CRF will release 100% of the N. All values of duration of nutrient release (except F6) were less than the duration claim by the product's manufacturer (Table 3-3).

Nitrogen Release Rates from Controlled Release Fertilizers at 100°C

Figure 3-2 shows the cumulative N release percentage from 5 CRFs incubated at 100°C. In 24 hours of incubation, the cumulative N release rate was over 80% for CRFs F1, F3, F5 and F6, but for F4, the N released rate was below 60%. During 168 hours of incubation, F6, F5 and F1 had similar N release patterns and the N release rate from F4 was the slowest among the five CRFs. N release rates at 25°C and 100°C were compared (Figures 3-1 and 3-2). Increasing the temperature from 25°C to 100°C accelerated the N release rate. After 72 hours (3 days) of incubation, the N release rate at 100°C was 6.5, 9.7, 23, 42.2 and 81 fold than that at 25°C for F5, F3, F1, F6 and F4, respectively.

Cumulative N release rates from 5 CRFs and incubation time at 100°C could be adequately described by a non linear regression equation in the general form:

$$y = a\mathrm{Ln}(h)+b \qquad (3\text{-}3)$$

where y is the cumulative N released at any hour (h), and a, b are constants (Table 3-4). The correlation coefficient R^2 was greater than 0.90 for all CRF products and showed significant correlations between the hours of incubation and cumulative N release rates.

The Predication of Nitrogen Release Rate at 25°C from Nitrogen Release Rates at 100°C

From the Regression Equation 3-1 at 25°C, the time (d) for cumulative N release of 10, 20, 30, 40 50, 60, 70, 80, 90, and100% was calculated for each CRF, the different times from d1 to d10 were obtained respectively. In the same way, the time (h) for cumulative N release of 10, 20, 30, 40 50, 60, 70, 80, 90, and100% was calculated for each CRF at 100°C from Equation 3-2.

Using the above two pair times calculated from 25 and 100°C, the relationship between the N release times at 25°C as a function of that at 100°C can be developed as follows:

$$D = aLn(H)+b \tag{3-4}$$

where D = release time (days) at 25°C; H = release time (hours) at 100°C (Table 3-5).

If an unknown coated product has similar coating characteristics with the product that is tested at 25°C, a short term test at 100°C can be performed for the product. The release time for a given percent of N release at 100°C can then be used to predict the time required to release a similar percent of N release at 25°C. Thus, the N release duration (about several months) at 25°C can be predicted by using a fast N release test at 100°C within hours.

Nitrogen Release Rates Measured by Weight Loss Method under Greenhouse Conditions

The weight loss methods of determining the percent of N released in greenhouse indicated the value of N release was lower than that incubated 25°C. After the 180 day incubation, the percent of N release was 28, 71, 51, 69 and 41 for F1, F3, F4, F5 and F6, respectively (Figure 3-3). Under the greenhouse condition, the temperature varied daily for the incubation period of six months. The lowest was 4°C on January 10, 2010 and the highest was 27°C on September 25, 2009. The average air temperature in the greenhouse was 21.1°C which was below 25°C in laboratory water incubation. Cooler temperatures inside the greenhouse might be one reason for lower N release rates.

The weight loss and laboratory incubation (25°C) methods of determining the percent of N release were highly correlated for the 5 CRFs (Table 3-6). The R^2 was greater than 0.89 for all CRF products examined in this study. Through the regression equation for each CRF, N release characteristics from CRFs in greenhouse can be predicted from N release test for CRF in the laboratory.

The release pattern and duration of N release from CRFs is an important quality index of CRFs. The pure water incubation at 25°C in the laboratory is commonly recognized as a traditional method to describe the N release characteristics from CRFs. Evaluating N release patterns from CRFs enables farmers to choose the most suitable CRFs to be applied to the particular crops, based on the pattern of N uptake. Many researchers tried to predicate the N release rate in the field from N release rate tested in a laboratory through mathematical and statistical methods. Despite a variety of predication models and methods being developed in the recent years (Shaviv, 2001; Dai et al., 2008; Trenkle, 1997), there is no consistent and standard method being recognized at present. Nutrient release from CRFs is mostly temperature dependent (Gandeza et al., 1991; Shaviv, 2001). The N release rates from CRFs were greatly enhanced by higher temperatures. The temperature coefficient (Q_{10}), which is defined as the rate of change of a chemical or biological reaction as a consequence of increasing the temperature by 10°C, could be greater than 2 (Gandeza et al., 1991). Because measuring N releases rates in the field or in the laboratory at 25°C requires several months to one year for completion, many researchers have endeavored to develop different models of prediction (Shaviv, 2001; Dai et al., 2008). Gandeza et al. (1991) used a quadratic equation corresponding to the mean air or soil temperature to describe the cumulative N release from CRFs over time. He found that the cumulative N release of CRFs could be determined by using the corresponding relationship between cumulative temperature and cumulative N release. Dai et al. (2008) showed N release from CRFs at 25°C can be predicated precisely from accelerated incubation method at 80°C. Research work by Medina et al. (2009) indicated that an accelerated laboratorial extraction procedure could successfully predict the N release rate of CRFs which can allow manufactures and regulators to make judgments of CRF label claims and effectiveness. The current study indicated the rapid test with accelerated incubation at 100°C is accurate and time saving for determining the release duration of CRFs.

Conclusions

Nitrogen release patterns and durations from five CRFs were measured with different methods in this study. The results demonstrated that a nutrient release test conducted in water at 100°C was a useful, acceptable quick testing method for predication of N release rates and duration at 25°C. Compared with the traditional method, the acceleration incubation method at 100°C would greatly save time for testing N release rate from CRFs. This study also indicated there was a good relation in N release rates between the laboratory incubation method at 25°C and the weight loss method in a greenhouse. It is possible to predict N release patterns from CRFs in a greenhouse from laboratory incubation method.

Table 3-1. Characteristics of controlled release fertilizers (CRFs) used in the experiment

Product	**Stated NPK Analysis**	**N derived from**	**Release claimed (days)**
F1	18-6-8	AN, AP, PN	140
F3	15-7-15	AN, AP, PN	90-120
F4	20-8-10	AN, AP, PN	180
F5	15-9-12	AN, AP, PN	120-150
F6	16-6-11	AN, Mono-Ammonium Phosphate	150-180

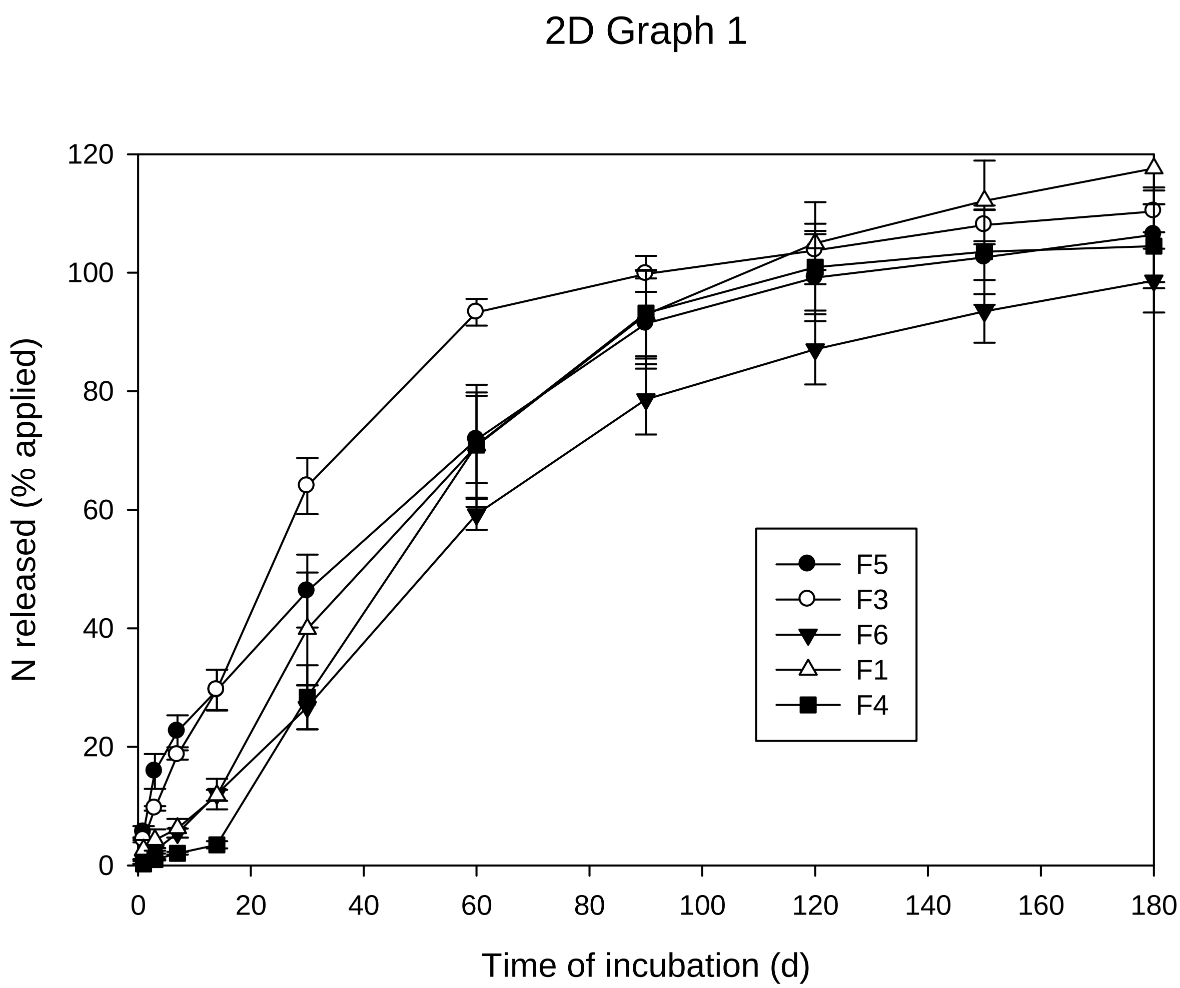


Figure 3-1. Nitrogen release rates from controlled release fertilizers in water at 25°C

Table 3-2. The regression equations of cumulative N release rates from controlled release fertilizers (CRFs) at 25°C

CRFs	Regression Equation	Coefficient of Determination (R^2)
F1	$y = -0.0042d^2 + 1.4127d - 1.2976$	0.9962
F3	$y = -0.0059d^2 + 1.5835d + 8.964$	0.97
F4	$y = -0.0051d^2 + 1.5243d - 7.3609$	0.99
F5	$y = -0.004d^2 + 1.2358d + 11.224$	0.99
F6	$y = -0.0035d^2 + 1.1783d - 2.0249$	0.99

Table 3-3. Longevity claimed (days) and duration tested (days) for five controlled release fertilizers (CRFs) used

CRFs	Longevity Claimed (days)	Tested (days)
F1	140	104
F3	90-120	84
F4	180	114
F5	120-150	114
F6	150-180	168

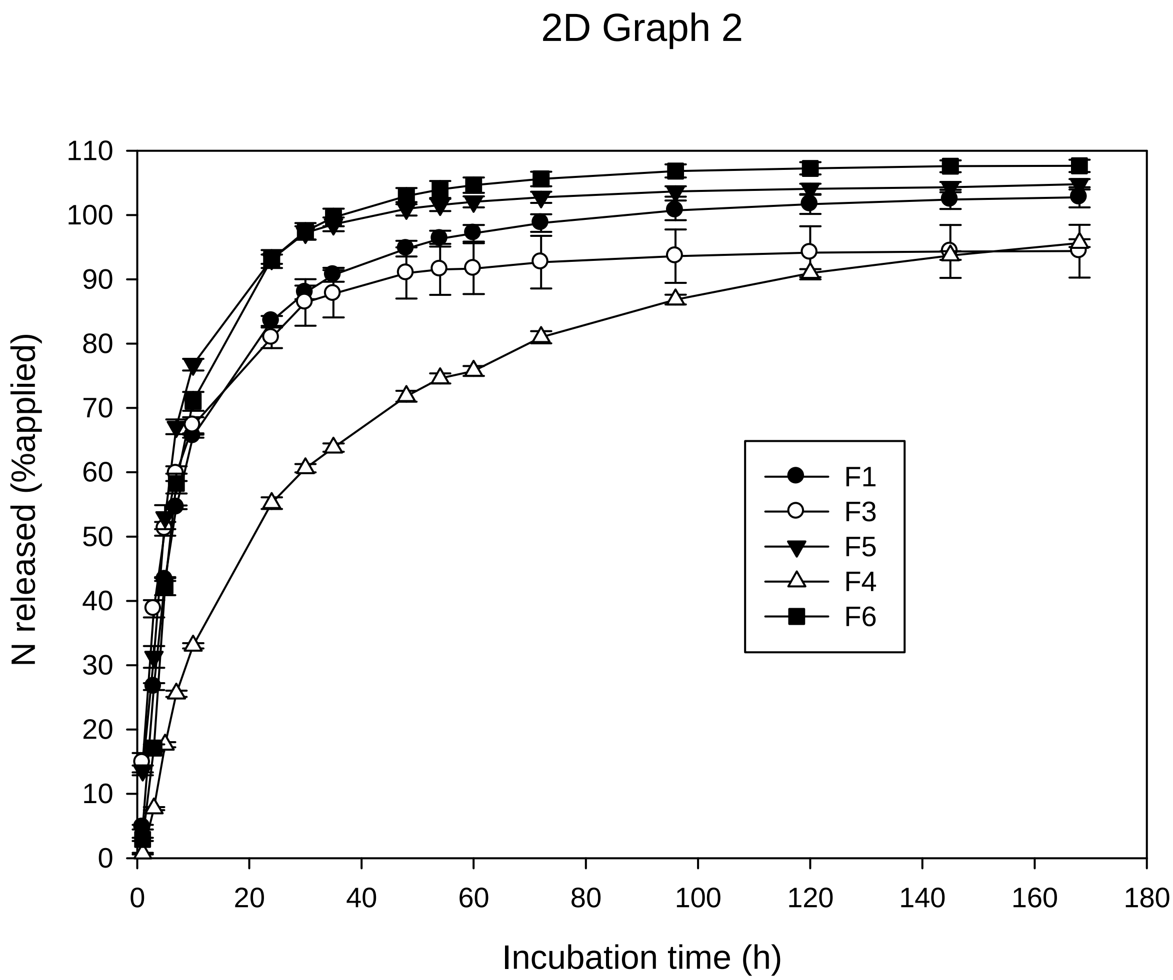


Figure 3-2. Nitrogen release rates from controlled release fertilizers (CRFs) in water at 100°C

Table 3-4. Regression equations and coefficients of determination (R2) for 5 controlled release fertilizes (CRFs) in water incubation at 100°C

CRFs	Equation	R^2
F1	y = 19.765Ln(h) + 13.031	0.95
F3	y = 14.526Ln(h) + 26.95	0.92
F4	y = 20.942Ln(h) - 10.675	0.98
F5	y = 18.204Ln(h) + 24.636	0.90
F6	y = 22.031Ln(h) + 10.338	0.92

Table 3-5. Regression equations and coefficients of determination (R^2) between times of nitrogen release at 25°C (days) and at 100°C (hours)

CRFs	Equation	R^2
F1	D = 14.297Ln (H) + 10.094	1.00
F3	D = 12.6Ln(H) + 13.11	0.98
F4	D = 21.288Ln(H) - 11.831	0.97
F5	D = 22.233Ln(H) + 9.2974	0.97
F6	D = $-0.374H^2 + 4.5844H + 15.508$	0.98

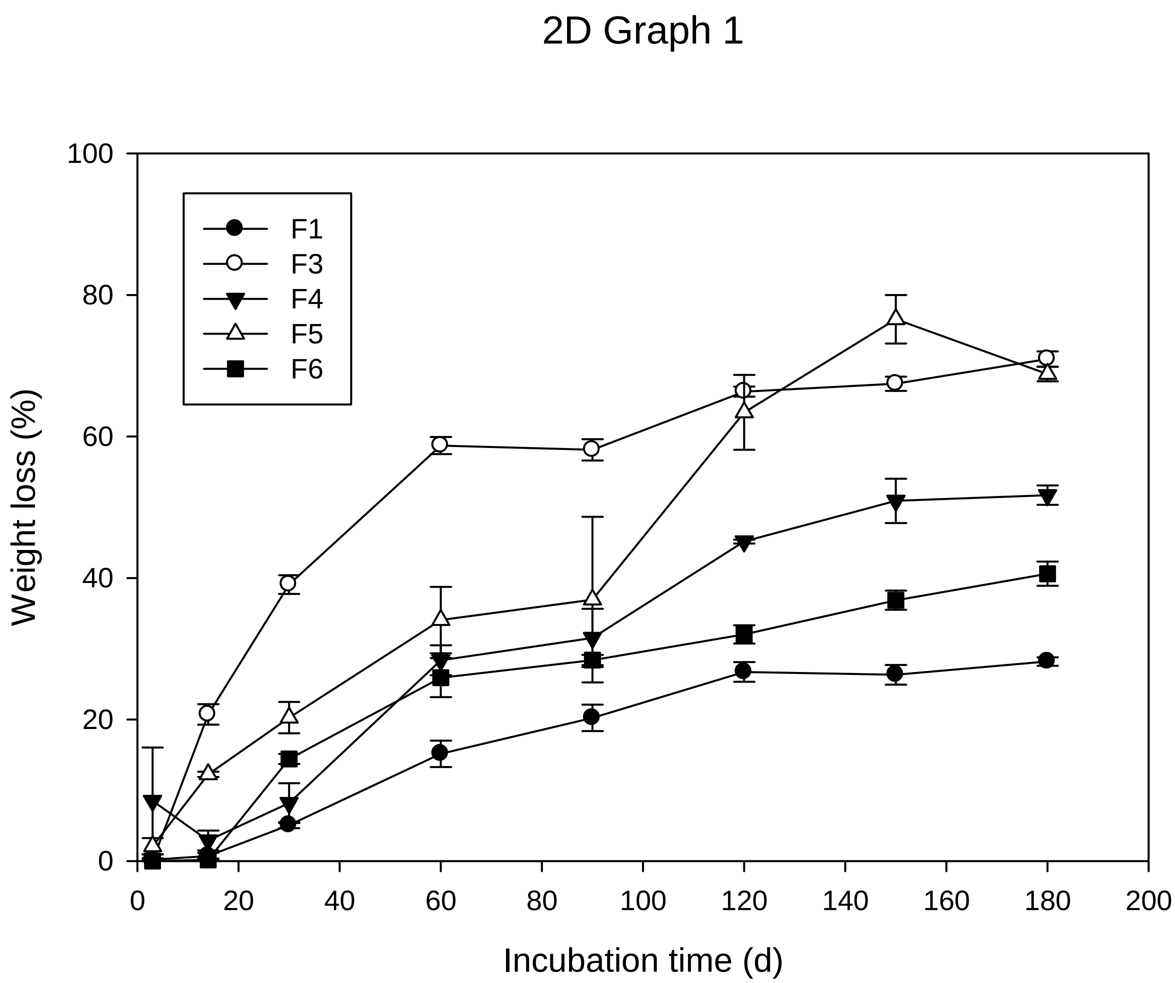


Figure 3-3. Percentage of weight loss of controlled release fertilizers (CRFs) incubated in a greenhouse

Table 3-6. Regression equations between cumulative N release rates from the weight loss method in a greenhouse and the water incubation at 25°C in a laboratory

CRFs	Equation	R^2
F5	y = 0.7354x - 12.481	0.89
F3	y = 0.6556x - 3.0186	0.99
F6	y = 0.4031x - 0.8021	0.97
F1	y = 0.2597x - 2.6743	0.98
F4	y = 0.4219x + 1.7244	0.91

Figure 3-4. A mesh bag of a controlled release fertilizer (CRF) in a 250 mL-bottle

Figure 3-5. A constant temperature extractor (CTE)

Figure 3-6. A bag of a controlled release fertilizer (CRF) for the weight loss method

CHAPTER 4
RESPONSE OF GROWTH AND NITROGEN UPTAKE BY FICUS ELASTICA ‘ROBUSTA’ TO NITROGEN RELEASES FROM CONTROLLED RELEASED FERTILIZERS

Introduction

The ornamental horticulture industry faces a fine line to maintain economical production while simultaneously protecting the environment from excessive nutrient leaching and runoff (Obreza et al., 2010). It is critical to improve nutrient use efficiency (NUE) to ensure sustainable crop production. The efficient use of fertilizers is influenced by soil, plant, and environmental conditions (Rose et al., 1994; Craig et al., 2003). Controlled released fertilizers (CRFs) are possible alternatives to quick release water soluble fertilizers. Their use could minimize nitrogen (N) losses to the environment and increase N uptake efficiency. It is important for growers to understand how particular CRFs work and to know their designed release rate before application. Sometimes certain CRFs release the nutrients too slow or too fast (Craig et al., 2003). The ideal approach would be to match the release curve with the crop nutrient demand during the crop’s growing season. For greenhouse and nursery crops, CRFs are typically incorporated into the potting media or top dressed after planting. When the CRFs are incorporated into the media, continuous nutrient release is more likely to have intermittent periods of dry-wet cycles (Obreza, 2010). Nitrogen not released to the soil remains in an insoluble form or is protected from dissolution by a coating, therefore it cannot be leached. Moreover, N released but not taken by the crop could be lost through leaching or runoff to groundwater or surface water. Knowledge of plant N requirements, fertilizer release properties, and expected temperatures would allow the best opportunity to apply CRFs most efficiently for container plant production.

Little attention has been given to identifying nutrient requirements of container-growth plants as related to plant age or stage of development (Tolman et al., 1990). As a root system develops, nutrient uptake by the plant becomes more efficient and less sensitive to fluctuations in nutrient release from CRFs. During rapid growth stages, fast-growing plants like *Ficus* require relatively high amounts of nutrients. Because CRFs must supply enough plant nutrients to support season-long growth of the crop in one application, matching nutrient release with plant requirements is a major challenge for both growers and CRF manufacturers (Yeager, 2010).

Another challenge preventing efficient fertilizer management use is the "one size fits all". Per example, a CRF's rate of 0.8 kilograms of nitrogen per meter (kg N m^{-3}) of media could be enough for a shrub in an 11-liter (3 gallons) container for 1 year, but maybe is too much for a shrub in a 3.8-liter (1 gallon) container for 3 months. A grower may tend to over fertilize because quality plays a major role in consumer preference for ornamental crops and high fertilizer rates produce dark green foliage. The added cost of applying additional fertilizer may provide a measure of insurance against producing under fertilized plants and could allow for extended growth during times when crops cannot be sold (Yeager et al., 2010).

Cultivars of *Ficus elastica* Roxb. Ex Hornem (Bailey and Bailey, 1976) have been popular houseplants for the last 50 years. Most of the production today in the United States (US) comes from vegetative propagation. Standard or multitrunked trees are also produced from cuttings or air layers. The plants are frequently grown in shadehouses with 47% to 63% shade. They need a well-drained growing medium and grow best when irrigated regularly (Griffith, 1998). The objective of this research was to evaluate the relationship between N release patterns of five CRFs and biomass and N uptake of *Ficus elastica* 'Robusta' grown in a greenhouse.

Materials and Methods

A greenhouse experiment was conducted from August 27, 2009 to February 27, 2010 at the University of Florida Tropical Research and Education Center, Homestead, FL. Liners of *Ficus elastica* 'Robusta' were obtained from a local nursery and transplanted on August 27, 2009 into 3.8-liter plastic containers using premier Promix BX / Mycorise Pro 3.8 as containing media

(Sungro, Vancouver, Canada) (Figure 4-1). The growing medium consisted of Sphagnum peat moss (85%) and perlite + vermiculite + limestone (15%).

Five CRFs were incorporated (mixed) with the growing medium at the rate of the equivalent of 0.8 kg N m^{-3}according to a University of Florida IFAS recommendation (Broschat, 2005; Obreza et al., 2010; Yeager, 2010). These CRF products were obtained from local fertilizer distributors and their formula, chemical composition and claimed release period are listed in Table 3-1. Nitrogen release rates for these products were determined in water over a 180 day period at 25° Celsius (C) and are described in Chapter 3.

The containers were placed on raised benches inside a greenhouse with a daily irrigation of approximately 0.25 liter/plant a day (Figure 4-2). The irrigation was supplied with a drip irrigation system (1 liter per hour (L h^{-1})). Roots, stems, and leaves were collected 30, 60, 90, 120, 150, and 180 days after planting (DAP). At each harvest, the medium was gently washed from the root system, and the plant was separated into roots, stems, and leaves portion. These portions were dried at 80°C until constant weight was recorded (approximately 7 days). The dry tissue samples were weighed for biomass and ground using a 4 canister ball-mill pulverizer (Kleco, model 4200, CA. USA). The N concentration was analyzed using a CN analyzer (Vario Max CNS, Elemental Americas, Mt. Laurel, NJ). Results were statistically analyzed using the general linear model procedure of SAS (v9.1; SAS Institute Inc., Cary, NC) as a completely randomized design with six treatments (F1, F3, F4, F5, F6, and no-fertilizer control), six harvesting time (30, 60, 90,120,150, and 180 DAP), and four replicates. Treatment means from the experiment were compared with Duncan's Multiple Range Test ($\alpha = 0.05$).

Results and Discussion

Plant Growth or Biomass

Plant biomass levels were evaluated for leaf, stem and root tissue and are presented in Figures 4-3, 4-4, 4-5, and 4-6. Statistics of the dry weight showed that there are not significant differences between fertilizer treatments at $P<0.05$. However, dry weights for 5 fertilizer treatments are significantly higher than those obtained from control (no fertilizer) treatment. Biomass for F5 has the greatest biomass with 142.1 grams/plant (g/plant), the control has the lowest with 17.7 g/plant and F1, F3, F4, and F6 have 126.2, 121.1, 124.2, and 132.5 g respectively, after 180 DAP. The daily or incremental biomass showed some variation in the growing rate mainly with F1 (Figure 4-7). This may be due to the characteristics of the release of the fertilizer or climatic variation (e.g. temperature in the winter). The leaves were responsible for the majority of the plant's overall weight. The roots and stems had approximately the same proportion of the dry weight.

Nitrogen Uptake in Plants

There were no significant differences of N concentrations in leaves, stems, and roots between treatments of CRFs ($P = 0.05$). However, it was interesting to find out that *Ficus elastica* 'Robusta' N leaf concentrations were high with 3.4% in the juvenile stages (30 DAP) and decreased to 1.2 % in the mature stages (150 DAP) (Figure 4-8A). The average concentrations for N in the leaves were 3.4, 2.4, 1.7, 1.1, and 1.2 % after 30, 60, 90, 120, and 150 DAP, respectively. Similarly, N concentrations were 1.5, 1.3, 1.0, 0.8, and 0.8 percent for stems and 1.5, 1.3, 1.0, 0.8, and 0.8 percent for roots after 30, 60, 90, 120, and 150 DAP (Figures 4-9A and 4-10A). The nitrogen concentration tends to decrease faster as the plants mature. This is because as the plant grows, the N will be diluted in more tissue (Figure 4-11A). Griffith (1998), working with the *Ficus* cultivar 'Decora' found similar values with very high N concentration >3.51%, medium concentration as 1.3% to 2.25%, and very low concentration <1.0%.

Nitrogen uptakes were calculated by multiplying N concentrations by the plant biomass, thus: UL = LN x BL x 1000

Where, UL = uptake by leave (milligrams of nitrogen per plant (mg N/plant)); LN = N concentration in the leave (milligrams per kilogram (mg kg^{-1})), and BL = leave biomass (g/plant).

In this experiment, leaf fraction was responsible for the majority of the total plant N gains with 59, 67, 70, 65, and 70 percent for the 30, 60, 90, 120, and 150 DAP. Roots were responsible for approximately 26% and the rest was due to the stem portion (Figures 4-8B, 4-9B, and 4-10B, and 4-11B). The total plant incremental N gains (mg N/plant) between 30 and 150 DAP for F1, F3, F4, F5, F6, and control were 779, 769, 772, 867, and 767 for 53 mg N/plant, respectively, (Figure 4-11B). There were no significant differences in N gains attributable to the CRF treatment (P = 0.05).

A plant's nutrient requirement increases with age and size during periods of growth, therefore the supply and uptake of nutrients must increase to maintain maximum plant growth. This is in accordance with what Tolman (1990) found while working with marigold plants and Yeager (1991) working with *Ilex*. Nitrogen not utilized immediately by a container plant can leach, volatilize, or adsorb on the container medium. Leaching is considered the greatest avenue of nutrient loss. Up to 90% of leachable nitrogen is lost when irrigation or rainfall volume exceeds container volume (Craig, 2003). Applying fertilizer during active root growth increases nutrient efficiency. Thus, if nutrient addition (source) remains constant, nutrient efficiency changes as nutrient uptake patterns changes. Nitrogen use efficiency is a measure of the crop's ability to take up the fertilizer N applied to the soil. It is defined as the total nitrogen absorbed by the plant as a percentage of total nitrogen supplied by that fertilizer for a given time interval.

Thus,

NUE at 150 DAP = N uptake {[(N source) – N uptake (control)] x 100} / (Total fertilizer N applied)

Where, N uptake (N source) is the weight of N taken up by the *Ficus* plant after 150 DAP , N uptake (control) is the weight of N taken up by the non treated control after 150 DAP, and total N applied is the weight of N applied to container after 150 DAP.

The NUE in the experiment was 34, 32, 35, 40, and 31 for the CRFs F1, F3, F4, F5, and F6, respectively (Table 4-1). These numbers are a little low comparing to other CRFs studies such as Obreza et al. (2010) and Fan (unpublished data, 2010).

Correlation between Nitrogen Uptake / Biomass and Nitrogen Release from Controlled Release Fertilizers

Tolman et al. (1990) suggested than young marigold plants may require higher N concentrations than mature plants because of a smaller root system. King and Stimart (1990) found that chrysanthemums had higher N uptake per unit dry weight in the first 4 weeks of growth than in later growth stages. This is similar to the *F. elastica* data in the current study (Table 4-5). The first 30 days had an N accumulation (mg N per gram of dry weight) ratio of 25, 10, 31, 25, 30, and 26 for F1, control, F3, F4, F5, and F6, respectively, which decrease after 180 days to 6, 3, 6, 6, 6, and 6 for the same products. This suggests the importance to fertilize container crops early and heavily after potting when root growth is critical (Rose et al., 1994).

Figures 4-12, 4-13, 4-14, 4-15, and 4-16 show the correlation between N uptake by *F. elastica* ‘Robusta’ and the N release in water at 25°C from F1, F3, F4, F5, and F6, respectively. In all the cases, the correlation and the coefficient of determination were high which means a good relation between the two variables and a strong fit between N uptake vs. N release (r>0.94 and R^2>0.83) (Tables 4-3 and 4-4). The cumulative percentage of N release from the F1, F3, F4, F5, and F6 after 180 days of incubation was 117, 110, 104, 106, and 110 percent, respectively. The N uptake by the plants were 908, 938, 940, 1127, 918 mg N/ plant, respectively from F1, F3, F4, F5, and F6 after 150 days of planting. There was no significant difference attributable to the CRF treatment (α = 0.05).

Conclusions

All tested fertilizers increased plant biomass compared to the control treatment. However, there is no significant difference between the biomass of plants attributable to the different CRFs. By the end of growing period, the highest biomass (142 g/plant) came from the treatment F5 and the lowest (17.7 g/plant) was from the control. All CRFs except F1 have similar patterns with slow growth in early season and quick growth in later season. *Ficus* leaf N concentrations ranged from 1.2% at mature stage (150 DAP) to 3.4% at juvenile stage (30 DAP). The ranges of N concentrations were 0.8 to 1.5 for both stems and roots. The cumulative N uptake by the end of growing season ranged from 90 g/plant (control) to 1069 g/plant (F5). The highest NUE came from F5 treatment with 40% and the lowest is F6 treatment with 31%. Low NUE values for all fertilizers may be caused by quick releasing of N from CRFs and over irrigation. Plant biomass and N uptakes were highly correlated to N release from CRFS measured at 25°C (r>0.94). The linear regression analysis also showed the biomass and N uptake can be predicted with N release of CRFs (R^2>0.83). This study indicated that CRFs hold great promise to improve plant growth and NUE, but additional research on characterization, plant response, environmental effects, and economics is needed.

Figure 4-1. *Ficus elastica* ‘Robusta’ grown in a greenhouse

Figure 4-2. *Ficus elastica* ‘Robusta’ treated with controlled release fertilizers (CRFs) F1, F2, F3, F4, F5, and F6 from left to right at 180 days after planting (DAP)

Table 4-1. Cumulative N uptakes and N use efficiency (NUE) of *Ficus elastica* 'Robusta' throughout the growing season (150 days)

	Net cumulative N uptake (mg/plant)					NUE
Treatment	**30 d**	**60 d**	**90 d**	**120 d**	**150 d**	**(%)**
Control	39	52	64	68	90	-
F1	110	458	545	752	932	34
F3	187	551	646	724	877	32
F4	173	520	717	736	953	35
F5	246	581	672	898	1069	40
F6	183	532	624	838	849	31

Table 4-2. Significant levels for means of dry biomass (g/plant)

CRF	30 days	60 days	90 days	120 days	150 days	180 days
F1	5.2 a	21.9 a	31.6 a	61.0 a	73.4 a	126.2 a
F2	3.4 a	4.6 b	9.7 b	13.1 b	14.6 b	17.8 b
F3	5.5 a	24.9 a	38.4 a	66.5 a	65.3 a	121.1 a
F4	6.8 a	19.0 a	34.8 a	62.3 a	78.0 a	124.2 a
F5	8.7 a	24.6 a	33.6 a	66.3 a	75.2 a	142.2 a
F6	5.8 a	24.5 a	40.0 a	76.4 a	76.4 a	132.5 a

Significant (P = 0.05)

Table 4-3. Correlation (r) between biomass of *Ficus elastica* 'Robusta' vs. N release of controlled release fertilizers (CRFs), and N uptake vs. N release

CRF	Biomass vs. N Release	N Uptake vs. N Release
F1	0.94	0.97
F3	0.90	0.98
F4	0.91	0.98
F5	0.91	0.96
F6	0.94	0.94

Table 4-4. Regression equations and coefficients of determination (R^2) between biomass of *Ficus elastica* 'Robusta' vs. N release of controlled release fertilizers (CRFs), and N uptake vs. N release

	Biomass vs. N uptake		Biomass vs. N release	
CRF	Equation	R^2	Equation	R^2
F1	y = 0.0878x-10.459	0.9478	y = 0.0476x - 36.912	0.8761
F3	y = 0.0943x - 16.18	0.8604	y = 0.0957x - 86.054	0.8037
F4	y = 0.0922x - 16.925	0.8313	y = 0.0523x - 28.548	0.8206
F5	y = 0.0869x - 18.58	0.945	y = 0.0712x - 48.175	0.8223
F6	y = 0.1113x - 21.083	0.9645	y = 0.0657x - 25.682	0.8813

Table 4-5. Nitrogen uptake per unit of dry weight (mg N/g biomass) of different controlled release fertilizers (CRFs) during the growing season

CRF	30 d	60 d	90 d	120 d	150 d	180 d
F1	25	21	1	12	12	6
F2	10	12	6	6	6	3
F3	31	22	16	11	14	6
F4	25	30	22	12	12	6
F5	30	24	16	13	15	6
F6	26	16	15	11	12	6

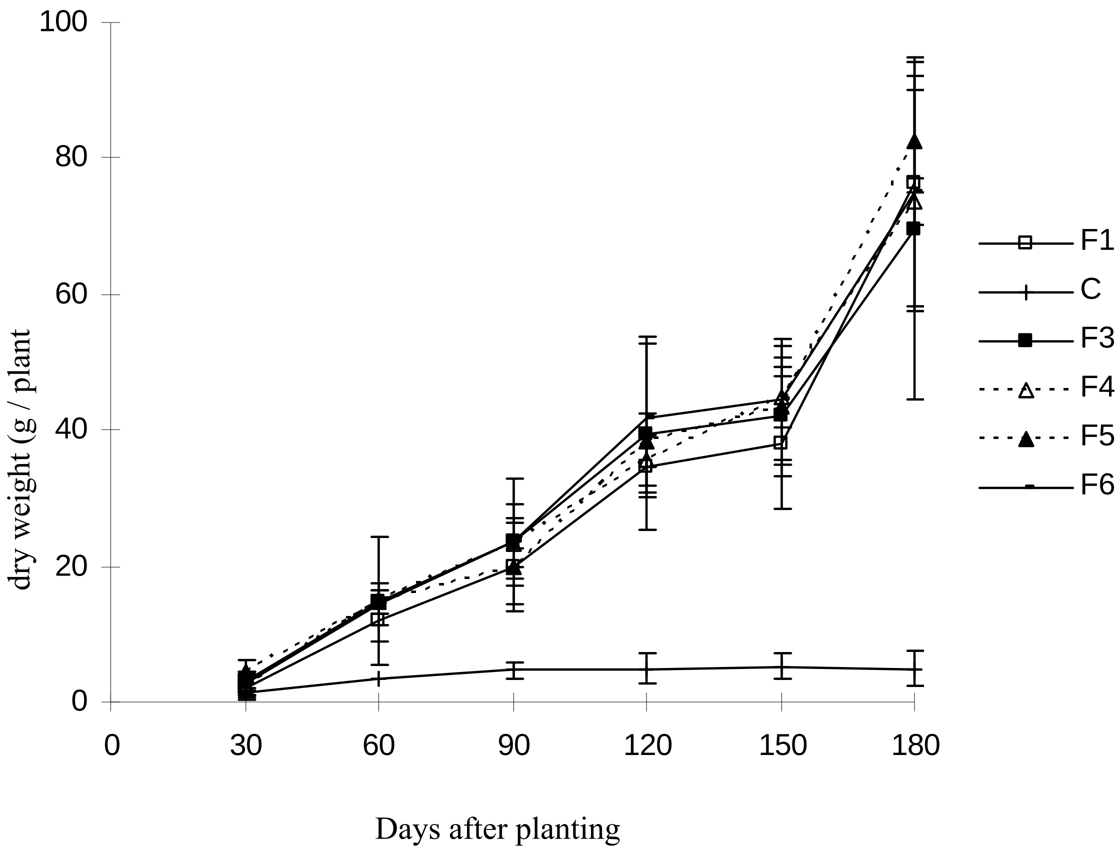


Figure 4-3. Leave biomass (g/plant) of *Ficus elastica* ‘Robusta’ treated with five controlled release fertilizes (CRFs) plus control (C) in a greenhouse

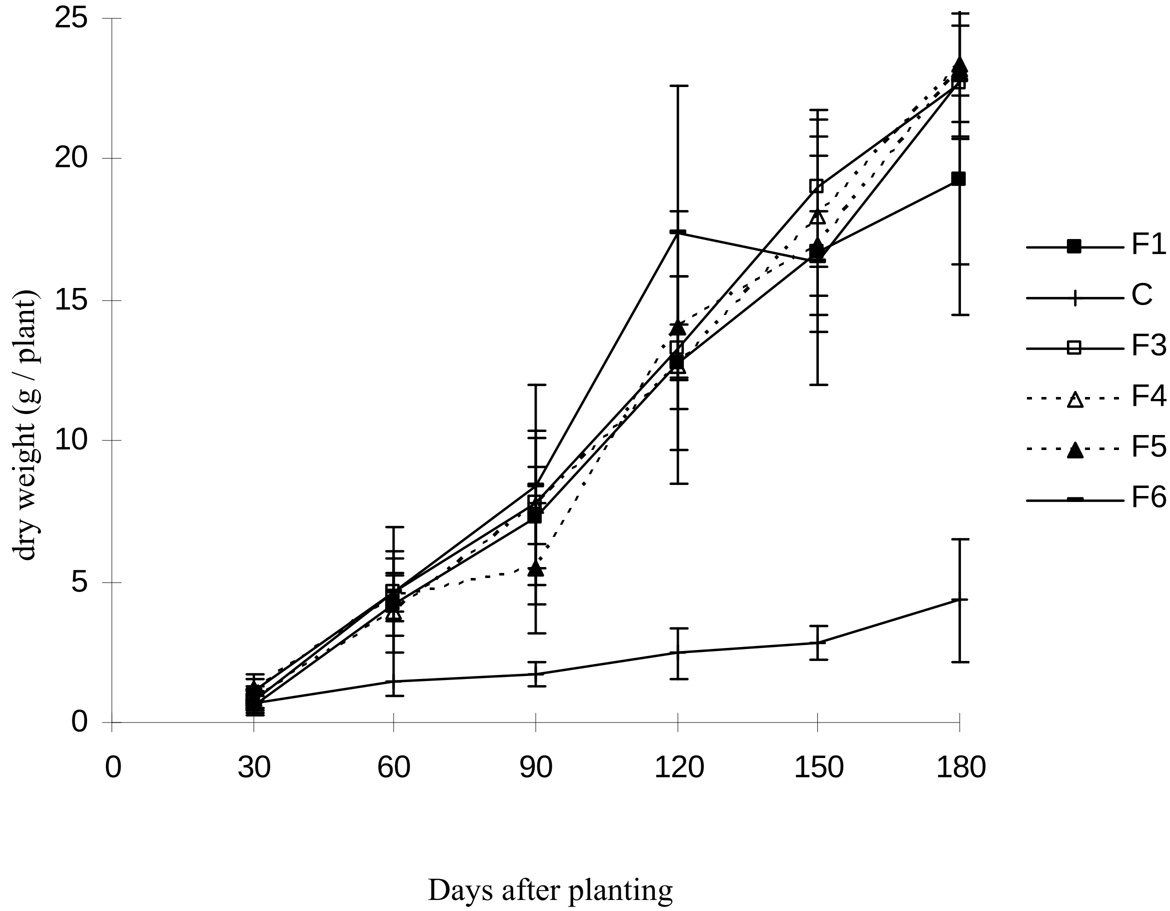


Figure 4-4. Stem biomass (g/plant) of *Ficus elastica* 'Robusta' treated with five controlled release fertilizers (CRFs) plus a control (C) in the greenhouse

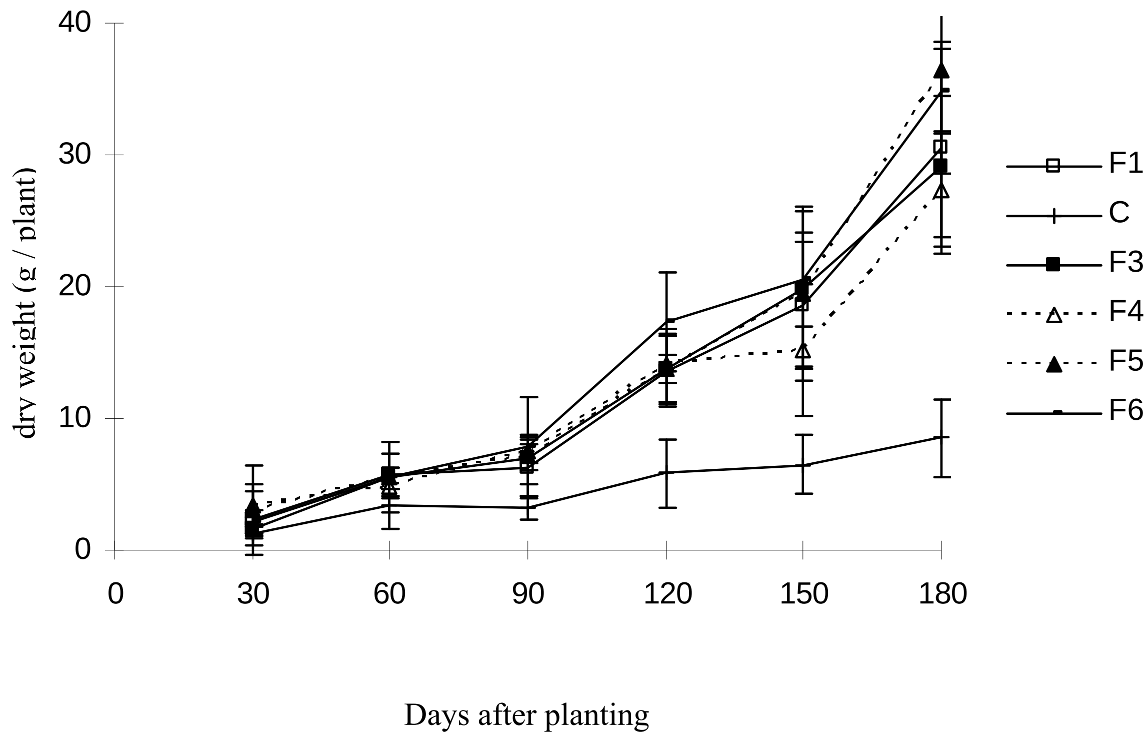


Figure 4-5. Biomass in the roots (g) of *Ficus elastica* 'Robusta' treated with five controlled release fertilizers (CRFs) plus a control (C) and grown in the greenhouse

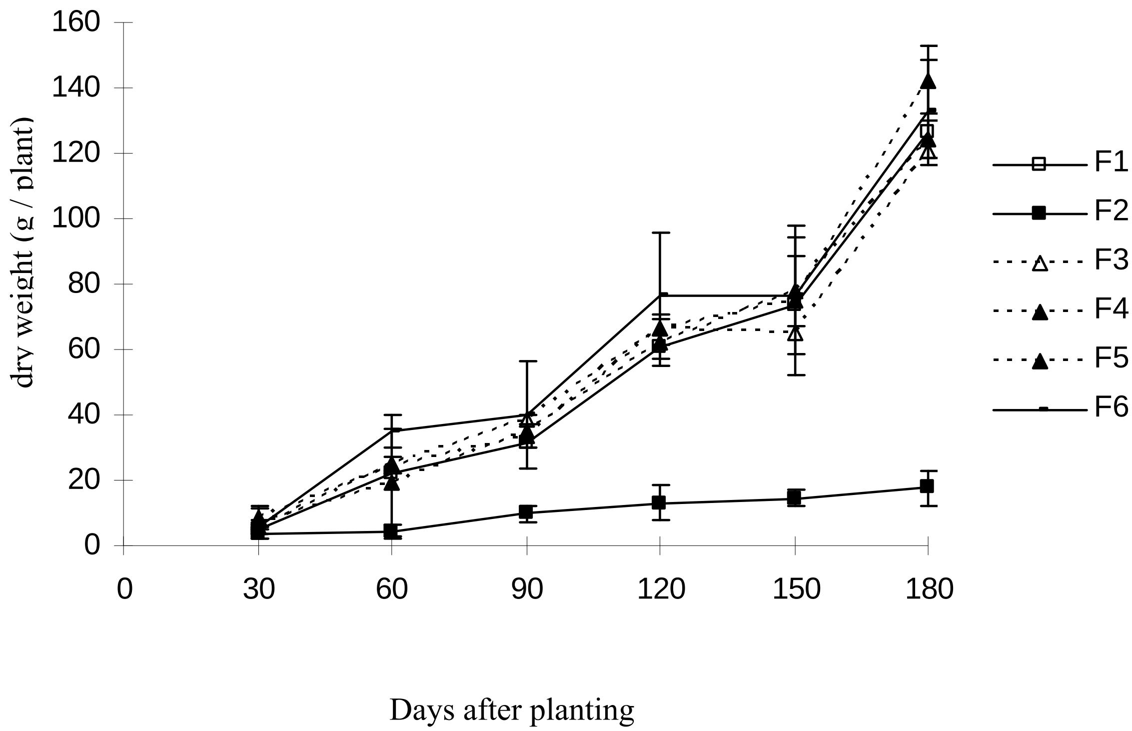


Figure 4-6. Total biomass (g) of *Ficus elastica* ‘Robusta’ treated with five controlled release fertilizers (CRFs) plus a control (C)

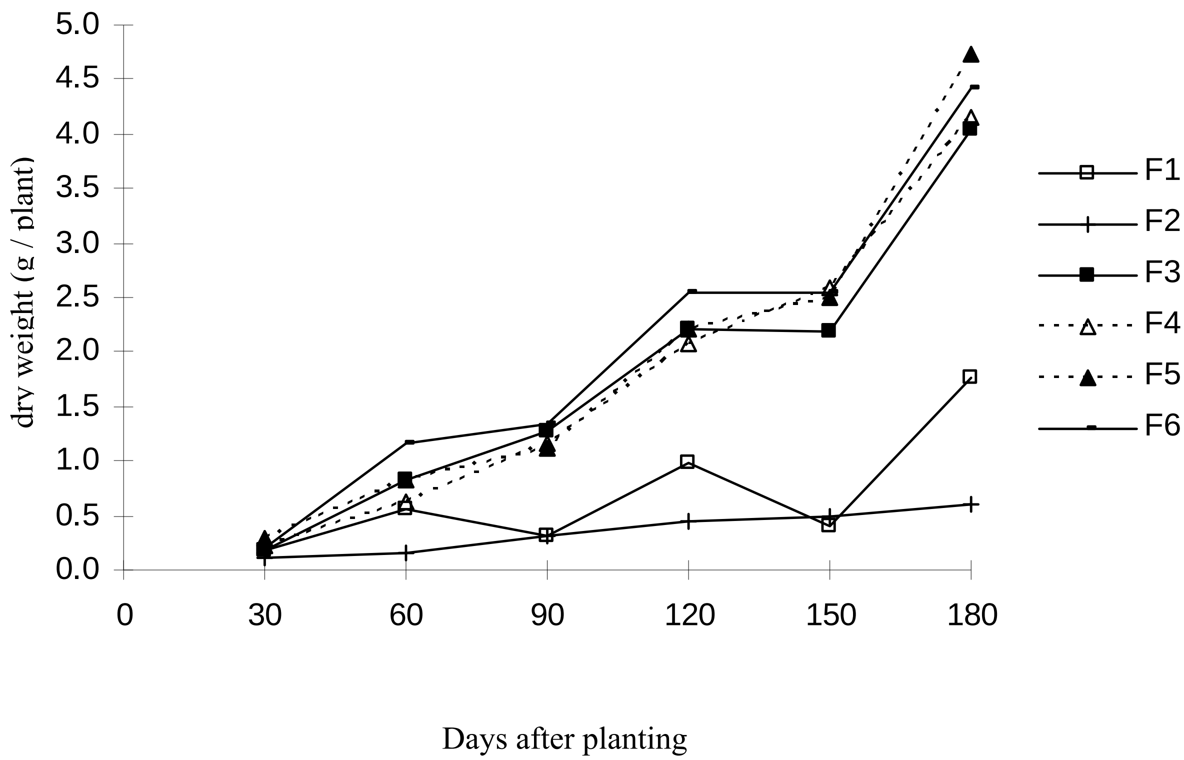
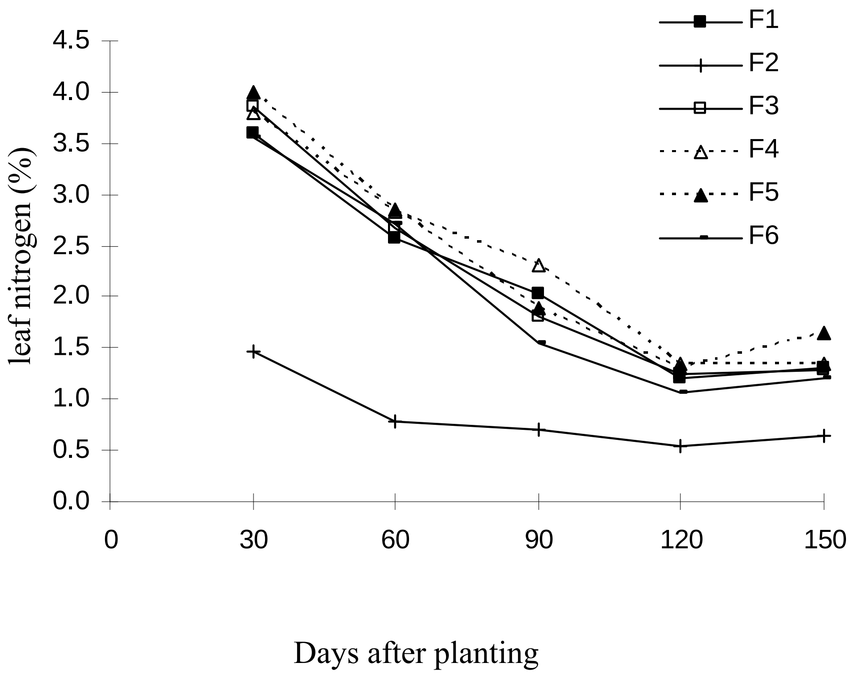


Figure 4-7. Daily biomass (g) of *Ficus elastica* ‘Robusta’ treated with five controlled release fertilizers (CRFs) plus a control (C)

A



B

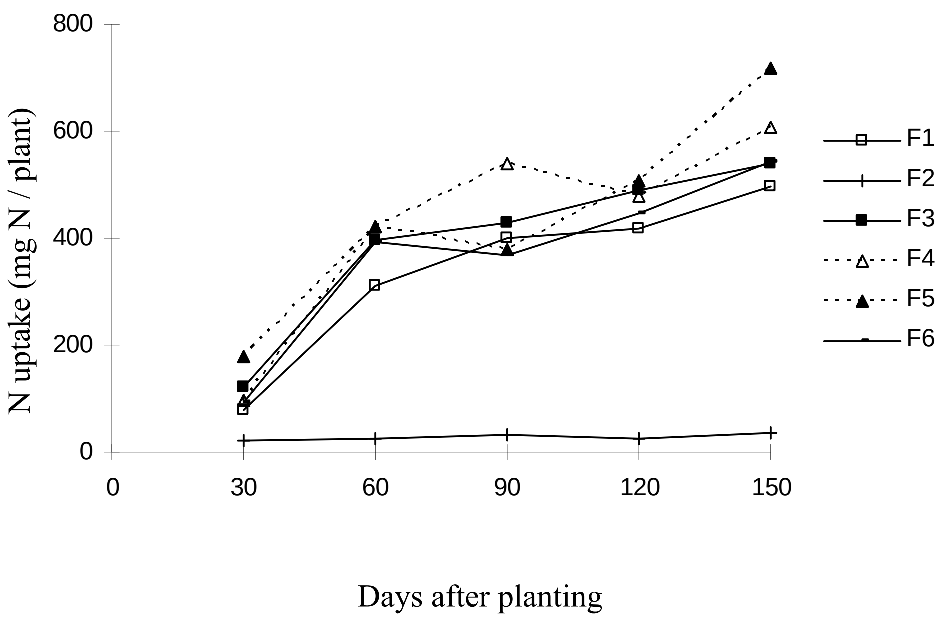
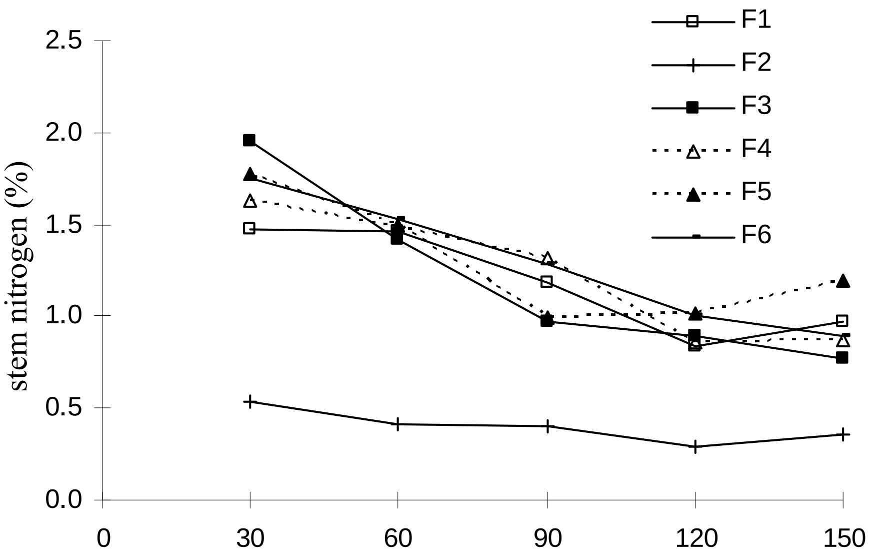


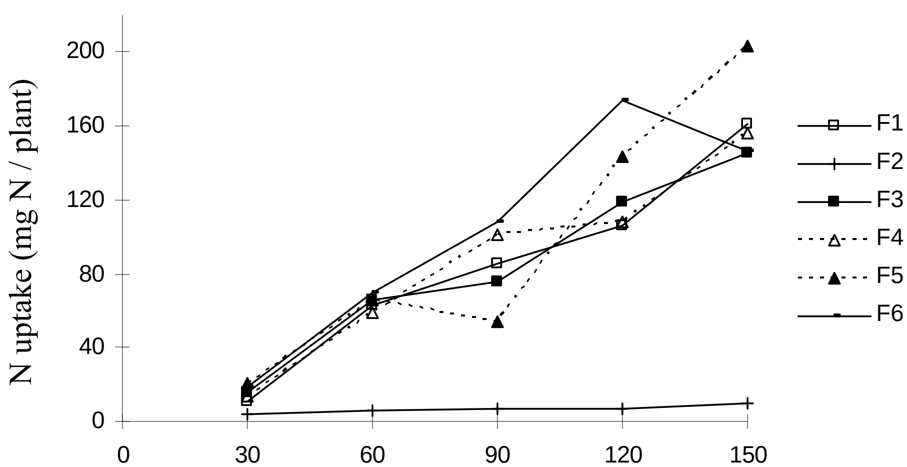
Figure 4-8. Leaf nitrogen concentration (%) (A) and nitrogen uptake (B) of *Ficus elastica* 'Robusta' treated with five controlled release fertilizers (CRFs) plus a control

A



Days after planting

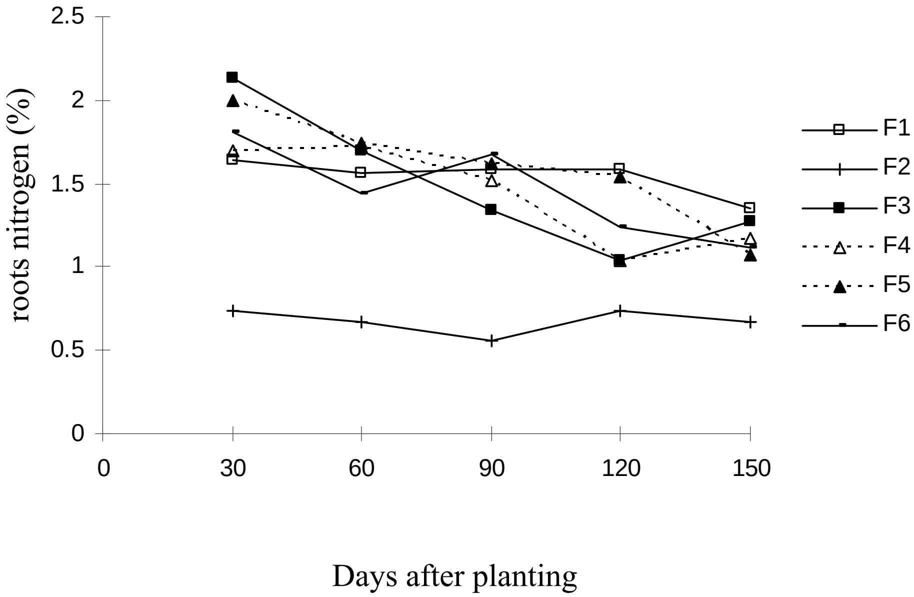
B



Days after planting

Figure 4-9. Stem nitrogen concentration (%) (A) and nitrogen uptake (B) of *Ficus elastica* 'Robusta' treated with five controlled release fertilizers (CRFs) and a control (C)

A



B

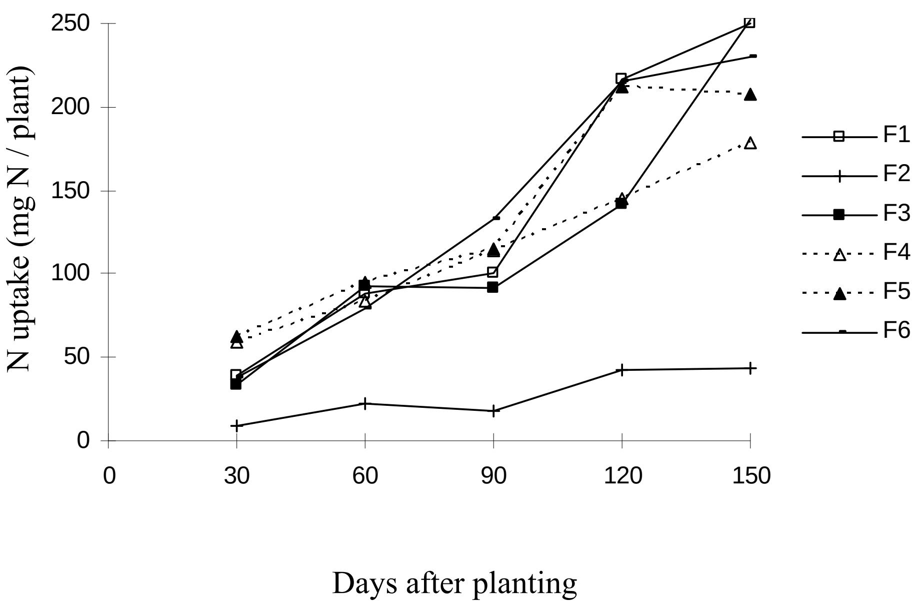
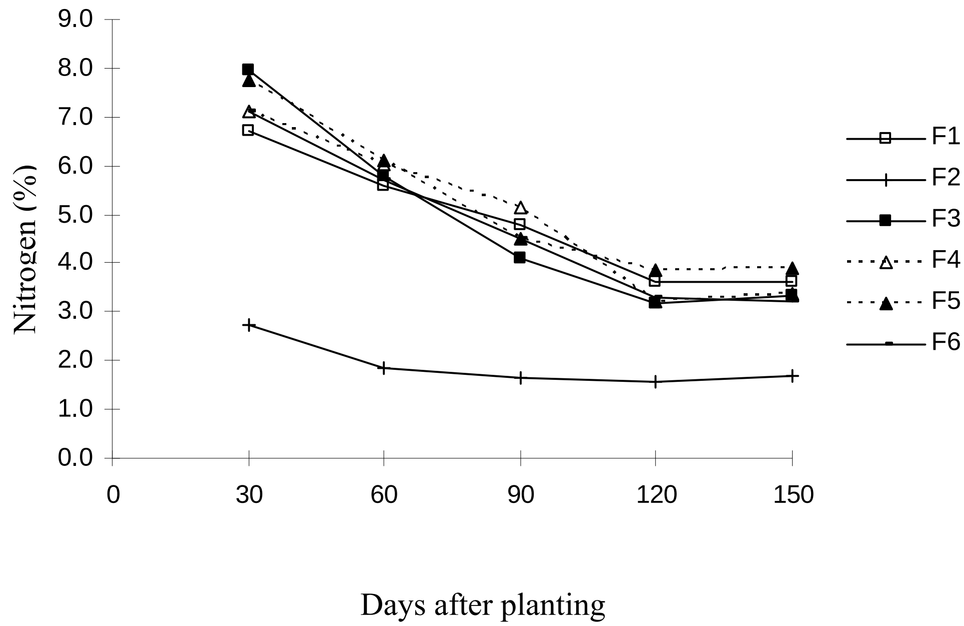


Figure 4-10. Root nitrogen concentration (%) (A) and nitrogen uptake (B) of *Ficus elastica* 'Robusta' treated with five controlled release fertilizers (CRFs) plus a control (C)

A



B

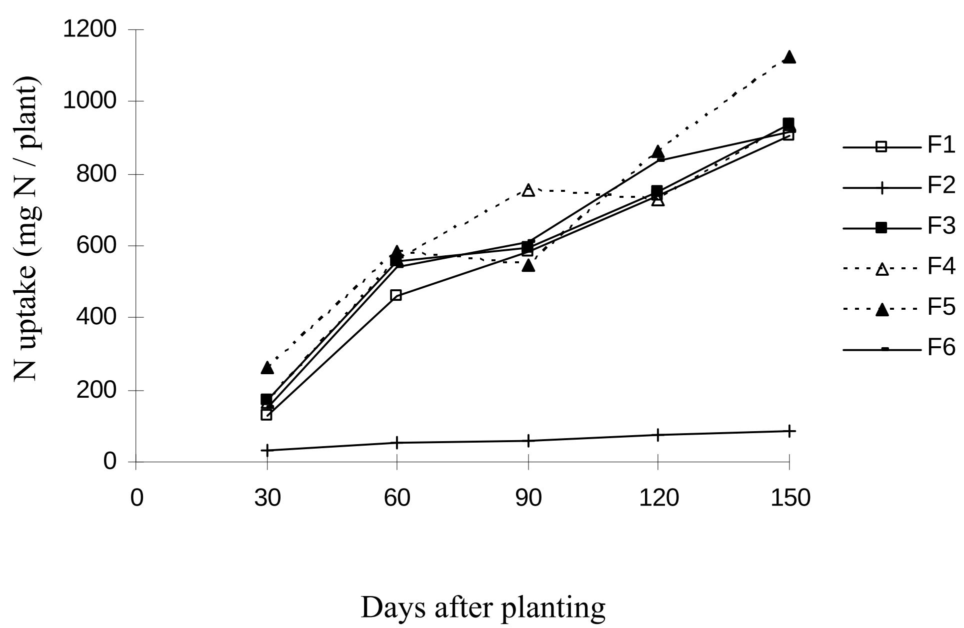


Figure 4-11. Total nitrogen concentration (%) (A) and uptake (B) of *Ficus elastica* 'Robusta' treated with five controlled release fertilizers (CRFs) plus a control (C)

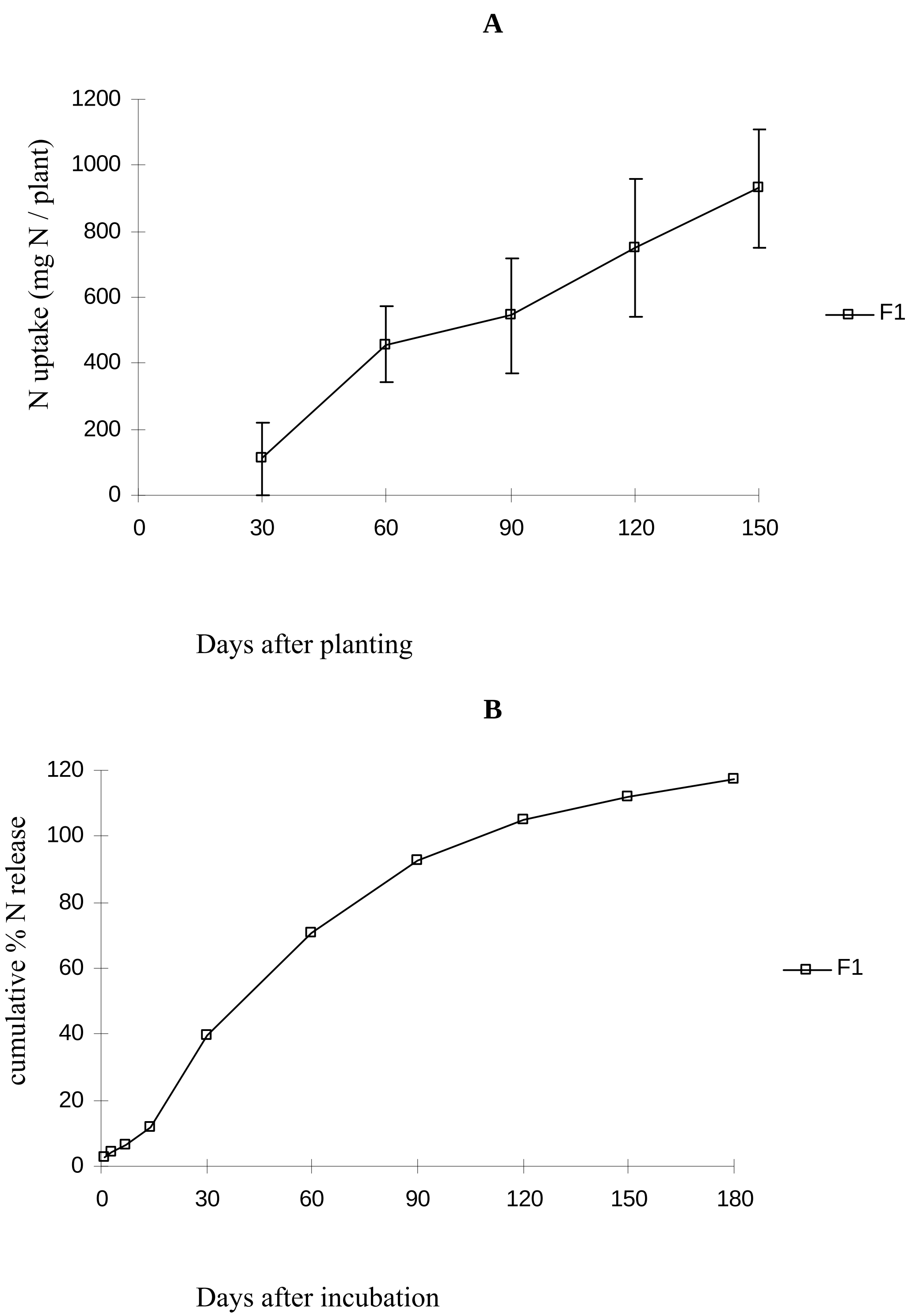


Figure 4-12. Comparison of nitrogen uptakes (A) of *Ficus elastica* ‘Robusta’ (mg N / plant) vs. nitrogen release (%) from F1 (B)

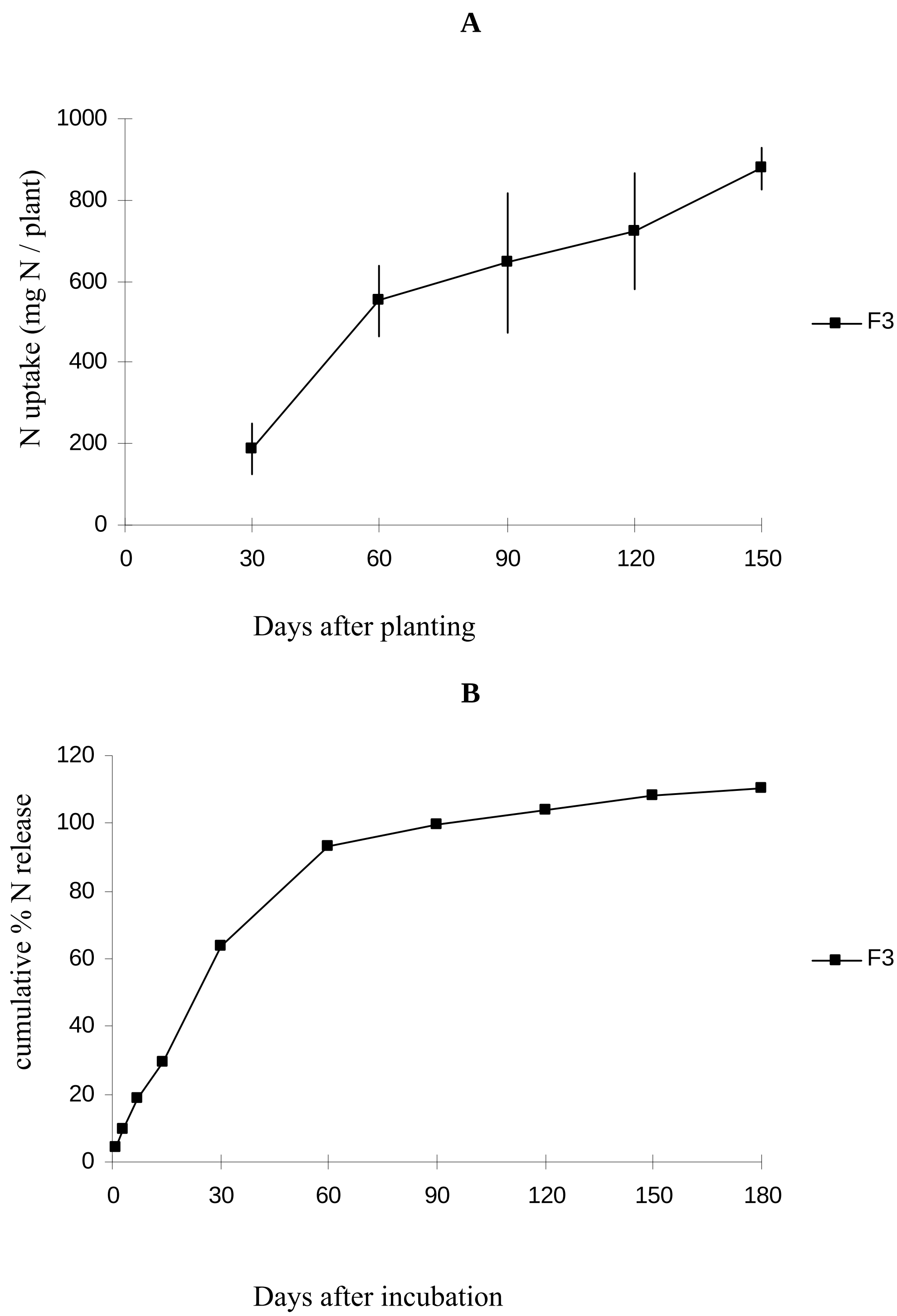


Figure 4-13. Comparison of nitrogen uptakes (A) of *Ficus elastica* 'Robusta' (mg N/plant) vs. nitrogen release (%) from F3 (B)

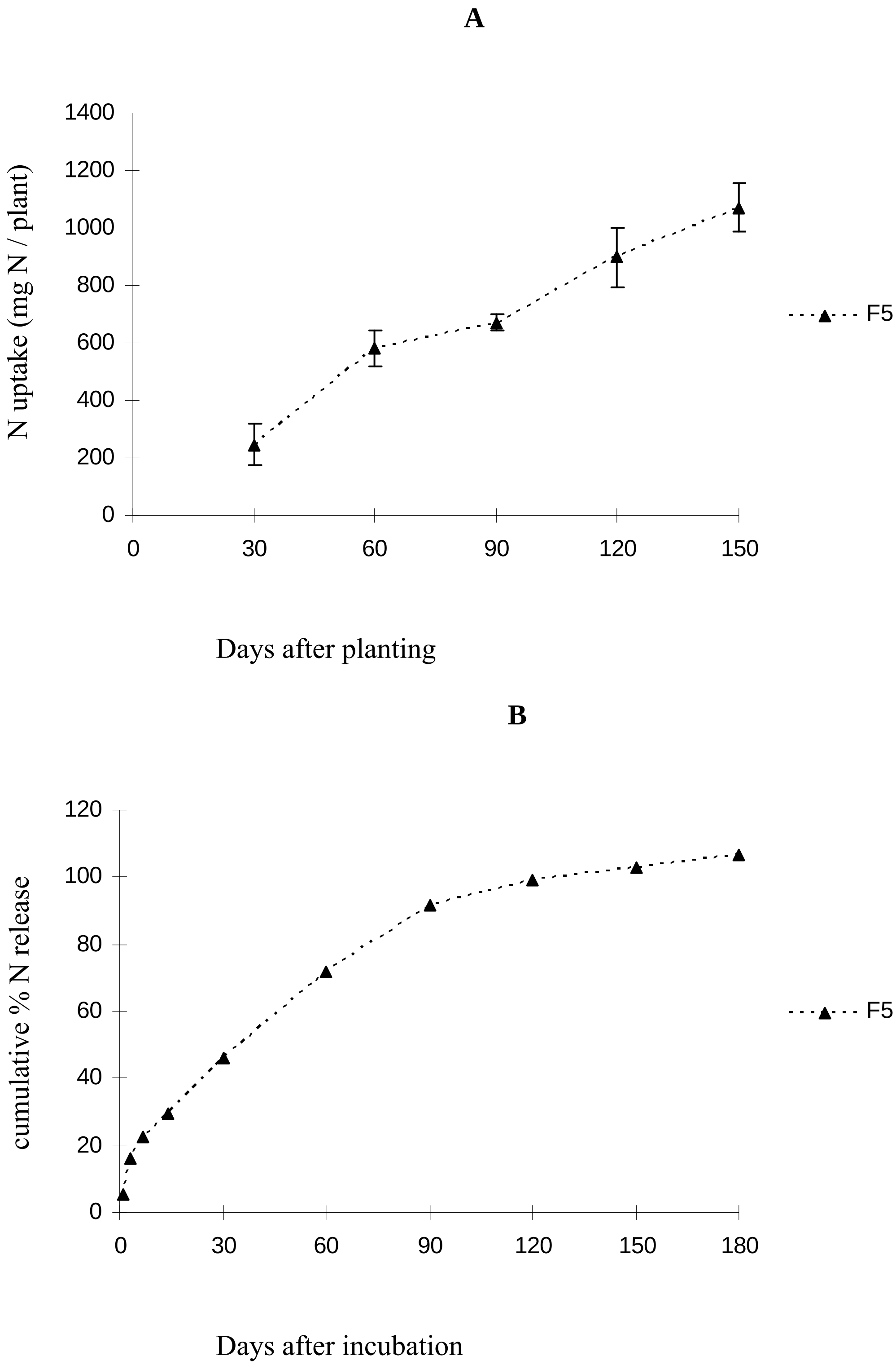
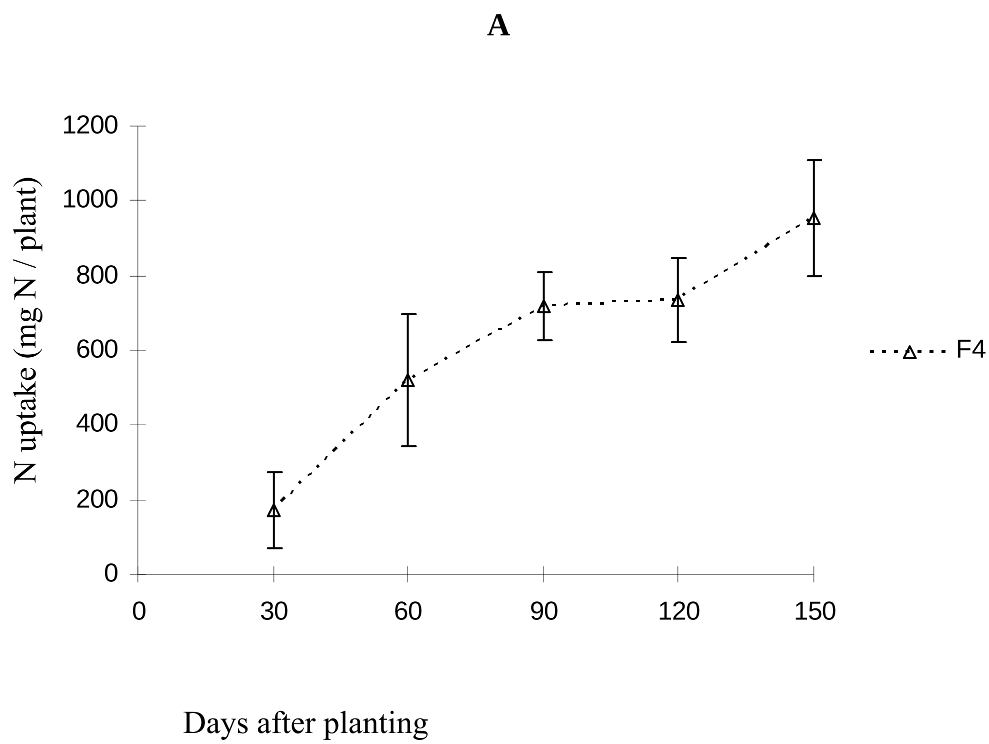


Figure 4-14. Comparison of nitrogen uptakes (A) of *Ficus elastica* ‘Robusta’ (mg N/plant) vs. nitrogen release (%) from F5 (B)



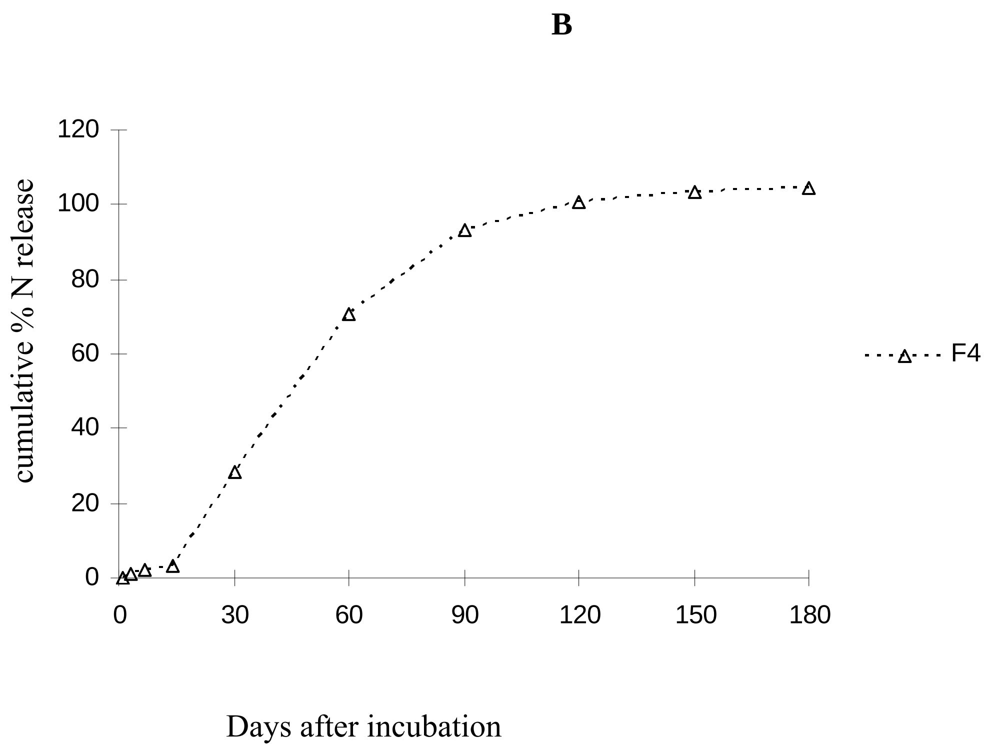
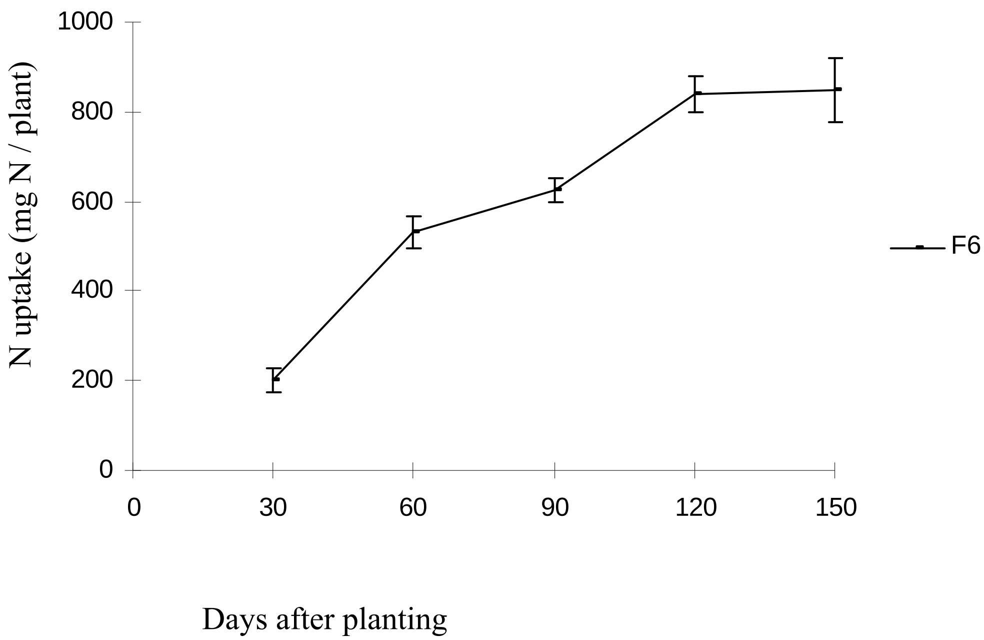


Figure 4-15. Comparison of nitrogen uptakes (A) of *Ficus elastica* 'Robusta' (mg N / plant) vs. nitrogen release (%) from F4 (B)

A



B

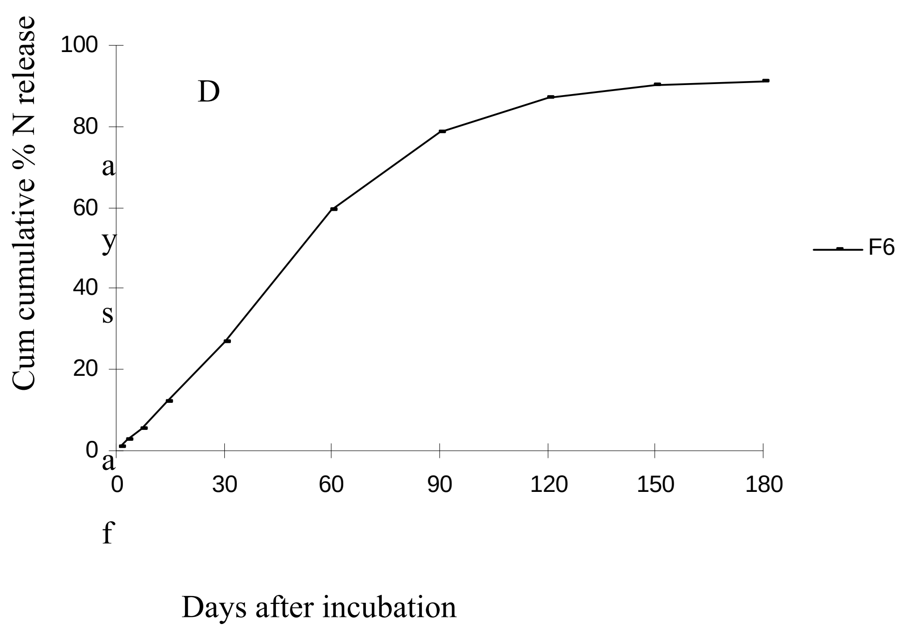


Figure 4-16. Comparison of nitrogen uptakes (A) of *Ficus elastica* 'Robusta' (mg N / plant) vs. nitrogen release (%) from F6 (B)

CHAPTER 5
SUMMARY AND CONCLUSIONS

Due to the prevalent high temperatures and rainfall that characterize South Florida's weather, the large numbers of nurseries located close to urban centers, and the sensitivity of the groundwater to nitrogen (N) pollution, Best Management Practices (BMP) guidelines are essential. In the actually very competitive horticulture market, there is a tremendous potential for container nurseries to become more efficient with their fertilizer use. Although today the controlled release fertilizers (CRFs) are increasing in popularity and are used by many growers in South Florida, there is a need to develop new methodologies and techniques to allow accurate predictions of N release patterns in the short term. Also, it is important to match plant growth characteristics with the N release pattern of the fertilizers used. This research includes in Chapter 3 the prediction for N release rates by different methods, and in Chapter 4, the response of plant growth to different CRFs.

Nitrogen Release Rate from Controlled Release Fertilizers Predicted by Different Method Study

Although many types of CRFs are available to crop producers, there is a lack of knowledge about N release patterns under field conditions. In Florida, there has been no quick and accurate test for determining N release rates. In the laboratory, the standard methodology for CRFs N release is at 25° Celsius (C) in soil or water incubation, but this procedure is very slow and can take several months or more than one year to be completed, which is inconvenient for practical purposes.

The objective of this study was to find an accelerated procedure to determine N release that could be correlated with the standard procedure in order to obtain N release results in short periods of time in hours or days. The research results of this study demonstrated that the N release test at 100°C was useful for prediction of N rate at 25°C. This procedure can be used by growers, manufacturers or regulators who want to test an unknown coated CRF product. We can conduct a short term test at 100°C for the product and use the regression equation found in this study. The release time for a given percent of N release at 100°C can then be used to predict the time required to release similar percent of N release at 25°C. Thus, the N release duration (about several months) at 25°C can be predicted by using a fast N release test at 100°C within hours. By using the accelerated incubation method, users can have a more accurate idea about the actual longevity of the CRF products used under South Florida conditions. This can save time and money. The field mesh bag study showed high correlation between the prill loss weight and the N release pattern; however it needs more research to be perfected, because environmental factors could have caused different values.

Response of Plant Growth Study

Supplying adequate nutrients for producing quality plants in containers poses interesting challenges to growers. CRFs can supply, in one application, enough plant nutrients to support a season long growth of crop, but matching nutrient release with plant requirements is a major challenge for both growers and CRF manufacturers. The objective of this research was to evaluate the relationship between N release patterns and plant growth (biomass and N Uptake). *Ficus elastica* 'Robusta,' which is a popular indoor and outdoor plant in Florida, was used as testing plants. All tested fertilizers that increased plant biomass were compared to the control treatment. However, there is no significant difference between the biomass of plants treated with various CRFs. We also tested nitrogen use efficiency (NUE), which show low values for all fertilizers. This may be caused by quick releasing of N from CRFs due to high temperature and over irrigation. Plant biomass and N uptakes were highly correlated to N release from CRFs measured at 25°C ($r>0.94$). The linear regression analysis also showed the biomass and N uptake can be predicted with N release of CRFs ($R^2>0.83$). This study indicated that CRFs hold great promise to improve plant growth and NUE but additional research on characterization, plant response, environmental effects, and economics is needed before CRFs use can be established in a much broader base.

LIST OF REFERENCES

Ahmed, I.U., O.J. Attoe, L.E. Engelbert, and R.E. Corey. 1963. Factors affecting the rate of release from fertilizers from capsules. Agron. J. 55:495-499.

Association of American Plant Food Control Officials (AAPFCO). 1995. Official Publication No. 48. Published by Association of American Plant Food Control Officials, Inc.; West Lafayette, Indiana, USA.

Broschat, T. K., and K. Moore. 2007. Release rates of ammonium-nitrogen, nitrate-nitrogen, phosphorus, , potassium, magnesium, iron, and manganese from seven controlled-release fertilizers. Commun. Soil Sci. Plan. Anal. 38: 843-850.

Cabrera, R.I. 1997. Comparative evaluation of nitrogen release patterns from controlled release fertilizers by nitrogen leaching analysis. HortScience. 32:669-673.

Craig, J.L., B.A. Birrenkott, and D.K. Struve. 2003. Nutrient uptake and dry weight patterns of three container-grown woody species. J. Environ. Hort. 21: 209-215.

Dai, J.J., X.L. Fan, J.G. Yu, F. Liu, and Q. Zhang. 2008. Study on the rapid method to predict longevity of controlled release fertilizer coated by water soluble resin. Agri. Sci. China 7(9):1127-1132.

Fan. X.H., and Y.C. Li. 2010. Nitrogen release from slow-release fertilizers as affected by soil type and temperature. Soil Sci. Soc. Am. J. 74:1082-1089.

Florida Department of Agriculture and Consumer Service. Bureau of Compliance Monitoring. 2004. Archive fertilizer tonnage data. Retrieved May 27, 2010, from http://www.flaes.org/complimonitoring/reports.html.

Florida Commercial Fertilizer Law. 2004. Florida Department of Agriculture and Consumer Service. Bureau of Compliance Monitoring Fertilizer Section. Chapter 576 Florida Statutes and Chapter 5E-1 Florida Administrative Code. Retrieved June 1, 2010 from http://www.doacs.state.fl.us/onestop/aes/fertilizer.html.

Florida Container Nursery BMP Guide. 2006. Container Production Guidelines. Retrieved June 3, 2010 from http://hort.ufl.edu/bmp/containerBMP.pdf.

Florida Department of Environmental Protection. 2002. Florida Green Industry. Best Management Practices for Protection of Water Resources in Florida. Retrieved June 4, 2010 from http://www.dep.state.fl.us/water/nonpoint/docs/nonpoint/BMP_Book_final.pdf

Foster, W. J., R.D Wright, M.M. Alley, and T.H. Yeager. 1983. Ammonium adsorption on a pinebark growing medium. J. Am. Soc. Hortic. Soc. 108:548-551.

Gandeza, A.T., S. Shoji, and L. Yamada. 1991. Simulation of crop response to polyolefin-coated urea: I. Field dissolution. Soil Sci. Soc. Am. J. 55:1462-1467.

Goertz, H.M. 1995. Technology development in coated fertilisers. In: “Proc. Dahlia Greidinger Memorial Goertz, Int. Workshop on Controlled/Slow Release Fertilisers” Technion Institute of Technology, Haifa, Israel.

Griffith, L.P. 2006. Tropical foliage plants. A grower’s guide. 2nd edition. pp.182-189. Ball Publishing, Batavia, IL, U.S.A.

Hodges, A.W., and J.J. Haydu. 2005. Economic impacts of the Florida environmental horticulture industry in 2005.Univ. of Florida-Institute of Food and Agricultural Science, Food and Resource Econ. Dep. EDIS document FE 675.

Huett, D.O. 1997. Fertiliser use efficiency by containerized nursery plants.1. Plant growth and nutrient uptake. Aust. J. Agric. Res. 48:251-258.

Huett, D.O., and B.J. Gogel. 2000. Longevities and nitrogen, phosphorus, and potassium release patterns of polymer-coated controlled release fertilizers at 30°C and 40°C. Commun. Soil Sci. Plant Anal. 31:959-973.

Husby, C.E., A.X. Niemiera, J.R. Harris, and R.D. Wright. 2003. Influence of diurnal temperature on nutrient release patterns of three polymer-coated fertilizers. HortScience. 38(3):387-389.

Ingram, D.I. 1981. Characterization of temperature fluctuations and woody plant growth in white poly bags and conventional black containers. HortScience. 16:762-763.

King J., and D. Stimart. 1990. Quantities and forms of N uptake throughout development in chrysanthemum. HortScience. 25:170.

Kochba, M., S. Gambash, and Y. Avnimelech. 1990. Studies on slow release fertilizers:1.Effects of temperature, soil moisture, and water vapor pressure. Soil Sci. 149:339-343.

Lamont, G.P., R.J. Worrall, and M.A. O’Connell. 1987. The effects of temperature and time on the solubility of resin-coated controlled-release fertilizers under laboratory and field conditions. Scientia Hort. 32:265-273.

Landels, S.P. 1994. Controlled release fertilizers: Supply and demand trends in US nonfarm markets. Proc. American Chemical Society National Meeting, Division of Fertilizers and Soil Chemistry. August 1994.

Meadows, W.A., and D.L. Fuller. 1983. Nitrogen and potassium release patterns of five formulations of Osmocote fertilizers and two micronutrients mixes for container grown woody ornamentals. Proc. Southern Nurserymen’s Assn. Res. Conf. 9:28-34.

Medina, C. L., T.A. Obreza, and J.B. Sartain. 2008. Nitrogen release patterns of mixed controlled release fertilizer and its components. HortTechnology. 18:475-480.

Medina, C.L., J.B. Sartain, T.A. Obreza. 2009. Estimation of release properties of slow-release fertilizer materials. HortTechnology. 19:13-15.

Obreza, T.A, R. Rouse, and E.A. Hanlon. 2006. Advancement with controlled-release fertilizers for Florida citrus production: 1996-2006. Univ. of Florida-Institute of Food and Agricultural Sciences, Soil and Water Science Dept. SL-243.

Obreza, T.A, and J.B. Sartain. 2010. Improving nitrogen and phosphorus fertilizer use efficiency for Florida's horticultural crops. HortTechnology. 20:23-33.

Oertli, J.J., and O.R. Lunt. 1962. Controlled-release of Fertilizer Minerals by Encapsulating Membranes: I. Factors Influencing the Rate of Release. Soil Sci. Soc. Am. Proc. 26:579-583.

Oertli, J.J., and O.R. Lunt. 1962. Controlled release of fertilizer minerals by encapsulating membranes: II. Efficiency of recovery, influence of soil moisture, mode of application, and other considerations related to use. Soil Sci. Soc. Am. Proc. 26:584-587.

Oertli, J.J. 1980. Controlled-release fertilizers. Fert. Res. 1:103-123.

Rose, M. A., and J. W. White. 1994. Nitrogen rate and timing of nitrogen application in poinsettia (Euphorbia pulcherrima Willd. Ex Klotz). HortScience. 29:1309-1313.

Rosen, C.J., P. Bierman, and M. McNearney. 2006. Kingenta controlled release fertilizer trial – 2006. Department of Soil, Water, and Climate. University of Minnesota. unpublished.

Shaviv, A. 2001. Advanced in controlled-release fertilizers. Adv. Agron. 71:1-49.

Shaviv, A. 2005. Controlled-release fertilizers. IFA International Workshop on enhanced-efficiency fertilizers. pp 15.Israel Institute of Technology, Haifa, Israel.

Sartain, J.B. 2008. The Florida Label. Univ. of Florida-Institute of Food and Agricultural Sciences, Soil and Water Science Dept. SL 3.

Sartain, J.B, and J.K. Kruse. 2001. Selected fertilizers used in turfgrass fertilization. Univ. of Florida-Institute of Food and Agricultural Sciences, Soil and Water Science Dept. CIR 1262.

Sartain, J.B., W.L. Hall, R.C.Littell, and E.W. Hopwood. 2004. New tools for the analysis and characterization of slow-release fertilizers, p. 180-195. In: Environmental impact of fertilizer on soil and water. Amer. Chem. Soc. Symo. Ser. 872. Washington. DC.

Simonne, E.H., and C.M. Hutchinson. 2005. Controlled release fertilizers for vegetable production in the era of best management practices: teaching new tricks to an old dog. HortTechnology. 15(1):36-46.

Tolman, D.A., A.X. Niemiera, and R.D. Wright. 1990. Influence of plant age on nutrient absorption for marigold seedlings. HortScience. 25:1612-1613.

Trenkel, M. A. 1997. Controlled release and stabilized fertilizers in agriculture. International Fertilizer Industry Assn., Paris.

Yeager, T.H., R.H. Harrison, and D.L. Ingram. 1991. 'Rotundifolia' Holy growth and nitrogen accumulation influenced by supraoptimal root-zone temperatures. HortScience. 26:1387-1388.

Yeager, T., J. Million, C. Larsen, and B. Stamps. 2010. Florida nursery best management practices: past, present, and future. HortTechnology. 20:82-88.

Wang, S.S., A.K. Alva, Y.C. Li, and M. Zhang. 2010. A rapid technique for prediction of nutrient release from controlled release fertilizers. Soil Sci. Soc. Am. J. Document submitted.

Wilson, M.L., C.J. Rosen, and J.F. Moncrief. 2009. A comparison of techniques for determining nitrogen release from polymer-coated urea in the field. HortScience. 44:492-494.

BIOGRAPHICAL SKETCH

Henrique Mayer was born in Caracas, Venezuela. He attended the Central University of Venezuela for five years where he received his bachelor's degree in agricultural engineering in 1984. In 1999, he moved with his wife and three daughters to the United States where he began working at the University of Florida / Institute of Food and Agricultural Sciences Extension office in Broward County. Actually, he works with the Miami-Dade Extension Service as a Commercial Urban Horticulture Extension Agent. He continued further studies in the Soil and Water Science Department at the University of Florida and will graduate with a Master of Science degree in August 2010.