NUTRIENT RELEASE PATTERNS OF COATED FERTILIZERS USED FOR CITRUS PRODUCTION AND THEIR EFFECT ON FRUIT YIELD AND FOLIAR NUTRITION

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my family

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Citrus trees require nitrogen (N) fertilizer to maintain optimum levels of fruit quality and productivity. Farmers have relied for many years on water-soluble fertilizers as the main method to provide N to Florida citrus trees. However, leaching of NO_3-N from excessive use of N containing water-soluble fertilizers can potentially contribute to contamination of groundwater, which supplies more than half of the total fresh water used in Florida. Controlled-release fertilizers (CRFs) have the potential to gradually release nutrients to coincide with the nutrient demand for crop growth, thereby maximizing N uptake efficiency while minimizing leaching losses.

A laboratory study was conducted to investigate the effect of various coated fertilizers (CitriBlen®; Agrocote® Type A; Agrocote® Type C(D) and Agrocote® Poly-S®) on nitrogen (N), phosphorus (P) and potassium (K) leaching using a soil incubation and leaching technique. The quantity of N, P and K released depended on composition and thickness of the coating. Release of N, P and K was delayed with CRF applications compared with water-soluble fertilizers.

A 1-year field study in a mature citrus tree environment was used to estimate N release characteristics of the same CRFs and a water-soluble formulation. Similar studies were simultaneously conducted in central and southwest Florida. Mesh bags containing 3.5 g of elemental N from each source were placed on the soil surface within the irrigated zone under the tree canopy and were retrieved from the field on a given. Despite differences in total amount of N released between locations, N release rates at both locations followed the same order: Water-soluble formulation>Agrocote® Type A > CitriBlen® > Agrocote® Poly-S® > Agrocote® Type C (D). Quantity and frequency of irrigation and rainfall and orchard orientation were determined as potential factors affecting these differences. N release patterns coincided with the citrus fertilization strategy recommended as a Best Management Practice (BMP).

Four commercial citrus orchards located in southwest and central Florida were used to compare the effects of CitriBlen® and a conventional water-soluble fertilizer program on mature citrus production and nutrition. Leaf tissue was sampled at each orchard in August 2004 and 2005. Results suggested that CitriBlen® applied only once per year at half the water-soluble N rate has the potential to produce leaf nutrient concentrations within the optimum range according to guidelines. An economic analysis compared costs and benefits between the two fertilization programs. A reduction in net income indicated that using CitriBlen® exclusively for citrus production is economically unfeasible due to its high cost. The implementation of a CRF program would not be attractive to citrus growers unless fertilizer prices change or a cost-share program was established.

CHAPTER 1
INTRODUCTION

Citrus plays an important role in Florida's agricultural industry. According to the Florida Agricultural Statistical Service (2004), commercial citrus production occupies 302,940 ha in five major production regions, with an annual production of 11.4 million metric tons. Nitrogen (N) supply is more important in citrus nutrition than any other element. It has a large influence on tree flowering, fruit set, appearance, and fruit production/quality (Zekri and Obreza, 2003). N is mainly provided to Florida citrus trees as dry soluble fertilizers. Because of Florida's poor natural soil fertility and humid climate, citrus trees require frequent applications of soluble N fertilizers at high annual rates to ensure sufficient vegetative growth, high yield and high fruit quality (Zekri and Koo, 1992). Efficient use of applied N is essential to maintain high quality trees while minimizing environmental hazards. N losses through leaching and/or volatilization are the main causes of low efficiency of applied N fertilizer.

In sandy Florida soils, excessive use of N-containing fertilizer can potentially contribute to leaching of NO_3-N and thus lead to contamination of groundwater or surface water resources (Paramasivam and Alva, 1997). A circa 1990 groundwater quality study revealed that 63% of the drinking water wells surveyed in the central Florida ridge counties of Lake, Polk, and Highlands contained detectable NO_3-N and 15% contained NO_3-N concentrations above the EPA Maximum Contaminant Level (MCL) of 10 mg L^{-1}. Most of the contaminated wells were located close to commercial citrus orchards (Lamb et al., 1999). The presence of nitrate in drinking water supplies above the EPA MCL represents a health hazard for Florida citizens. Although the source of groundwater nitrate in central Florida has never been confirmed, proper nutrient management practices and judicious use of existing fertilizer technology may minimize or eliminate N leaching from citrus fertilization and its potential to contribute to the nitrate problem.

Controlled-release fertilizers (CRFs) have the potential to synchronize nutrient release patterns with crop demand and therefore optimize nutrient uptake efficiency while reducing nutrient losses to the environment. Coated fertilizers occupy the largest share of controlled-release fertilizer technology due to their flexible nutrient release patterns and to their ability to control the release of other nutrients in addition to N. Despite continuing technological improvements and the commercial availability of several CRFs, their agricultural use remains limited. Many studies conducted on citrus fertilization in past years have shown that CRFs have the potential to produce similar or greater tree growth and fruit yield than water-soluble fertilizers. CRFs have also been shown to decrease N leaching potential. However, the higher cost of CRFs per unit of nutrient and the lack of experience about their performance in the field have caused Florida citrus growers to avoid them. Information is needed regarding field performance and economic feasibility of coated N fertilizers applied in commercial citrus orchard environments.

The objectives of this study were (1) to evaluate the cumulative N, P and K released from coated fertilizers with time using a soil incubation method; (2) to evaluate the N release patterns of coated fertilizers applied to a citrus orchard; (3) to develop N release curves for the coated fertilizers; (4) to evaluate the effects of a resin/polymer-sulfur coated mixture on fruit yield and foliar N, P, K, Ca and Mg concentrations of mature citrus trees; and (5) to evaluate the economic feasibility of using a controlled-release fertilization program compared with a water-soluble fertilization program for commercial orange production.

CHAPTER 2
LITERATURE REVIEW

Fate of Nitrogen in a Citrus Environment

Any nutrient added to the soil undergoes numerous complex interactions between plant roots, soil microorganisms, chemical reactions and pathways for loss (Shaviv and Mikkelsen, 1993). For citrus, a maximum of 50 to 55% of the N fertilizer annually applied can be accounted for by plant uptake even considering exceptionally high fruit yield scenarios (He et al., 2000A). Applied nutrients not recovered by the trees and fruit may be lost to the environment by different mechanisms. Thus, there is a need to understand the fate of nitrogen in a citrus environment to maintain high quality trees while minimizing the effects of N fertilization on the environment, particularly water resources.

Fate of nitrogen in a citrus environment includes several mechanisms: 1) plant uptake; 2) runoff and leaching into groundwater and surface water; 3) denitrification; and 4) volatilization (He et al., 1999). Figure 2-1 illustrates N dynamics in a citrus ecosystem.

Plant Uptake

Nitrogen uptake efficiency (NUE), defined as the percentage of applied N taken up by crops, is often low in Florida soils because of the high mobility of N fertilizer (Obreza and Rouse, 1992). In sandy soils receiving 100- to 125-cm of rainfall, the efficiency of N uptake by plants may not exceed 20 to 30% (Oertli and Lunt, 1962). Mattos (2000) estimated NUE for 6-year old 'Valencia' trees grown in a sandy soil to be 40% and 26% for ammonium nitrate and urea, respectively. Paramasivam et al. (2001) showed that

NUE for 25-yr-old ‘Hamlin’ orange trees grown in an Entisol ranged between 40 and 53%.

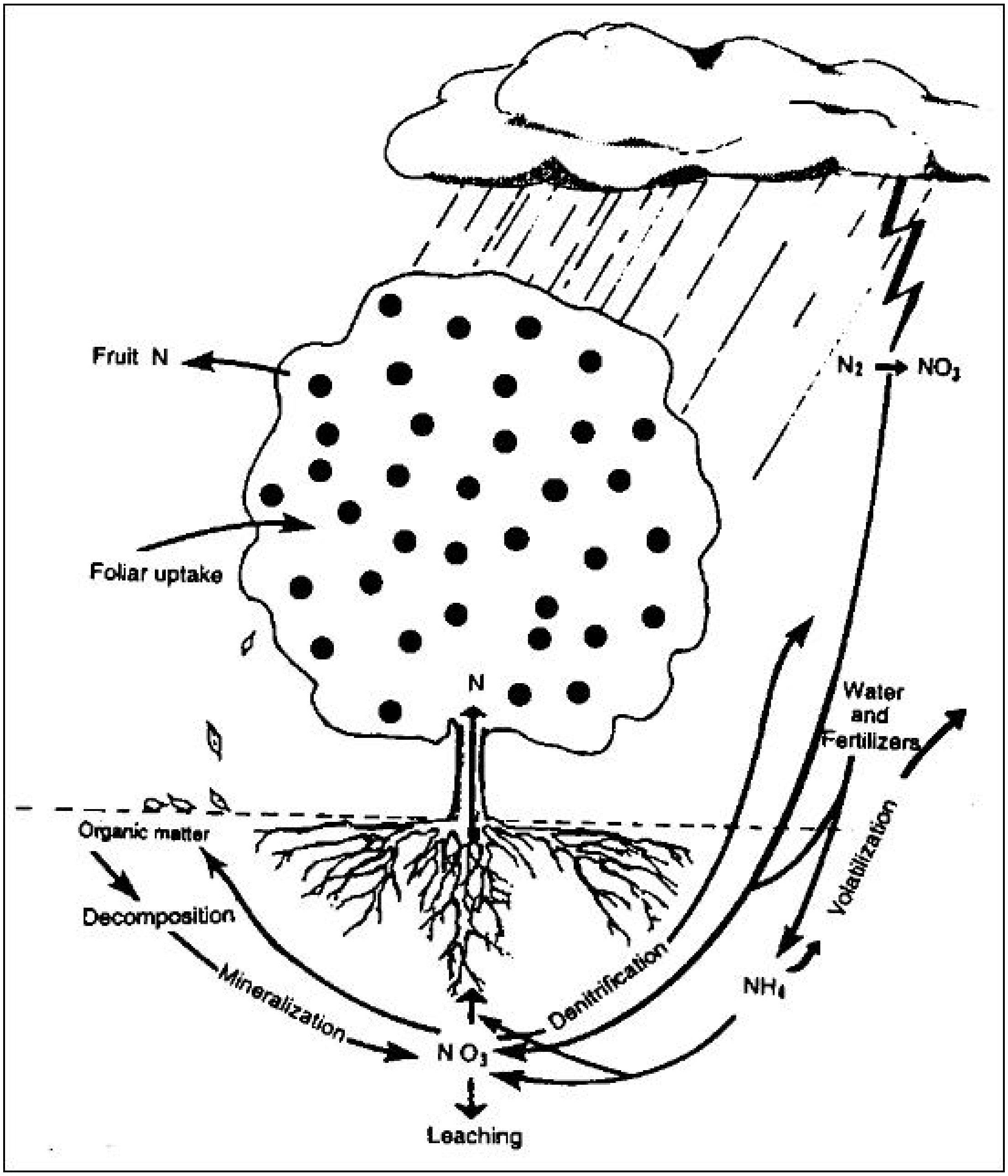

Figure 2-1. Citrus nitrogen cycle

NUE of young citrus trees can vary from 57 to 68% depending on tree growth rate, supply of other nutrients, and irrigation water quality (He et al., 1999). However, NUE is more complex to measure for bearing-citrus trees since they can store nutrients to sustain fruit production and growth. N removal in the harvested fruit can be a measure of NUE for mature citrus, since this is the only portion that is removed from the tree-soil system on an annual basis. Therefore, the annual fertilization program should aim to replenish nutrients removed by the harvested fruits along with adequate consideration of the nutrient requirement for the annual regrowth of leaves and roots, storage for flowering and fruit setting, application efficiency, and the contribution of nutrients from recycling of organic residues in the soil (Alva and Paramasivam, 1998B).

Alva (1997) reported that the amount of N removed by harvested fruit was significantly correlated (quadratic relationship) with N rates. When N fertilizer was applied at 112 kg ha^{-1} $year^{-1}$, total N in the fruit was equivalent to 70 to 80% of the annual N applied depending on fertilizer source. This N recovery was higher than average, and is often difficult to reach under normal production conditions. Consequently, it is apparent that mineralization of N from crop residues plays an important role in supplying a fraction of the N requirement.

Leaching and Runoff

Currently, there is an increasing concern regarding large accumulations of NO_3-N in ecosystems, mainly from N leaching from agricultural fields. High nitrate concentrations are related to (i) methemoglobanemia in infants and in ruminants; (ii) stomach cancer, for which a possible link with nitrates or nitrosoamines has been suggested; (iii) other diseases such as goiter, birth defects, and heart disease; and (iv) eutrophication of surface water (Shaviv and Mikkelsen, 1993).

Transport of NO_3-N through the soil profile is a function of many variables, including soil, climate factors, biological N, and cultural characteristics. Edaphic characteristics include texture, porosity, structure, consistency, depth of profile, and percolation rates. Climatic characteristics include amount, frequency, duration, and timing of precipitation. Presence or absence of plant cover, depth of root zone, N use characteristics of the vegetation, and periods of plant growth also influence N dynamics in agricultural soils. Amount of organic matter and microbial population affect leaching of NO_3-N to groundwater (Alva, 1997).

Under Florida's warm, humid conditions, NO_3-N easily moves through the soil profile due to rapid transformation of NH_4-N into NO_3-N, inherently low soil fertility, low cation exchange capacity, and unique hydrologic features (e.g. a thin surface soil layer, high water table and porous limestone in many areas) (Tucker et al., 1995; Paramasivam et al., 2001). Consequently, a substantial portion of applied N fertilizer may leach from the root zone into surface and groundwater. Paramasivam and Alva (1997) reported that about one-third of N applied to citrus on Florida's extremely sandy soils is lost to leaching or volatilization. Similarly, leaching losses in a large southern California watershed planted with citrus were equivalent to 45% of the annual N applied (Paramavisam et al., 2001).

Most Florida citrus orchards have been planted on Entisols, Spodosols or Alfisols, depending on geographical region (Obreza and Collins, 2002). Nearly 40% of citrus orchards are found on the deep sandy Entisols along the Central Florida ridge, while more than 21.5% of total state citrus plantings are on the flatwoods and marsh soils of southwest Florida. A mixture of Alfisols and Spodosols is found in the Indian River citrus-growing area near the east coast.

In a study conducted by Lamb et al. (1999), 15 months of baseline data indicated that groundwater NO_3-N concentrations were above the EPA Maximum Contaminant

Level (MCL) of 10 mg L^{-1} beneath mature citrus groves on the central Florida ridge. This area contains primarily Entisols (ridge soils) with no confining subsurface soil horizon, very low organic matter content and sand content > 96%. Most of the well-drained soils of this region are classified as vulnerable to leaching of N (Tucker et al., 1995). Alva and Tucker (1993), in a leaching study on an Entisol using coated and soluble fertilizers for young citrus, reported that NO_3-N concentration detected 1.5 m below ground were above the MCL in the treatments that received soluble fertilizer at high rates. Results from another study on an Entisol showed that NO_3-N concentrations in soil solution below the rooting depth (240 cm) peaked occasionally at 17 to 33 mg L^{-1}, but under careful irrigation and N management conditions concentrations were normally below 10 mg L^{-1}. It was also demonstrated in the same study that NO_3-N leaching losses below the rooting zone increased with increasing rate of N application and the amount of water drained (Paramavisam et al., 2001).

In contrast to the well-drained Entisols, the acid, sandy Spodosols (flatwoods soils) are typically poorly drained with a spodic and clay strata that impede water flow vertically from the profile. Consequently, water draining from these soils flows laterally along the top of the subsurface hardpan to a surface water body. Hence, potential leaching of NO_3-N to the groundwater is more important in ridge soils than in flatwoods soils. However, in some cases, the hardpan is broken during the bedding process, and thus, there could be a potential for downward migration of pollutants below the hardpan (Alva et al., 1997). Calvert (1975) demonstrated that NO_3-N concentrations in the tile drainage water of a Spodosol varied from <1 to 8 mg L^{-1}, depending on rainfall, irrigation and fertilization practices. In a study by He et al. (2000) on a Spodosol, solution NO_3-N concentrations at 120- and 180-cm depths increased with increasing fertilizer rates, but never exceed the MCL even at the highest rate of fertilizer (168 kg N ha^{-1} yr^{-1}). However, results from a study in west central Florida (He et al., 1999) revealed that NO_3-N concentrations in groundwater exceed the MCL even at 3-m depth below surface on flatwoods soils. Mansell et al. (1977) in a flatwood soils management study found that surface runoff typically occurs from deep-tilled flatwoods during intense rainfall or irrigation of long duration after the soil profile has become water-saturated.

Denitrification

Denitrification is the gaseous loss of nitrogen to the atmosphere via a microbial respiration process. This process occurs under anaerobic conditions where microbes obtain their O_2 from NO_2^- and NO_3^- with the accompanying release of N_2 and N_2O (Havlin et al., 1999). Environmental concerns about emission of nitrous oxides are mainly related to the effect on global warming and the role of nitrous oxides in ozone destruction. The destruction of O_3 is catalyzed by NO, halogens, hydroxyl, and hydrogen. A possible source of NO is from N_2O, the product of denitrification, which can diffuse into the upper atmosphere and lead to atmospheric "holes", hence causing problems for plants and animal life from excessive exposure to ultraviolet radiation. However, depletion of the ozone layer is also greatly associated with the intensive industrialization that has taken place during the past 5 decades (Shaviv, 2001).

The presence of NO_3-N in the soil profile, lack of O_2, denitrifier population, and availability of soluble carbon sources are the main factors determining the magnitude of denitrification activity. These characteristics are often found in flatwoods soils, especially associated with a shallow water table. Results of a study conducted by Mansell et al. (1977), indicated that a significant portion of the N fertilizer applied to citrus grown in a deep-tilled flatwoods soil was denitrified due to the relatively slow drainage characteristics and the capacity of the soil located in the lower portion of the profile to denitrify NO_3-N. Another study on Spodosols (He et al., 2000A) showed that the concentrations of NO_3-N were greater in the soil solution at the 120-cm depth than at the 180-cm depth, which might be due to greater denitrification at the 180-cm depth.

Although some localized anaerobic microsites can exist in a well-drained soil, gaseous loss of N by denitrification is often insignificant in central Florida ridge soils (Alva and Paramasivam, 1998B). However, Paramavisam et al. (1999) demonstrated that denitrification occurred in well-drained sandy Entisols particularly at the soil/groundwater interface and was dependent on the amount of available carbon and denitrifier population.

Volatilization

Volatilization, the gaseous loss of ammonia from surface applied ammonium and urea fertilizers, is controlled by various soil properties and environmental factors and is directly proportional to ammonium concentrations in the soil solution. Ammonia volatilizing from fertilized fields can accumulate in neighboring natural ecosystems, possibly causing damage to the vegetation. Some of the ammonia may be converted into nitric acid, and this product coupled with sulfuric acid (from industrial sources) forms acid rain that can affect plants directly and can acidify lakes, resulting in aluminum toxicity in fish and plants (Newbould, 1989).

Ammonia volatilization increases with soil temperature and soil pH (Ernst et al., 1960). Nitrification, the transformation of NH_4 to NO_3, is inhibited at high temperature, resulting in increased availability of N as NH_4, which contributes to increased volatilization losses. Ammonia volatilization is favored in sandy soils with low buffering capacity, since the ability of NH_4 to form electrostatic bonds with clay minerals and organic colloids to impair losses of soil and fertilizer N is low. In well-drained ridge soils with high pH, volatilization losses can account for 10 to 15% of NH_4-N applied to the soil surface on an annual basis (Alva and Paramasivam, 1998B).

He et al. (1999) measured ammonia volatilization from four N fertilizer sources surface-applied to an Alfisol (Riviera fine sand, pH 7.9) using a sponge-trapping technique in the laboratory. Ammonia volatilization increased significantly with an increase in NH_4-N application rate, and by 2- and 3- fold, respectively, with an increase in incubation temperature from 5 to 25 C, and from 25 to 45 C, respectively. Ammonia volatilization was minimal at pH of 3.5 and increased rapidly with increasing pH up to 8.5. In a field study by Mattos et al., (2003), ammonia volatilized from dry-granular ammonium nitrate and urea fertilizers surface-applied to a sandy Entisol was evaluated using a semi-open static system of ammonia sorbers. Ammonia volatilization losses from both N sources were greater when air was circulated inside the collection chamber to simulate ambient air movement compared with volatilization measured with no air circulation. This result showed the remarkable effect of environmental conditions such as aeration, temperature, and soil moisture on ammonia volatilization.

Citrus Management Practices

Most Florida citrus is grown on extremely sandy soils with inherently low fertility, low cation exchange capacity and low retention of applied plant nutrients. Due to these soil properties and climatic conditions in Florida, nitrate ions can freely leach from root zones into groundwater, potentially leading to pollution of drinking water supplies. Proper fertilization and irrigation management practices are required to ensure sufficient vegetative growth, high fruit yield, and good fruit quality while minimizing detrimental effects on the environment.

Fertilizer Management

Citrus fertilization practices can be tracked back to the late 1800s. In the early 1900s low analysis fertilizers and organic N sources were used. Since the 1930s, inorganic fertilizers have played a major role in increasing citrus production per unit land area (He et al., 1999).

Fertilizer Form

Traditionally, broadcast application of dry soluble fertilizer material has been the main method to provide N to citrus trees in Florida. The majority of N applied has been ammonium nitrate either in granular or solution form. Also, the use of ammonium sulfate in sulfur-deficient or high soil pH conditions has increased in Florida during the past decade (Sartain, 2003). However, the soluble nature of these materials in combination with Florida's soil and climatic conditions may potentially cause leaching of NO_3-N below the root zone.

Fertigation, the delivery of liquid fertilizers through the irrigation system, has become a popular way to apply nutrients since the introduction of microirrigation systems for citrus irrigation. Fertigation facilitates (i) placement of fertilizer under the canopy for efficient root uptake, and, (ii) increased frequency of application without substantial increase in application cost (Alva et al., 1998). By increasing frequency of application, small amounts of fertilizer can be applied many times through the course of the growing season, improving nutrient uptake efficiency and reducing leaching losses. A study by Lamb et al. (1999) showed that when 142 kg N ha^{-1} was applied as a combination of fertigation and foliar spray, groundwater NO_3-N concentration decreased from 30 mg L^{-1}

to less than 10 mg L^{-1} while maintaining optimal fruit production and nutritional status of leaves. Some studies (Alva et al., 2002; Alva and Paramasivam, 1998A) showed that fruit yield was significantly greater for fertigation than for a soluble, granular source applied at similar rates. These results suggest that nutrient uptake efficiency may be greater with fertigation compared with the application of dry soluble fertilizers. However, fertigation does not always provide better efficiency. For example, Koo (1980) reported no significant differences in fruit yield and leaf nutritional status between water-soluble granular fertilizers and fertigation.

Controlled-release fertilizers were developed to improve nutrient use efficiency while reducing environmental hazards. Many studies (Alva and Tucker, 1993; Dou and Alva, 1998; Wang and Alva, 1996) have shown that controlled-release fertilizers applied in part or throughout a citrus fertilization program have potential to reduce N leaching on Florida sandy soils. It was also reported that greater fruit yield was obtained using controlled-release fertilizers compared with water soluble fertilizers (Obreza et al., 1999; Zekri and Koo, 1992). However, due to its greater cost, the use of controlled-release fertilizers for citrus has been limited to young-tree situations (reset or solid-set new plantings) where high frequency application of conventional fertilizers is not feasible (Obreza and Rouse, 1992).

Fertilizer Rate

In general, increasing N rate tends to 1) increase juice volume, total soluble solids (TSS), acid content and juice color; 2) increase number of green fruit at harvest, and incidence of creasing and scab; and 3) decrease fruit size, weight and peel thickness (He et al., 1999).

Applying less than the recommended N rate may substantially reduce yield and/or fruit quality, while over-application may increase the risk of nitrate contamination of the groundwater. Optimal N-fertilizer rates are dictated by overall tree N-requirements and N-fertilizer use efficiency. Currently, fertilizer rates for non-bearing citrus trees are recommended in weight of a complete N-P-K fertilizer per plant (e.g. lbs tree^{-1}), while for bearing citrus trees (4 years and older), fertilization is based on the expected production and N is recommended on a weight per unit area basis (e.g. lbs acre^{-1}). The current recommended N rate for bearing citrus trees ranges from 134 to 269 kg N ha^{-1} yr^{-1} (120 to 240 lb N acre^{-1} yr^{-1}) depending on variety and expected production volume per unit area (Tucker et al., 1995). A worldwide review of long-term citrus fertilization experiments indicated that application of 202 kg N ha^{-1} yr^{-1} is sufficient to sustain optimal tree growth and maintain high fruit quality and production (Alva and Paramasivam, 1998B). Another study by Lamb et al. (1999) demonstrated that when applying N at rates of 180 kg ha^{-1}yr^{-1} to mature citrus located on the central Florida ridge, the groundwater may on average comply with the MCL. Similarly, in a 4-yr study on an Entisol, Alva et al., (1998) showed that leaf N concentrations and fruit production did not significantly change when lowering N rates to 180 kg ha^{-1}yr^{-1}.

Irrigation Management

Since transport of water through the soil profile plays a major role in leaching of NO_3-N, optimal irrigation management practices are important to minimize NO_3-N leaching losses and to improve N uptake efficiency, principally in sandy soils. Traditionally, citrus was grown under overhead irrigation, where the entire grove area was irrigated. More recently, due to the increasing need to conserve water, microsprinkler irrigation has been introduced where the irrigated area is greatly reduced to under the canopy, which is also the area of maximum root activity. Young trees usually use microsprinklers that wet only a small area and provide efficient application of water and fertilizer, and cold protection when needed. For mature trees with an expanded root system, the wetted area should cover at least 50% of the ground surface under the canopy in order to supply adequate irrigation and fertigation, and avoid leaching (Tucker et al., 1995).

The depth of wetting for each irrigation event should be restricted to the root zone, so that soluble N is maintained within the rooting depth and NO_3-N uptake is facilitated. Therefore, irrigation duration should be limited to replenish the water storage capacity of the root zone (45 to 90cm) under the wetted area in order to avoid leaching. The use of tools such as tensiometers, other soil moisture probes, and rainfall data is a recommended N-BMP for irrigation scheduling (Schumann, 2003). Timing of fertilizer application also plays a critical role in preventing groundwater pollution. It is recommended to avoid fertilizer application during intense rainfall months (June through August) to minimize the risk of NO_3-N leaching below the root zone. Several studies (Alva, 1997; Alva et al., 1998; Alva and Paramasivam, 1998A; He et al., 2000B; Paramasivam et al., 2001; Paramasivam et al., 2002) have shown that under appropriate irrigation scheduling and timing of fertilizer application, optimal fruit production can be economically attained at lower N rates than recommended, leaching of NO_3-N below the rooting depth can be minimized and N uptake efficiency can be increased.

Leaf Analysis

Leaf analysis has been extensively used in the past two decades as a research tool to gain valuable nutritional information about citrus trees. Leaf analysis can be helpful in the following ways: 1) It can reflect the citrus tree nutritional status with respect to most nutrients, but is particularly effective for nutrients that readily move with soil water like N and K; 2) It can help confirm visual nutrient deficiency symptoms; 3) It can reveal nutritional problems where none are suspected to exist because of absence of marked deficiency symptoms (Smith, 1966). Leaf analysis plays an important role in formulating an efficient fertilization program, since trends in leaf nutrient content may indicate whether the supply of a particular element is inadequate, satisfactory or unnecessarily high.

Leaf tissue sampling has been used in many studies (Alva and Tucker, 1993; Dou and Alva, 1998; Obreza, 1993; Obreza et al., 1999) as a technique to determine the effects of particular fertilizer sources and rates on growth and production of both young and mature citrus trees. In Florida, 4- to 6-month-old spring flush leaves are sampled following the procedure described by Obreza et al. (1992). Five ranges (deficient, low, optimum, high, and excess) for each element have been established to classify the nutritional status of mature, bearing trees. Maintenance of leaf sample elemental concentrations in the optimum range is desirable.

Soil sampling can also be important in fertilization decisions, but for long-term crops such as citrus, leaf sampling is a better indicator of the effectiveness of soil-applied fertilizers. Soil sampling should be used for only those elements that have low mobility in most soils (such as P, Ca, and Mg) as support information to help make future fertilization decisions (Obreza, et al., 1992).

Controlled-Release Fertilizers

CRFs are designed and manufactured to gradually deliver nutrients to plants at a rate that fits plant physiological requirements during growth, while simultaneously reducing nutrient loss potential since only a small fraction of the total application is present in a readily available form at any one moment (Oertli, 1980). This type of fertilizer can provide many benefits to agriculture, such as (i) higher fertilizer use efficiency; (ii) reduced nutrient losses via leaching, ammonia volatilization and denitrification; (iii) savings in labor and equipment costs for transportation, preparation, and application of the fertilizer since large single fertilizer applications are possible without causing stress or toxicity to plants; (iv) less soil compaction or mechanical damage to crops since fewer field operations are necessary; and (v) reduction of soil chemical processes that decrease the availability of nutrients, such as the fixation of P (Lunt, 1971; Oertli, 1980; Sharma, 1979).

There are, however, some concerns related to the use of CRF. With regard to fertilizer longevity, nutrient release patterns from some CRFs under laboratory testing (data provided by the manufacturer) do not correlate with the actual nutrient release pattern under field conditions. A study done by Meadows and Fuller (1983) revealed that nutrient release periods of several polymer-coated CRFs were shorter than those claimed by the manufacturers. The initial nutrient release with sulfur coated controlled-release fertilizers may be too rapid, causing damage to the crop and a higher fertilization cost compared with non-coated water soluble fertilizers (Trenkel, 1997). Lastly, with regard to residual effects, there is a possibility that nutrient release from CRF may continue during the non-cropped season and result in serious leaching losses (Shaviv and Mikkelsen, 1993). All the possible disadvantages from CRF mentioned above may result in environmental or crop damage and economic losses.

Types of Controlled-Release Fertilizers

Controlled-release fertilizers can be classified into four types: (i) materials of limited water solubility containing plant available nutrients (e.g. metal ammonium phosphates); (ii) materials of limited water solubility which, during their chemical and/or microbial decomposition, release plant available nutrients (e.g. ureaforms, oxamides); (iii) water-soluble or relatively water soluble materials that gradually decompose, thereby releasing plant available nutrients (e.g. guanylurea salts), and (iv) water soluble materials where dissolution is controlled by a physical barrier, e.g. by an impermeable or semi-impermeable coating (Hauck, 1985). Coated fertilizers represent the fastest growing segment in 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). Currently, CRF coating materials are composed of either sulfur or polymeric materials or hybrid products that utilize a multilayer coating of sulfur and polymer (Sartain and Kruse, 2001). As shown in Figure 2-2, for nutrient release of polymer-coated fertilizers (PCF), water (mainly vapor) passes in through the coating. The vapor condenses on the solid core and dissolves part of it, thus inducing a build-up of internal pressure. At this stage, two pathways are possible. If the internal pressure exceeds the membrane resistance, the coating ruptures and the entire content of the granule is released instantaneously. If the membrane resists the internal pressure, the fertilizer is released by diffusion driven by a concentration gradient across the coating, by mass flow driven by a pressure gradient , or by combination of the two (Shaviv, 2001). For polymer/sulfur coated fertilizers, the nutrient release mechanism is through a combination of diffusion and capillary action. Water vapor must first diffuse through the continuous polymeric membrane layer. Once at the sulfur/polymer interface, the water subsequently penetrates the defects in the sulfur coat through capillary action and solubilizes the fertilizer core. The solubilized fertilizer then exits the particle in reverse sequence (Sartain and Kruse, 2001). PCFs are the most sophisticated and advanced means of controlling fertilizer durability and nutrient release. The use of most polymer-coated products has been generally limited to high value applications due to the high cost of the coatings (Sartain, 1999).

The potential of PCF to produce comparable or improved plant growth compared with water-soluble forms has been demonstrated. For example, 5-year-old bearing Hamlin orange trees responded better when a resin/Poly-S mixture was applied once per year at 101 kg N ha^{-1} than water-soluble fertilizer applied three times per year at 202 kg N ha^{-1} (Obreza and Rouse, 2004). However, there are still concerns about whether or not nutrient release patterns from PCFs match plant nutrient demands. A study by Cabrera (1997) indicated that despite similar longevity ratings, the intensity and pattern of nutrient release can be significantly different among polymer-coated CRFs. Therefore, there is a need to better understand the basis for differences in PCF nutrient release characteristics and the effects of environmental factors on PCF nutrient release patterns. An increased understanding of these factors could potentially lead to more efficient use of PCFs.

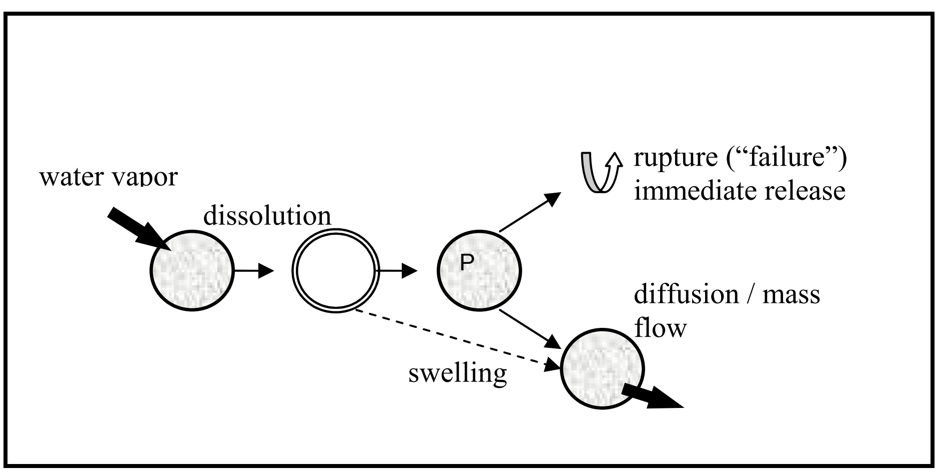

Figure 2-2. Nutrient release mechanism for polymer-coated fertilizers.

Predicting Nutrient Release from PCFs

Efforts have been made during the last decade to develop empirical, semi-empirical, and mechanistic models describing nutrient release from coated fertilizers. Most of these models were based on the assumption that the release of nutrients from coated CRFs is either controlled by the rate of solute diffusion from the fertilizers or by the rate of water vapor penetration into the CRF through the coating (Shaviv, 2001).

The nutrient release patterns of PCFs have been studied by several investigators. Shaviv (2001) described a diffusion release process from PCFs where the driving force is the vapor pressure gradient across the coating. This release course consists of three stages: (1) the initial stage during which almost no release is observed (lag period), (2) the constant-release stage, and (3) the stage where a gradual decay in release rate occurs. Kochba et al. (1990) considered nutrient release to be a first-order kinetic process where water vapor movement into the fertilizer is the rate-limiting process. The authors suggested a release sequence consisting of two stages: water vapor diffusion into the granule, and solution flow out of the coating. Ahmed et al. (1963) demonstrated that water condensation on salts increases with the lowering of vapor pressure by the saturated salt solution and thus the rate of release is affected. Other investigators, such as Oertli and Lunt (1962) and Lunt and Oertli (1962), used several elution and leaching experiments to conclude that the mechanism controlling the nutrient release is the diffusion of salts out of the fertilizer granules.

Factors Influencing PCF Nutrient Release

Temperature

Temperature is the most important environmental factor influencing PCF nutrient release (Oertli and Lunt, 1962). The nutrient release rate was found to significantly increase with an increase in temperature (e.g., an increase in temperature from 10 to 20 C almost doubled the initial release rate). Because the release rate increased much greater than would have been expected from a simple diffusion mechanism, Oertli and Lunt (1962) speculated that properties of the coating materials could possibly change with temperature.

Ahmed et al. (1963) showed in a pot study that nutrient release rate was directly related to temperature. The investigators suggested that the direct relation between temperature and the rate of release could possibly have been due to either an increase in viscosity of water at the lower temperature if it had entered as a liquid or to a reduction in water vapor pressure if it entered as a vapor. Kochba et al. (1990) determined in a soil incubation study that the change of the nutrient release rate with temperature is expected to be exponential since vapor pressure is an exponential function of temperature. Cabrera (1997) studied the N leaching patterns of different PCFs in containers under greenhouse conditions during the growing season. It was found that some PCFs exhibited N leaching patterns that closely followed changes in average daily ambient temperature over the season. This relationship was curvilinear, with N leaching rates being highly responsive to temperature changes between 20 and 25 C. Lamont et al. (1987) investigated the nutrient release rate of PCFs in beakers of distilled water at different temperatures. It was found that the nutrient release rate was affected by both incubation temperature and time. Generally, as temperature increased, nutrient release increased. Subsequently, nutrient release decreased with time after high initial release rates.

Other Factors

Oertli and Lunt (1962) found that the release rate was independent of pH as well as microbial activity. Coating thickness also had an effect on release rate. The release rates from heavily coated materials were relatively low and from lightly coated material were high. Furthermore, they determined that there was an effect of ionic species; nitrate and ammonia were released more rapidly than potassium and phosphate under comparable conditions.

Lunt and Oertli (1962) found that moisture level 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. This result supports the hypothesis of Kochba et al. (1990) that substrate vapor pressure is the rate-limiting step in nutrient release, since lowering the substrate moisture level within range of field capacity does not have a marked effect on the substrate vapor pressure. Likewise, they found that the time for nutrient release through a membrane was substantially extended if the fertilizer was top-dressed compared with incorporated. This finding was apparently due to intermittent drying of top-dressed material between watering. Cabrera (1997) also found that top-dressing decreased release rates relative to incorporation. The release rate from PCF can also be altered by composition of the coating and the fertilizer N source being coated (Sartain and Kruse, 2001).

CHAPTER 3
NUTRIENT RELEASE CHARACTERISTICS OF COATED FERTILIZERS UNDER GREENHOUSE AND FIELD CONDITIONS

Introduction

The efficient use of applied N fertilizers is influenced by soil, plant, and environmental conditions. High mobility of N fertilizers in deep sandy Florida soils and poorly distributed annual rainfall of around 1250 mm combine to make applied N highly leachable, therefore large N doses are required to maintain high yield and quality of citrus. High N fertilizer rates may cause environmental damage while at the same time increasing production costs. Controlled-release fertilizers (CRF) are a possible alternative to minimize N losses to the environment and increase N uptake efficiency while meeting production goals of citrus growers.

CRFs contain one or more plant nutrients in a form that extends their availability to the plant considerably longer than rapidly-available water-soluble fertilizers. This gradual release of nutrients brings a potential to match plant nutrient demand. The use of CRFs has currently increased due to pressure from environmental groups and regulatory agencies to overcome environmental impacts. Hence, the use of controlled-release materials in fertilization programs is now being considered as a Best Management Practice (BMP). A BMP is defined as a “recommended technique that is technically and economically feasible, which will minimize water quality impact with no adverse effects on the agricultural production and/or quality, as well as net returns” (Alva et al., 2002). In 1994, the Florida legislature passed a ‘Nitrogen Best Management Practice (N-BMP)’ law that mandated the state to develop crop specific nitrogen BMPs designed to meet groundwater standards. An interim BMP for citrus was established at that time based on previous N rate studies and current IFAS recommendations. In 2002, a revised citrus BMP was established as an incentive-based program that contains fertilization and irrigation guidelines designed to minimize the risk of leaching nitrates from fertilizers to groundwater.

Despite recommendation of CRFs in BMPs, the lack of experience about their field performance is one reason why citrus growers avoid them. Information regarding the release periods and patterns of individual CRFs is needed to increase acceptance of CRFs for citrus production. Different techniques have been used to estimate release characteristics of controlled-release N-fertilizers. According to Sharma (1979), the most direct and widely used technique is the soil incubation methodology that determines some or all of the mineral N released during CRF incubation in soil. Methods used for laboratory evaluation of N fertilizers include: determination of fertilizer fractions soluble in cold water, hot water, buffer solutions, or permanganate solution; direct incubation in soil; indirect incubation in soil; Neubauer tests; short-term nutrient uptake and microbiological assays.

The objectives of this study were:

1. Determine N, P and K release patterns of four coated fertilizers and water-soluble fertilizer in a short-term laboratory incubation.
2. Measure the N release characteristics of the fertilizers in a long-term field evaluation.

Materials and Methods

Nutrient release patterns were simultaneously evaluated in greenhouse and field studies from spring 2004 to spring 2005.

CRF Incubation and Nutrient Leaching Study

Nitrogen (N), phosphorus (P) and potassium (K) release patterns were evaluated using a soil incubation-column leaching study in the greenhouse. Four controlled-release fertilizers (CRF) and a water-soluble product were compared for 270 days. CRFs were CitriBlen®; Agrocote® Type A; Agrocote® Type C(D) and Agrocote® Poly-S® (Table 3-1). The soluble formulation was a Hydro® 21-7-14 product. CitriBlen® is a mixture composed of coated (Agrocote® Type A; Agrocote® Type C(D) and Agrocote® Poly-S®) and water-soluble (Hydro®, Potassium-magnesium sulfate, Potassium chloride and Iron) nutrients.

Table 3-1. Nitrogen sources in each controlled-release fertilizers

Source	Formulation (N-P_2O_5-K_2O)	Ammoniacal %	Nitrate %	WSON[1] %
CitriBlen®	15-3-19	5.3	4.5	5.2
Agrocote® Type A	19-6-12	10	9	0
Agrocote® Type C(D)	18-7-12	10	8	0
Agrocote® Poly-S®	37-0-0	0	0	37

[1]Water-soluble organic N (primarily urea)

The leaching column technique as described by Sartain et al. (2004) was used in this study. A surface layer (0 to 5 cm depth) of Arredondo fine sand (90 g) (Loamy siliceous, hyperthermic, Grossarenic Paleudult) from central Florida was mixed with non-coated white sand (1710 g) and the equivalent of 450 mg N from each source. These mixtures were placed in 30-cm long, 7.5cm diameter PVC incubation lysimeters (Figure 3-1). The sand/soil/N source mixture was brought to 10% moisture by adding 180 mL of 0.01% citric acid solution.

A 50 mL beaker containing 20 mL of 0.2 M H_2SO_4 was placed in the head space of the incubation lysimeter as an ammonia trap. This solution was replaced and analyzed for NH_4-N by titration every 7 days to determine volatile-N. The soil columns were incubated at about 24 C in a greenhouse. Each lysimeter was leached after 7, 14, 28, 42, 56, 84, 112, 140, 180, 210, 240 and 270 days with one pore volume of 0.01% citric acid (500 mL) using a vacuum manifold for 2 min. Leachate volume was recorded and an aliquot was frozen for later analysis of N, P and K. All samples were analyzed for NO_3-N and NH_4-N using an air segmented Rapid Flow Analyzer (RFA). The concentration of urea-N was measured using a colorimetric method (Bremner, 1982). An estimation of the total N released with time was calculated by adding the three forms of N present in the leachate and the volatile-N. The concentrations of P and K in the leachates were analyzed at the University of Florida Analytical Research Laboratory following USEPA method 200.7 (USEPA, 1994) using an Inductively Coupled Plasma Spectrophotometer (ICP). The electrical conductivity (EC) and pH of each leachate fraction were also measured.

Non-amended controls were included, and treatments were replicated four times in a randomized complete block design. Statistical analysis of data was performed using Statistical Analysis System (SAS) software (SAS Institute, 1999), and means were compared with Duncan's Multiple Range Test (α=0.05).

Figure 3-1. Incubation lysimeters.

Field Mesh Bag Study

A 1-year field study in a mature citrus tree environment was used to measure N release patterns of four controlled-release fertilizers and a water-soluble material. Similar studies were conducted in central (Citrus Research and Education Center, Lake Alfred) and southwest (Southwest Florida Research and Education Center, Immokalee) Florida simultaneously since most Florida citrus is grown under these rainfall and temperature conditions (Figure 3-2). Mesh bags (13 x 13 cm) were constructed from typical fiberglass window screen, using heat to seal the edges. Each bag was filled with 3.5 g of elemental N from each source and then placed on the ground surface within the irrigated zone under bearing orange trees (Figure 3-3). Six trees were used as replicates. Each line of five bags contained the five fertilizer sources and was retrieved from the field on a given date. A control treatment (15-2-18) fertilizer consisting of water-soluble N, P and K (ammonium nitrate, concentrated superphosphate, and potassium chloride) was included as a conventional standard. It was applied three times during the year (February, May and September), while controlled-release materials (Table 3-2) were applied only once at the beginning of the experiment.

Figure 3-2. Field study locations.

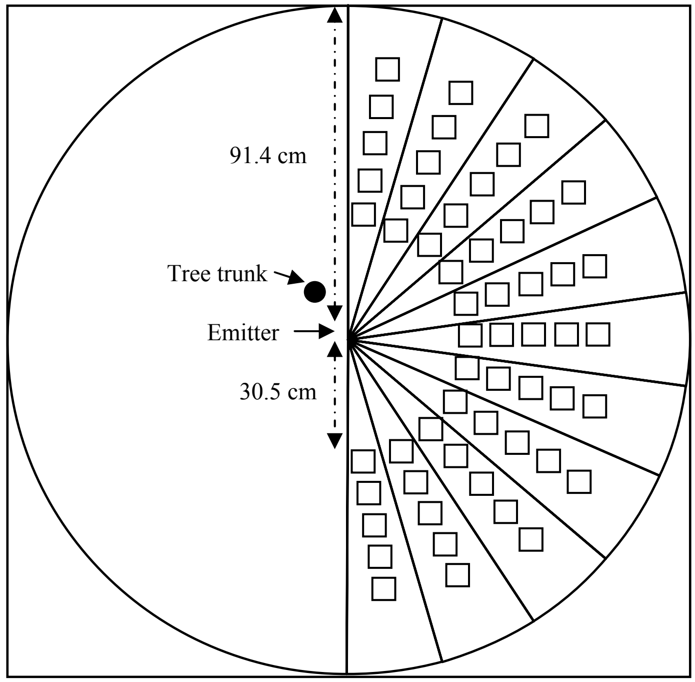

Figure 3-3. Layout of mesh bags placement under citrus tree canopy.

Table 3-2. Controlled-release fertilizer specifications.

Source	Formulation (N-P_2O_5-K_2O)	Release duration (months)[1]	Principle source[2]		
			N	P_2O_5	K_2O
CitriBlen®	15-3-19	12	AN, AP, PSCU	AP,CP	KMgS, KS
Agrocote® Type A	19-6-12	3-4	AN,AP	AP,CP	KS
Agrocote® Type C(D)	18-7-12	12-14	AN,AP	AP,CP	KS
Agrocote® Poly-S®	37-0-0	6	PSCU	----	----

[1]Approximate at 21°C soil temperature
[2]AN= ammonium nitrate; AP= ammonium phosphates; CP=calcium phosphate; PSCU= polymer sulfur coated urea; KMgS= potassium-magnesium sulfate; KS= potassium sulfate.

Six replicates of each fertilizer material were removed from the field after 14, 28, 42, 60, 90, 120, 150, 180, 240, 300 and 360 days. They were air-dried in the greenhouse and then stored in plastic bags at room temperature for later analysis of urea-N, NO_3-N, and NH_4-N in residual fertilizer granules. NO_3-N, and NH_4-N were analyzed using an air segmented Rapid Flow Analyzer (RFA) unit. The concentration of urea-N was measured using a colorimetric method (Bremner, 1982). Total nitrogen (TN) in residual fertilizer granules was calculated by adding the three N forms detected in the granules. An estimation of the TN released with time was calculated by subtracting the TN in the residual fertilizer granules from the 3.5g N applied.

The average daily ambient temperature 60 cm above the ground and daily rainfall (mm) for both locations were collected from the Florida Automated Weather Network (FAWN). FAWN's weather stations at both locations were located close to the experimental sites. Treatments were arranged in a randomized complete block design. Separation of means was accomplished with the general linear model procedure (PROC GLM) and single degree of freedom contrasts at $P \leq 0.05$ (SAS Institute, 1999). Non-linear regression curves were fitted to the N release data separately for each material at each location to develop N release curves.

Results and Discussion

CRF Incubation and Nutrient Leaching Study

The pH of the leachate varied from 6.4 to 7.1 in the non-amended soil. The soil amended with CRFs maintained a pH between 5.0 and 6.9 until the fifth leaching event (56 days) and then gradually decreased to 4.0 until the termination of the experiment. This low pH was probably a result of the citric acid solution used in the study. However, pH of the leachate from soil columns amended with a urea-based controlled release fertilizer (Agrocote® Poly-S®) increased from 6.0 to 7.0 during the initial three leaching events and then decreased to pH 5.5. The initial increase in leachate pH was likely due to hydrolysis of urea into ammonium carbonate through the action of the urease enzyme. The pH of leachate then decreased as a result of production of nitrate through nitrification (Paramavisan and Alva, 1997). N was recovered from the soil columns amended with CRFs despite the low pH of 4.0 observed during the last leaching events, since their nutrient release mechanism is not pH dependent. However, the lower N recovery from Agrocote® Poly-S® was probably due to low pH since the rate of release from this type of fertilizer is affected by pH and microbial activity.

Among the coated fertilizers, CitriBlen® had the highest initial N release. This result was expected since water-soluble N components are present in this blend. After the completion of the twelve leaching events, the cumulative recoveries of total N in the leachate were 90, 86, 85, 82 and 69% of the total N applied as CitriBlen®, Hydro®, Agrocote® Type C(D), Agrocote® Type A and Agrocote® Poly-S® respectively. Almost all N applied as Hydro® was leached after the 1st week. The low recovery of total N from the soil amended with Agrocote® Poly-S® could also be explained by losses through denitrification, since minimum losses of N due to NH_3 volatilization were obtained. Furthermore, it was likely that there was still some N left inside the prills after the 270 day incubation. Table 3-3 shows the effect of N source on N release rate.

The total NH_4-N recovered in twelve leachates was 46.6, 35.8, 33.8, 31.4 and 27.9% of the total N applied as Hydro®, CitriBlen®, Agrocote® Type C(D), Agrocote® Type A, and Agrocote® Poly-S® respectively (Figure 3-4, for each fertilizer, bars with the same letter were not significantly different). The peak concentration of NH_4-N for all fertilizers but Agrocote® Type C(D) was present after 7 days of incubation and then decreased gradually (Figure 3-5). The decrease in leaching of NH_4-N was likely due to the transformation of NH_4-N to NO_3-N by nitrification. A gradual increase in leaching of NH_4-N observed from the first to the eighth leaching event from Agrocote® Type C(D) was likely due to its slower release characteristics compared with the other materials.

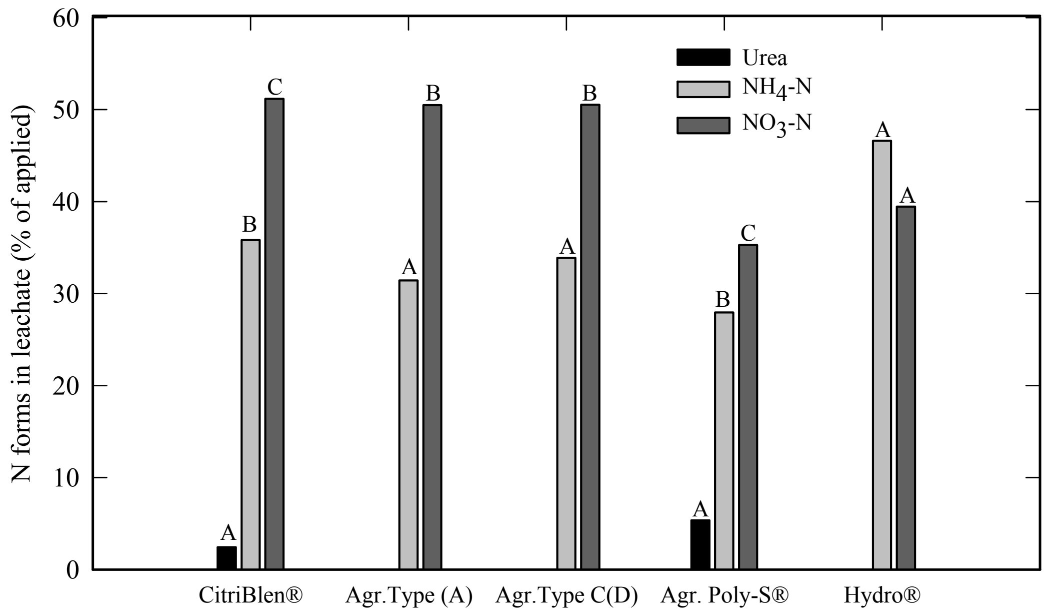

Figure 3-4. Cumulative leaching of N forms.

In the case of soils amended with urea-based CRFs, peak concentrations of urea (1.7 and 3.0% of total N applied as CitriBlen® and Agrocote® Poly-S® respectively) occurred in the first leachate and then decreased significantly by the third leachate. As shown in Figure 3-5, leaching of urea stopped after the third event as a result of the hydrolysis of urea. Similar leaching behaviors were expected from both materials since Agrocote® Poly-S® is the only urea-based component of CitriBlen®.

The total NO_3-N recovered during the experiment accounted for 51.2, 50.5, 50.4, 39.4 and 35.5% of the total N applied as CitriBlen®, Agrocote® Type C(D), Agrocote® Type A, Hydro®, and Agrocote® Poly-S® respectively (Figure 3-4). For urea-based CRFs, a gradual decrease in urea-N after the first leachate and a stable increase of NO_3-N in the subsequent leachate fractions suggested that the urea-N released was being rapidly hydrolyzed and nitrified (Figure 3-5).

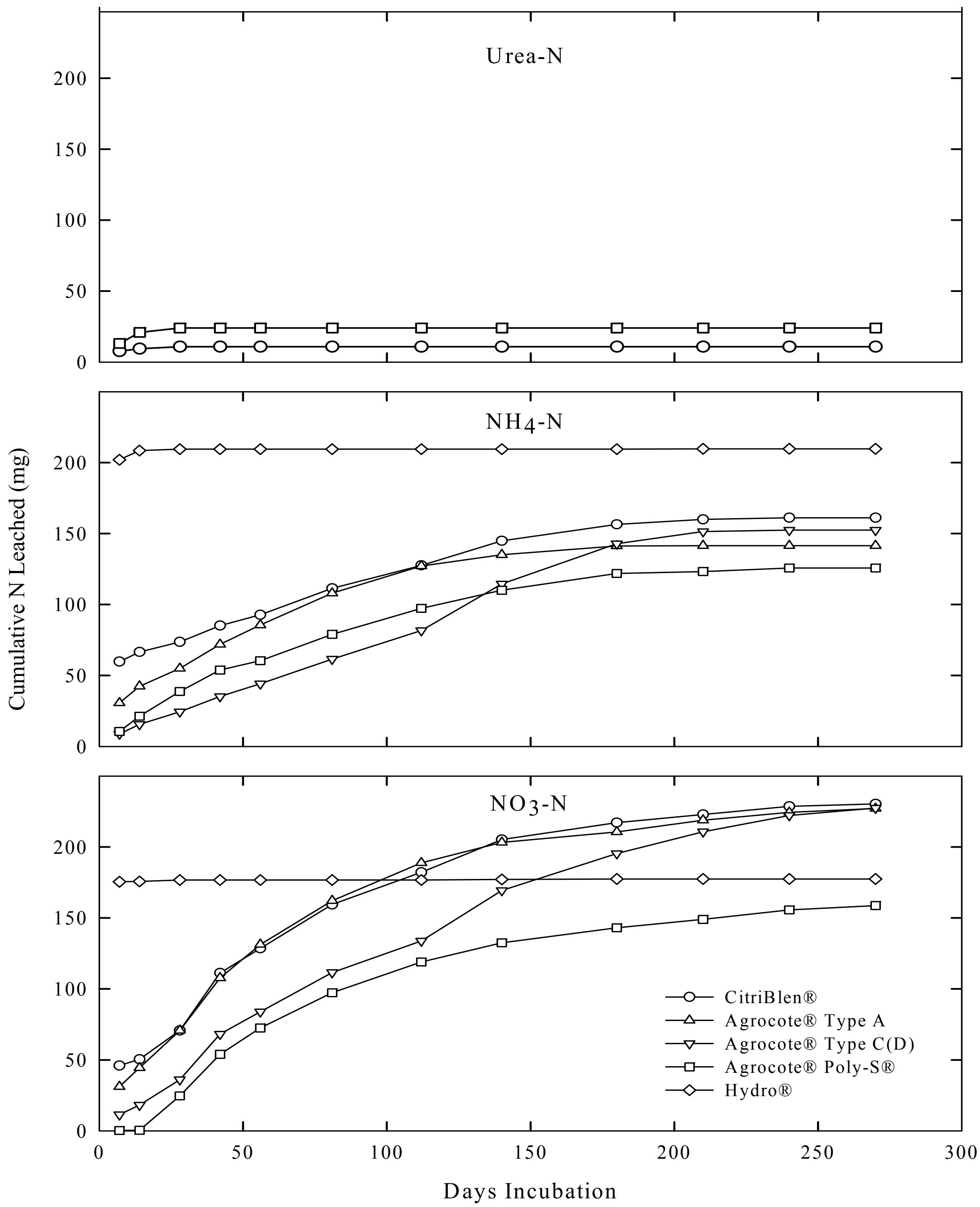

Figure 3-5. Leaching of N forms from soil columns.

Table 3-3. Effect of N source on total N released from four CRFs with time.

Total Nitrogen Released (mg)

N Source	Time (days)												Cumul.
	7	**14**	**28**	**42**	**56**	**84**	**112**	**140**	**180**	**210**	**240**	**270**	**(mg)**
CitriBlen®	113.6[a]	13.8[b]	28.7[b]	52.1[a]	24.9[b]	49.5[a]	38.9[a]	40.4[b]	23.5[b]	9.3[b]	6.9[a]	1.6[ab]	403.1[a]
Agrocote® Type A	62.2[b]	25.7[a]	38.9[ab]	53.9[a]	37.3[a]	53.3[a]	45.8[a]	22.4[b]	13.6[b]	8.5[b]	5.4[a]	2.8[ab]	369.6[b]
Agrocote® Type C(D)	20.9[c]	14.7[b]	26.7[b]	43.0[a]	24.6[b]	45.2[a]	42.3[a]	68.5[a]	54.3[a]	23.8[a]	12.6[a]	5.2[a]	381.6[ab]
Agrocote® Poly-S®	25.4[c]	18.8[b]	44.7[a]	44.4[a]	25.1[b]	43.5[a]	39.9[a]	26.3[b]	22.4[b]	7.3[b]	9.2[a]	3.1[ab]	309.9[c]
Statistical Significance[1]	***	*	*	NS	**	NS	NS	**	**	***	NS	*	**

[1]NS = not significant, *= significant P<0.05, **= significant P<0.01 and ***= significant P<0.001.
[2]Means with the same letter within columns are not significantly different.

Inorganic P added to soil that is not absorbed by plant roots or immobilized by microorganisms can be adsorbed to mineral surfaces or precipitated as secondary P compounds. Surface adsorption and precipitation reactions collectively are called fixation or retention (Havlin et., al 1999). Relatively little P leached from any fertilizer treatment suggested P fixation in the soil columns. P leaching was appreciably retarded with all CRFs except CitriBlen® (Figure 3-6). A high initial P release from CitriBlen® was expected since 40% of its P_2O_5 is water-soluble, then a similar lag period was observed between the third and fifth leaching event. P leached from all CRFs generally increased with time after the fifth leachate (56 days of incubation). Total P leached was higher for the Hydro® formulation than for the CRFs since it is a readily-soluble material.

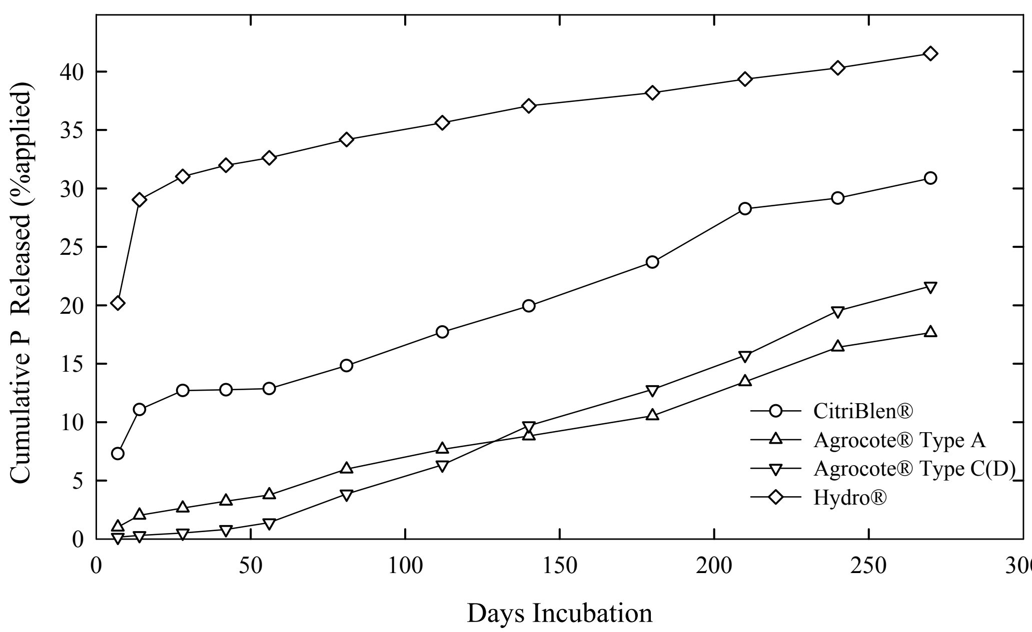

Figure 3-6. Phosphorus leached from soil columns.

The ionic composition of the fertilizer source and the charged component of the soil have a significant influence on leaching losses of K source fertilizers. The soil used in this experiment (Arredondo fine sand) is composed of 960 g kg^{-1} sand and has a cation exchange capacity (CEC) of 7.7 cmol(+) kg^{-1} (Sartain, 2002), thus the potential for K leaching is great. Sartain (2002) reported significant K leaching from this soil. As shown in Figure. 3-7, small differences in the total quantity of K leached relative to K sources were obtained. Of all the materials studied, the Hydro® formulation leached the largest quantity of K. This result was expected since it is a water-soluble formulation. However, a similar trend was obtained from one of the CRFs (CitriBlen®), likely due to the large amount (80%) of water-soluble K components present in this blend. K recovered from these materials (CitriBlen® and Hydro®) was greater than the amount applied. It is likely that the actual amount of K_2O in these fertilizer granules was greater than the claimed analysis. Agrocote® Type A and Agrocote® Type C(D) did not differ in quantity of K leached. Similar K leaching might have been due to the same ionic composition of the K source (K_2SO_4) and the same amount (83%) of K coated for slow-release.

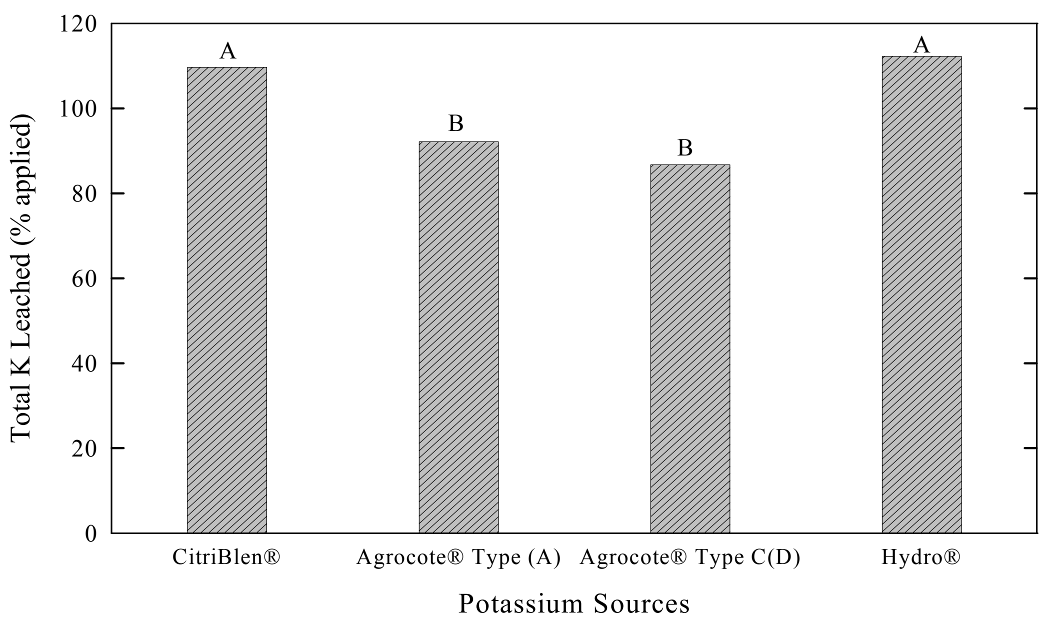

Figure 3-7. Effect of K source on the quantity of K leached from soil columns.

Potassium release patterns are presented in Figure 3-8. Timing and quantity of K leached was influenced by K source. Most of the K from Hydro® leached during the 1st week and then decreased for the next two events, at which point all the applied K had been leached. Similarly, CitriBlen® leached 85% of the applied K after 1 week and then declined during the rest of the experiment. Some retardation in quantity of K leached was observed with Agrocote® Type A and Type C(D). For Agrocote® Type C(D), the initial peak of K was delayed for longer (81 days). A slower release of K from this material was expected since it has a thicker polymer coating. This result showed the influence of coating technology on K release.

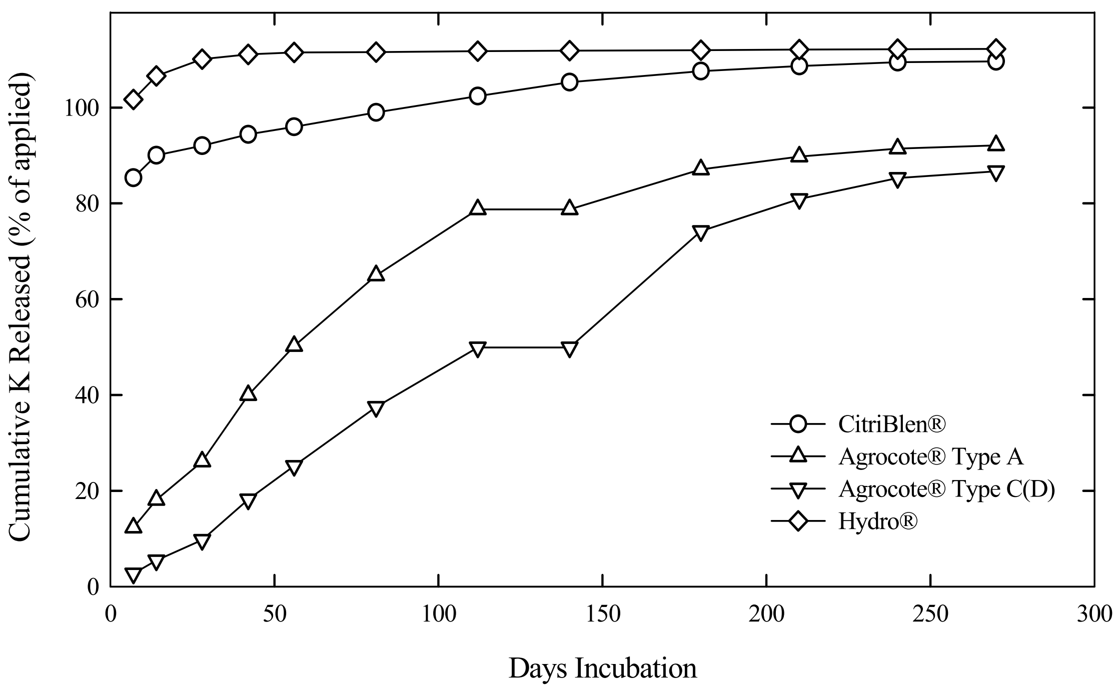

Figure 3-8. Effect of K source on K leaching.

Field Mesh Bag Study

After 365 days in the field, the percentages of N released were 99, 95, 93 and 88% of the total N applied as Agrocote® Type A, CitriBlen®, Agrocote® Poly-S®, and Agrocote® Type C(D), respectively at Immokalee, and 97, 90, 81, and 79% of the total N applied as Agrocote® Type A, CitriBlen®, Agrocote® Poly-S®, and Agrocote® Type C(D), respectively at Lake Alfred (Figure 3-9). The entire N from the water-soluble formulation was released after the first rainfall it was exposed to, which was a 5-cm event.

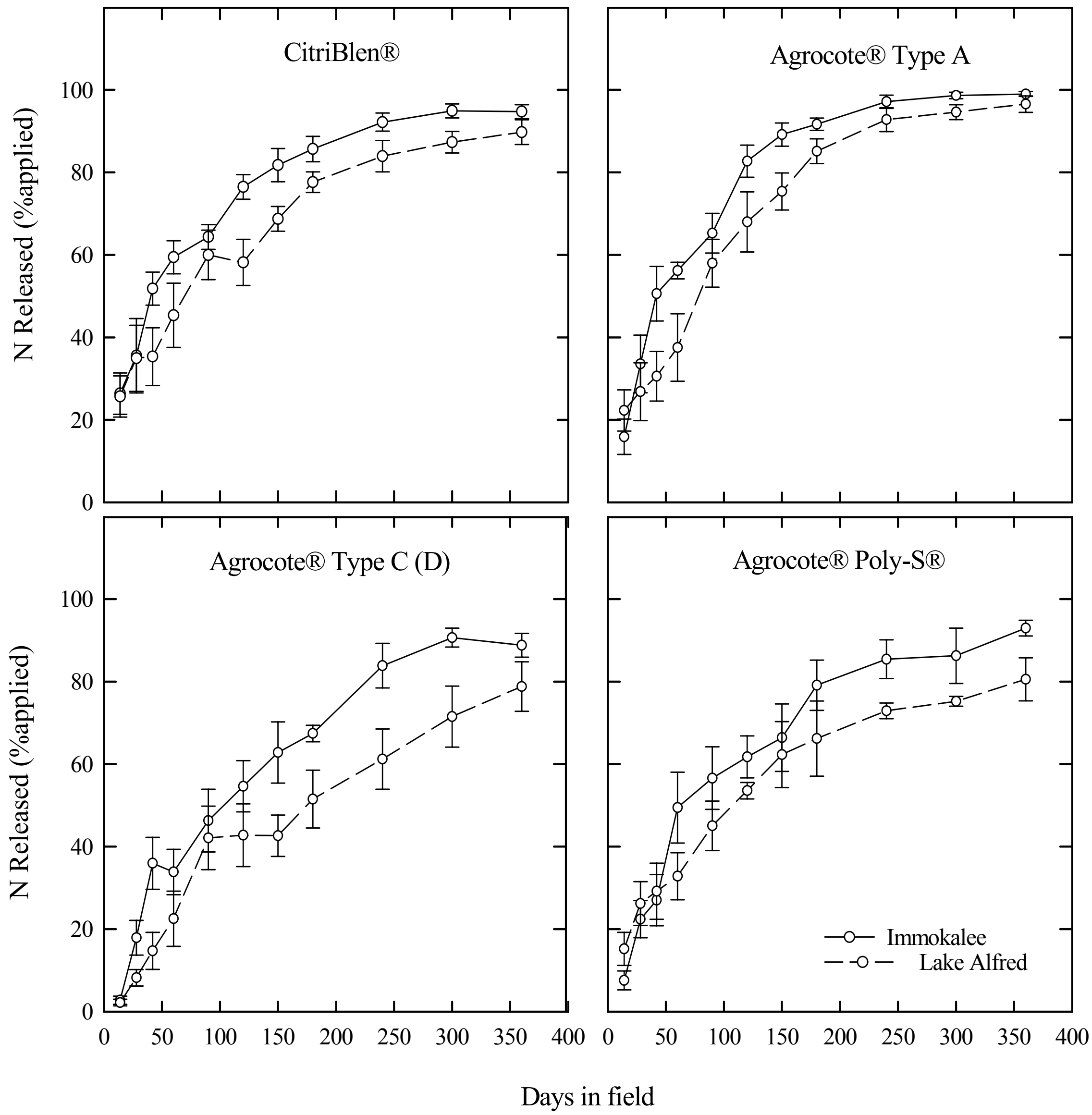

Figure 3-9. Nitrogen released (% of applied) with time.

The effect of N source, location and the interaction of these factors (N source x location) on N release rates are shown in Table 3-4. The interaction of the two factors had generally no effect on N release during the study. N sources had a significant influence on the quantity of total N released.

Table 3-4. Effect of controlled-release nitrogen fertilizer type and location on N release rates (% of applied).

	Main Effect[1]		
Days in field	Fertilizer Source	Location	Source x Location
14	***	NS	NS
28	**	NS	NS
42	***	**	*
60	***	**	NS
90	***	**	NS
120	***	***	NS
150	***	***	*
180	***	***	NS
240	***	***	***
300	***	***	***
360	***	***	*

[1]Indicates whether main effects of fertilizer type, location, or fertilizer type x location affected the data. NS, *, **, *** represent not significant, and significant where $P< 0.05$, 0.01 and 0.001, respectively.

Single degree of freedom contrasts were used to compare means of total N released among N sources (Table 3-5). Generally, N released from CitriBlen® was significantly different from the other N sources. Similar release patterns among N sources were observed after 180 days in the field at Immokalee. When comparing Agrocote® Type A with Agrocote® Type C(D), a highly significant difference in N release rates was found during the entire study. Although both are resin coated materials, a slower N release rate was expected from Agrocote® Type C(D) since it has a thicker coating. However, when Agrocote® Type C(D) was compared with Agrocote® Poly-S® (polymer/sulfur coating), no differences in N release patterns were observed periodically during the experiment. This result suggested that polymer/sulfur coated fertilizers (PSCF) have the potential to release N approaching polymer-coated fertilizers performance. This is an interesting finding since PSCFs are produced at a much reduced cost and therefore are more affordable to farmers

Table 3-5. Percentage of controlled-release nitrogen (CRN) fertilizers released with time.

DIF[1]	CRN Type[2]				Contrast[3]		
	1	2	3	4	1 vs. rest	2 vs. 3	3 vs. 4
14							
IMM[4]	26.4	15.9	2.8	7.6	***	***	*
LAL	25.7	22.3	2.2	15.2	*	**	*
28							
IMM	35.5	33.6	17.9	22.4	NS	NS	NS
LAL	34.9	26.8	8.2	26.2	*	*	*
42							
IMM	51.8	50.6	36.0	27.0	***	**	*
LAL	35.3	30.6	14.7	29.2	NS	*	*
60							
IMM	59.4	56.2	33.9	49.4	**	***	**
LAL	45.4	37.5	22.5	32.8	***	**	*
90							
IMM	64.3	65.3	46.3	56.6	**	***	**
LAL	59.9	58.0	42.1	45.0	**	**	NS
120							
IMM	76.5	82.7	54.6	61.8	***	***	*
LAL	58.2	67.9	42.8	53.6	NS	***	**
150							
IMM	81.8	89.2	62.8	66.4	*	***	NS
LAL	68.7	75.4	42.6	62.3	**	***	***
180							
IMM	85.7	91.7	67.4	79.1	**	***	***
LAL	77.6	85.1	51.5	66.2	**	***	**
240							
IMM	92.2	97.1	83.9	85.4	NS	***	NS
LAL	83.9	92.8	61.2	72.9	**	***	***
300							
IMM	94.9	98.6	90.7	86.3	NS	**	NS
LAL	87.3	94.6	71.5	75.2	**	***	NS
360							
IMM	94.7	99.0	88.8	93.0	NS	***	NS
LAL	89.7	96.5	78.8	80.6	NS	***	NS

[1]Days in field
[2]CRN type: 1, 2, 3 and 4 represent CitriBlen®, Agrocote® Type A, Agrocote® Type C(D) and Agrocote® Poly-S®, respectively.
[3]Single degree of freedom contrasts were generated using SAS GLM Proc. NS, *, **, *** represent not significant, and significant where $P< 0.05$, 0.01 and 0.001, respectively.
[4]IMM and LAL represent Immokalee and Lake Alfred, respectively.

Location had a significant influence on N release rate. In general, slower release rates and less N released during the 365-day experimental period were observed at Lake Alfred. For this study temperature and rainfall were considered as the potential environmental factors that caused differential N release rates between locations. The 12-month average temperatures were 22.3 and 22.0 C for Immokalee and Lake Alfred, respectively. Figure 3-10 compares daily average temperatures during the study for both locations. Temperature trends were very similar between locations. Sporadic lower temperatures were observed after 250 days at Lake Alfred. However, at this point most N had been released from all sources. Since little difference was found in annual average temperature and temperature trends between locations, it was concluded that temperature was not the main reason for differential N release rates between locations.

Total amount of rainfall and irrigation were used as an estimation of the amount of water received by the fertilizers during the experiment. The trees were irrigated using under-canopy microsprinklers (one emitter per tree). Irrigation was scheduled based on rainfall and season (spring/fall or winter) and it was normally applied when there was no rain and delayed when rainfall occurred. At Immokalee, Maxi-jet green jets with a delivery rate of 6.05×10^{-2} m^3 h^{-1} were used to irrigate three times per week for 4 hours per application. At Lake Alfred, Maxi-jet violet jets with a delivery rate of 5.79×10^{-2} m^3 h^{-1} were used to irrigate twice per week for 4 hours per application. An estimation of the total amount of water received by the fertilizers through irrigation was calculated based on these parameters. It was found that approximately twice as much irrigation water was delivered at Immokalee (23.22 m^3) compared with Lake Alfred (11.06 m^3), thus the fertilizer bags at Immokalee were exposed to more irrigation.

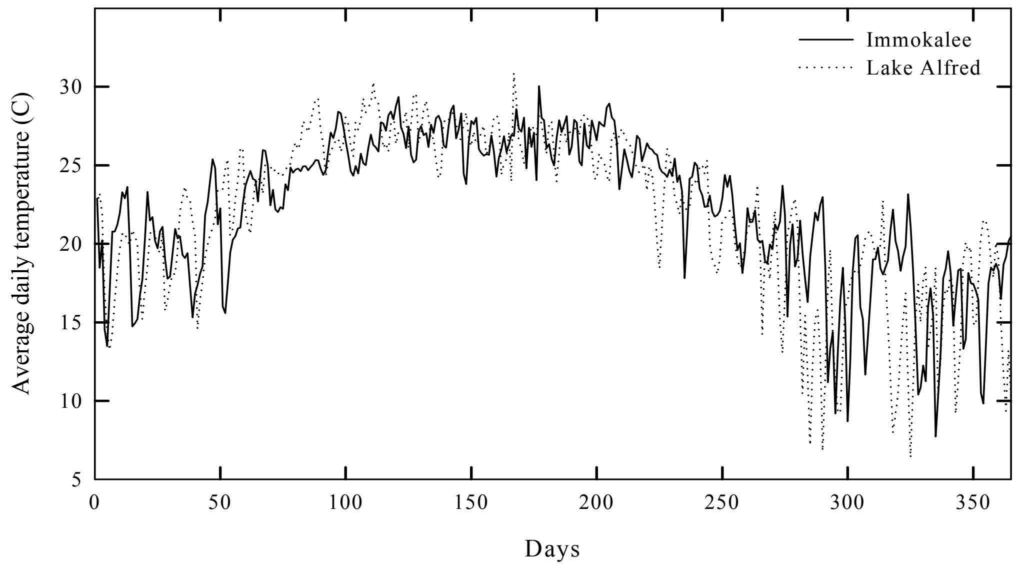

Figure 3-10. Comparison of average daily temperature (C) between locations.

Rainfall distribution at each location is compared in Figure 3-11. The total volumes of rainfall during the study were 829 and 854 mm for Immokalee and Lake Alfred, respectively. Although total rainfall was very similar between locations, rainfall distribution was not the same. There were more rainfall events at Immokalee (92 rainy days) than at Lake Alfred (77 rainy days). Quantity and frequency of irrigation and rainfall did probably influence the N release rates between locations. Less and slower N release rates observed at Lake Alfred were presumably due to more frequent intermittent drying of fertilizer materials between wetting by irrigation or rainfall. Similar results were found by Kochba et al. (1990).

Furthermore, differences in orchard orientation may have also contributed to different N release patterns between locations. At Immokalee, rows were north-south oriented while at Lake Alfred they were oriented in an east-west direction (Figure 3-12). In citrus orchards, more sunlight is intercepted by trees planted in rows oriented north-south than east-west (Tucker et al., 1994). Thus, the amount of sunlight that was intercepted by the fertilizer bags on the ground was greater in rows planted in an east-west direction than north-south. This occurrence resulted in more frequent drying periods of the fertilizer granules which extended the time for N release through the coating.

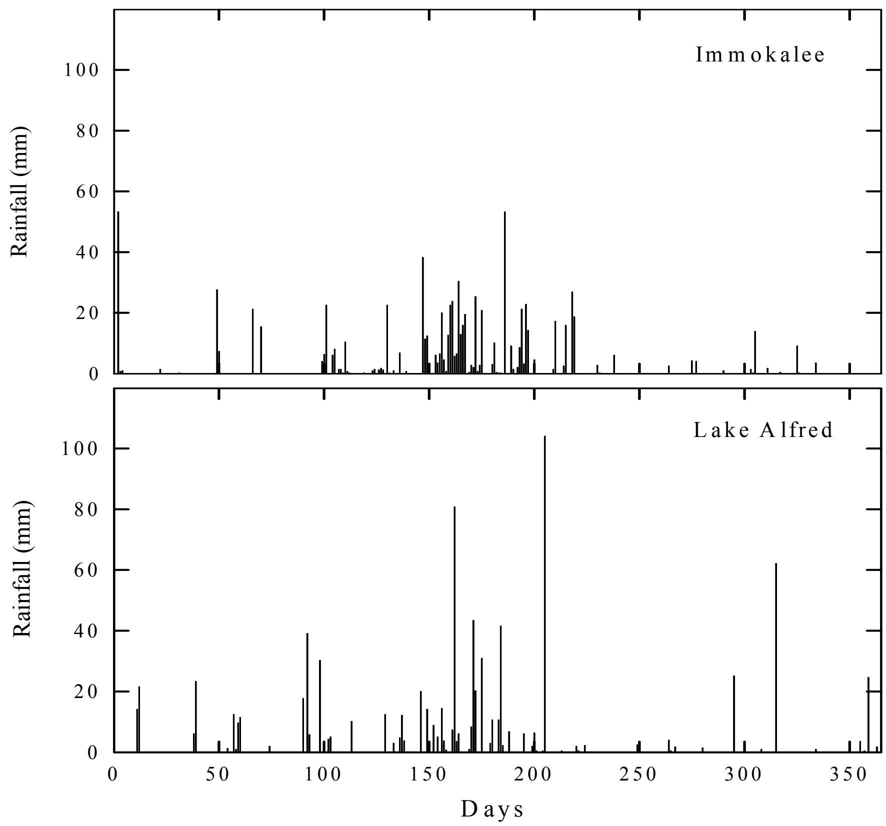

Figure 3-11.Comparison of rainfall distribution (mm) between locations.

North – South East - West

Figure 3-12. Citrus orchard orientation at Immokalee and Lake Alfred, respectively.

Nitrogen Release Curves

Regression coefficients, R^2 and P values of the non-linear regression equations are provided in Table 3-6 and 3-7 for Immokalee and Lake Alfred, respectively. The R^2 values for all the equations at both locations were close to unity, and all relationships were statistically significant at the $P < 0.0001$. This result indicated that the equations provided a good approximation of the N release rate (% of applied) for a given time in the field. Figures 3-13 and 3-14 show N release curves for all materials at both locations.

Table 3-6. Regression analysis of estimated N release rate from different N sources against time using an exponential rise to a maximum model (Immokalee).

N Source	Y_0	a	b	R^2	P-value
CitriBlen®[1]	15.16	80.90	0.011	0.99	<0.0001
Agrocote® Type A[2]		99.85	0.014	0.99	<0.0001
Agrocote® Type C(D)[2]		98.79	0.007	0.98	<0.0001
Agrocote® Poly-S®)[2]		93.70	0.009	0.98	<0.0001

[1] $Y = Y_0 + a\,(1-\exp^{-bx})$ where X = time, Y_0 = mean value of %NR when t equals zero and a, and b are regression coefficients.
[2] $Y = a\,(1-\exp^{-bx})$ where X = time and a, and b are regression coefficients.

Table 3-7. Regression analysis of estimated N release rate from different N sources against time using an exponential rise to a maximum model (Lake Alfred).

N Source	Y_0	a	b	R^2	P-value
CitriBlen®[1]	18.38	78.40	0.007	0.98	<0.0001
Agrocote® Type A[1]	7.11	97.98	0.008	0.99	<0.0001
Agrocote® Type C(D)[2]		95.61	0.005	0.97	<0.0001
Agrocote® Poly-S®)[1]	8.52	76.87	0.007	0.99	<0.0001

[1] $Y = Y_0 + a\,(1-\exp^{-bx})$ where X = time, Y_0 = mean value of %NR when t equals zero and a, and b are regression coefficients.
[2] $Y = a\,(1-\exp^{-bx})$ where X = time and a, and b are regression coefficients.

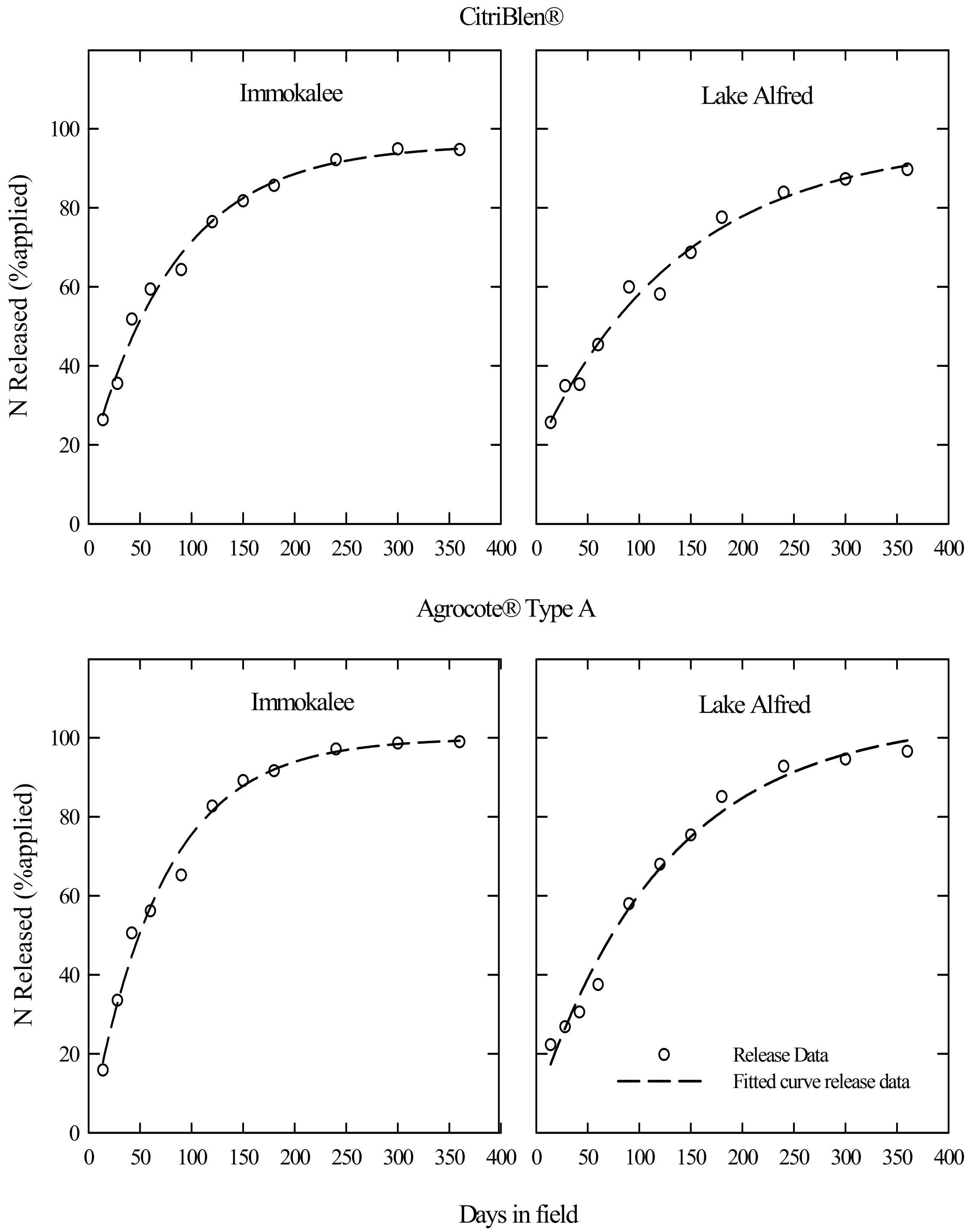

Figure 3-13. Nitrogen release curves for CitriBlen® and Agrocote® Type A at Immokalee and Lake Alfred, respectively.

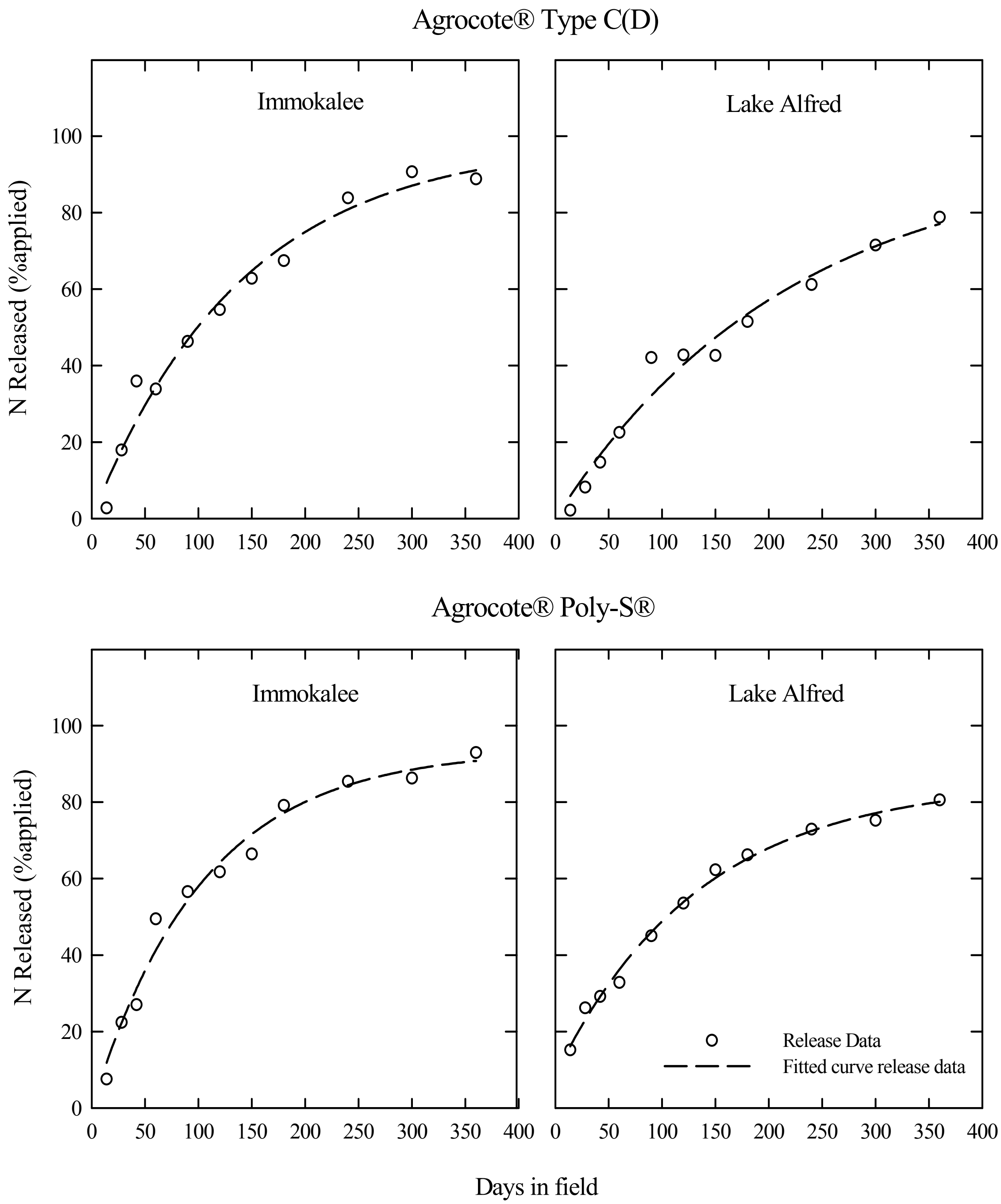

Figure 3-14. Nitrogen release curves for Agrocote® Type C(D) and Agrocote® Poly-S® at Immokalee and Lake Alfred, respectively.

Conclusions

CRF Incubation and Nutrient Leaching Study

N source had a significant effect on N released to the soil solution. Among the controlled-release formulations, N release followed the order: CitriBlen® > Agrocote® Type C(D) > Agrocote® Type A > Agrocote® Poly-S®, and the proportion of NO_3-N in twelve leachate fractions was greater than either urea-N or NH_4-N. This result indicated that nitrification was taking place and thus suggested that the system was microbiologically active, mimicking the conditions of a natural soil system. Little P recovered (~30% of applied) from any fertilizer treatment suggested P fixation in the soil due to chemical reactions. Incorporation of P in the soil columns also made P more vulnerable to fixation.

Fertilizer source had a significant effect on quantity and timing of K released to the soil. The low CEC of the soil also accelerated K leaching. Rapid release of N, P and K from the Hydro® formulation was due to its large water solubility. This study demonstrated that the time to transfer a given fraction of N, P and K through a membrane was considerably longer with CRFs applications than water-soluble fertilizers. Also, N, P and K release patterns varied depending on composition and thickness of the coating.

Field Mesh Bag Study

CRFs showed different intensities and patterns of N release due to differences in coating material and technology. The N release patterns measured were similar to those claimed by the manufacturer. Environmental conditions were more favorable for N release at Immokalee than at Lake Alfred. Despite differences in total amount of N released between locations, N release patterns at both locations followed the same order: Agrocote® Type A > CitriBlen® > Agrocote® Poly-S® > Agrocote® Type C (D).

Potential factors affecting these differences were quantity and frequency of irrigation and rainfall, and orchard orientation. It is suspected that intermittent drying of fertilizer granules between wetting by irrigation or rainfall extended the time for N release.

CitriBlen®, a complete N-P-K controlled- release fertilizer composed mostly of coated nutrients is made and marketed exclusively for mature Florida citrus as a single annual application material. CitriBlen® was developed to gradually release nutrients in such a way that matches tree nutritional requirements and thus increases nutrient uptake efficiency while reducing nutrient losses to the environment. In addition, CitriBlen® nutrient release mechanism is temperature dependent and therefore it potentially provides nutrients to the tree anytime growth is induced as a result of warm growing conditions.

Citrus trees require the highest amount of nutrients for each year from late winter through early summer when flowering and fruit development compete with the spring flush of growth. After the flower-fruitlet shedding process is completed in May-June, the tree is left with only the fruit it can satisfactorily support to maturity. Fewer nutrients are required for fruit development after this period, with the best fruit quality being obtained with moderately low nutritional levels, mainly N, during fall and early winter. Based on these nutrient requirements, current UF-IFAS citrus fertilizer guidelines recommend that 2/3 of the tree nutritional requirements should be made available between March and June 15th (105 day period) and the remaining 1/3 can be applied after September 15th.

This study demonstrated that N release patterns from CitriBlen® matched tree nutritional requirements recommended by BMPs. The dashed line in Figure 3-15 shows that after 105 days in the field approximately 70 and 60% of total N applied as

CitriBlen® was released at Immokalee and Lake Alfred, respectively. Then a gradual release of the remaining N was observed until termination of the 1-yr field experiment.

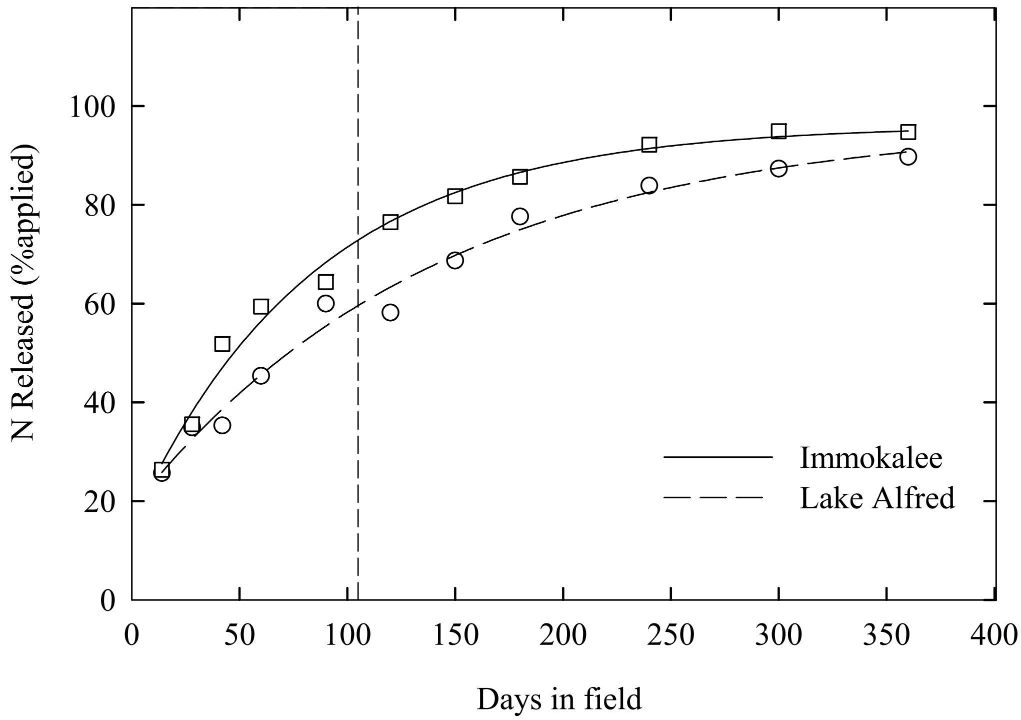

Figure 3-15. CitriBlen® N release curves for Immokalee and Lake Alfred.

CHAPTER 4
EVALUATION OF CITRIBLEN® ON FRUIT PRODUCTION AND FOLIAR NUTRIENT STATUS OF MATURE CITRUS TREES

Introduction

A structured fertilization management program is needed to ensure high yields and optimal fruit quality while minimizing environmental impacts and costs. Leaf analysis is the best indicator of proper fertilization in long-term crops such as citrus. It is a useful management tool for making fertilization decisions since the composition of the plant tissue reflects prior fertilization and production practices (Tucker et al., 1995). It can also assist with diagnostic problems within the orchard or reveal symptomless nutritional problems. Leaves have to be properly sampled, handled, processed and analyzed to ensure that analytical results are meaningful and can be used as guidelines for managing citrus nutritional programs. In Florida, 4- to 6-month-old spring flush leaves are sampled following the procedure described by Obreza et al. (1992).

CRFs have the potential to produce comparable or improved fruit yield relative to water-soluble fertilizer. Many studies have evaluated the effects of CRFs on production of both young and mature citrus trees. Increased fruit yield has been reported using controlled-release sources of N compared with water soluble sources (Koo, 1986; Alva and Paramasivam, 1998; Obreza et al., 1999). The economic feasibility however of using CRFs exclusively to produce citrus needs to be further evaluated.

The objectives of this study were:

1. Compare leaf nutrient status of commercial orange trees subjected to a controlled-release nutrient management program with trees fertilized using a conventional water-soluble fertilizer program.
2. Evaluate the economic feasibility of using a controlled-release fertilizer program relative to a conventional water-soluble nutrient management program for commercial orange production.

Materials and Methods

Three commercial citrus orchards in southwest Florida (Collier and Hendry counties) and one in central Florida (Polk county) were used to assess the potential use of CitriBlen® on mature citrus production and nutrition. All management practices were done on a commercial basis. The orchards used in this study represent the two major sections of the citrus industry. Three of the four sites were located on poorly drained soils on the flatwoods (site A, B, and C). The fourth site (D) located in central Florida was planted on well drained sandy Entisols. Characteristics of the studied citrus orchards are described below.

Site A

Characteristics of site A are shown in Table 4-1. Beginning in 2000, CRF (CitriBlen®) was applied once per year (late March) at a rate of 101 kg N ha^{-1} yr^{-1} while the soluble conventional fertilizer was applied four times (March, June, August and October) at a rate of 202 kg N ha^{-1} $year^{-1}$. Blocks 1 and 3 received the conventional water-soluble treatment during the first 2 years, and then CitriBlen® was applied for the rest of the experiment. Blocks 2 and 4 received CitriBlen® and the conventional water-soluble fertilizer, respectively, during the entire experiment.

Table 4-1. Characteristics of site A.

Variables	Block number/(total area of the block in the study)			
	Block 1 (25 ha)	Block 2 (38 ha)	Block 3 (34 ha)	Block 4 (18 ha)
Scion	Hamlin	Hamlin	Hamlin	Hamlin
Rootstock	Swingle	Cleopatra	Cleopatra	Carrizo
Year planted	1987	1987	1987	1987
Tree density (no. ha^{-1})	373	299	299	299
Spacing (m.)	3.7 x 7.3	4.6 x 7.3	4.6 x 7.3	4.6 x 7.3
Percentage of resets	15	20	11	5

Site B

Scion/rootstock combinations at site B are shown in Table 4-2. Two treatments were applied to each block. The water-soluble N standard was applied three times per year (late March, June and September) at an N rate depending on fruit production. Trees received 202 kg N ha^{-1} $year^{-1}$ in 2002 and 224 kg N ha^{-1} $year^{-1}$ from 2003 through 2005. CitriBlen® was applied once per year in late March at a rate of 50% of the total N applied to the standard plots.

Table 4-2. Characteristics of site B.

Variables	Block number/(total area of the block in the study)	
	Block 1 (113 ha)	Block 2 (30 ha)
Scion	Valencia	Hamlin
Rootstock	Carrizo	Carrizo

Site C

An 8-ha fertilizer source comparison was conducted on mature Valencia orange trees budded on Swingle citrumelo (*Citrus paradisi* Macf. x *Poncirus trifoliata* (L.) Raf.) rootstock planted in 1990 in a commercial citrus orchard. Tree rows were spaced 7.3 m apart, with 3.0 m between trees within each row (448 trees ha^{-1}). Percentage of non-bearing resets was negligible. Conventional fertilization practices consisted of a water-soluble fertilizer compound applied three times per year (late March, June and September) at a rate of 224 kg N ha^{-1} $year^{-1}$ from 2000 to 2002. Then CitriBlen® was applied once per year at a rate of 101 kg N ha^{-1} $year^{-1}$ from 2003 to 2005.

Site D

The orchard characteristics are shown in Table 4-3. Percentage of non-bearing resets was negligible. Three fertilizer treatments were applied in this orchard. A fertigation program that consisted of 202 kg N ha^{-1} $year^{-1}$ split in 4 applications per year (February, March, August, and October) was applied to blocks 1 and 4. A conventional dry water-soluble fertilizer compound was applied to blocks 2 and 3 under the same specifications as the liquid program. CitriBlen® was applied to block 5 once per year (late March) at a rate of 101 kg N ha^{-1} $year^{-1}$.

Table 4-3. Characteristics of site D.

Variables	Block number/(total area of the block in the study)				
	#1 (11 ha)	#2 (11 ha)	#3 (11 ha)	#4 (12 ha)	#5 (8 ha)
Scion	Valencia	Valencia	Valencia	Valencia	Valencia
Rootstock	Cleopatra / Carrizo	Carrizo	Cleopatra / Carrizo	Carrizo	Cleopatra
Year Planted	1997	1998	1997	1998	1997
Trees (ha^{-1})	287	287	287	287	287
Spacing (m.)	4.6 x 7.6	4.6 x 7.6	4.6 x 7.6	4.6 x 7.6	4.6 x 7.6

Leaf Sampling of Commercial Citrus Orchards

Leaf tissue was sampled at sites A, B and D. Treatment blocks were partitioned into management units of approximately 8 ha and about 20 trees were sampled within each management unit. About 100 4-month-old spring flush leaves from each management unit were collected from non-fruiting twigs in late August 2004 and 2005.

Leaves at the edge of orchard blocks were avoided when sampling because of possible surface contamination that could lead to measurement errors. The leaves were dried at 70 C for 3 days and then finely-ground. Samples were sent to a commercial agricultural laboratory for analysis of total N, P, K, Ca and Mg concentrations. Statistical analysis was performed on the leaf tissue data independently for each site and sampling date using the Statistical Analysis System (SAS) software (SAS Institute, 1999).

Economics of CitriBlen® Use on Commercial Mature Citrus Trees

A partial budget analysis compared the costs and benefits of using a CRF (CitriBlen®) program with a conventional water-soluble fertilizer program for mature orange trees. Partial budgeting is a planning and decision-making tool used to compare the costs and benefits of alternatives faced by a farm business. It focuses only on the changes in income and expenses that would result from implementing a specific alternative while all aspects of farm profits that are unchanged by the decision are ignored (Roth and Hyde, 2002). It is based on the principle that a small change in a farm business eliminates or reduces some costs and returns, adds costs, and/or adds revenues.

Costs of the fertilization programs were estimated by adding the fertilizer product and application cost for each orchard. Fertilizer cost ($ ha^{-1}) was calculated by multiplying the price of fertilizer ($ kg^{-1} product) by its application rate (kg product ha^{-1}). Thus, fertilization costs varied based on fertilizer rate, source, and application frequency. Fruit yield data for each block were obtained from the growers for sites A, C and D in terms of quantity (box ha^{-1})[1] and quality (pound-solids box^{-1})[2].

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[1] One box is equal to 41kg for oranges.

[2] Pound-solids per box is an expression of total soluble solids per unit weight of fruit and is the basis on which a grower gets paid for his fruit.

The standard water-soluble fertilization program was taken as 202 kg N ha^{-1} $year^{-1}$ split in four applications per year, while the CitriBlen® program consisted of 101 kg N ha^{-1} $year^{-1}$ applied once per year. The CitriBlen® (15-3-19-2.5Mg) price was obtained from the distributor. The price of the standard water-soluble formulation (15-2-15-2.4Mg) and the average cost of a single dry fertilizer application including labor and equipment were taken from Muraro et al. (2004). Even though the two fertilizer products did not have exactly the same P and K analysis, they were considered to be equal for this economic analysis.

Results and Discussion

Leaf Sampling of Commercial Citrus Orchards

Results are described independently for each study site due to differences in scion/rootstock combinations and treatment applications.

Site A

No statistical analysis was performed on these data due to differences in rootstock types between blocks. Mean leaf nutrient concentrations are summarized in Table 4-4. Similar leaf N concentration trends were observed for both sampling dates. Trees that received only the conventional water-soluble fertilizer (Block 4) had numerically the highest leaf N content. Since water-soluble N was applied to those trees only a few weeks before sampling, leaf N concentration was expected to be the highest among blocks. A variation in leaf nutrient concentrations was observed from 2004 to 2005. Yearly variations in macronutrient concentrations have been confirmed in other long-term studies.

Table 4-4. Effect of soluble and controlled-release fertilizers on N, P, K, Ca, and Mg (site A).

Block	Mean leaf element concentration (%)									
	N		P		K		Mg		Ca	
	08/04	08/05	08/04	08/05	08/04	08/05	08/04	08/05	08/04	08/05
1	2.84	2.53	0.13	0.16	1.09	1.45	0.31	0.32	4.50	4.21
2	2.69	2.20	0.14	0.16	1.39	1.74	0.38	0.40	3.97	4.76
3	2.70	2.22	0.13	0.16	1.45	1.78	0.36	0.42	4.10	4.75
4	2.92	2.54	0.13	0.15	1.38	1.60	0.36	0.36	4.41	4.80

In fact, a consistent pattern from year to year appears to be the exception rather than the rule. Various phenological factors such as light intensity, temperature, relative humidity and water availability interact with edaphic and physiological factors in such a way as to produce profound changes in leaf composition from one year to the next (Smith 1966). Lower leaf N occurred when the rainfall was about 35% greater than the previous year. Perhaps because of increased vegetative growth of the trees, the concentration of N was lower in the leaves during this year.

Generally all treatments resulted in leaf P, K, Ca and Mg status in the optimum range according to current guidelines (Table 4-5). Overall, trees that were planted on the same rootstock type (blocks 2 and 3) showed similar leaf concentrations for all nutrients. This result suggested that rootstock type may have influenced leaf nutrient status.

Table 4-5. Leaf analysis standards for mature, bearing citrus trees based on 4 to 6-month old spring-cycle leaves from nonfruiting terminals.

Element	Deficient	Low	Optimum	High	Excessive
Nitrogen (N) (%)	<2.2	2.2-2.4	2.5-2.8	2.9-3.2	>3.3
Phosphorus (P) (%)	<0.09	0.09-0.11	0.12-0.17	0.18-0.29	>0.30
Potassium (K) (%)	<0.7	0.7-1.1	1.2-1.7	1.8-2.3	>2.4
Calcium (Ca) (%)	<1.5	1.5-2.9	3.0-5.0	5.1-6.9	>7.0
Magnesium (Mg) (%)	<0.20	0.20-0.29	0.30-0.50	0.51-0.70	>0.80

Adapted from Obreza et al. (1992).

Site B

The effect of fertilizer source on leaf nutrient concentration is shown in Table 4-6. For Block 1, leaf nutrient concentrations did not differ between treatments on any sampling date, except for K and Mg in the first year. Trees treated with the standard water-soluble fertilizer had the highest leaf N. However, leaf N concentrations of CitriBlen®-treated trees were within the high range (Table 4-5) and then decreased to the optimum range. Leaf P, K, Mg and Ca were within optimum ranges through the entire study regardless of treatment.

For Block 2, leaf nutrient concentrations did not differ between treatments either year. CitriBlen®-treated trees had the highest leaf N in August 2005, while the conventional standard had the highest leaf N in August 2004 and the lowest in August 2005. These results suggested that the N in the water-soluble fertilizer had short residual effects on leaf N compared with that in CitriBlen®. A study by Zekri and Koo (1992) showed similar results. All treatments resulted in leaf P, K, Mg and Ca status in the optimum or high range according to guidelines (Table 4-5).

Table 4-6. Effect of soluble and controlled-release fertilizers on N, P, K, Ca, and Mg (site B).

	Mean leaf element concentration (%)									
Source	N		P		K		Mg		Ca	
	------Block 1------									
	08/04	08/05	08/04	08/05	08/04	08/05	08/04	08/05	08/04	08/05
CitriBlen	2.90	2.54	0.15	0.18	1.32	1.45	0.47	0.48	3.62	3.70
Std. Sol.	2.96	2.60	0.15	0.17	1.45*	1.48	0.43*	0.45	3.52	3.68
	------Block 2------									
	08/04	08/05	08/04	08/05	08/04	08/05	08/04	08/05	08/04	08/05
CitriBlen	2.52	2.61	0.15	0.19	1.35	1.26	0.44	0.41	3.97	4.13
Std. Sol.	2.64	2.49	0.14	0.17	1.37	1.32	0.42	0.41	3.70	4.40

*Significant at $P<0.05$.

Site D

These data were not statistically analyzed since treatments were replicated on trees that had different rootstock types. Rootstock selection influences the concentration of major elements in leaves appreciably (Smith, 1966). A summary of the leaf mineral status for each block is shown in Table 4-7. Generally, leaf N content was within the low range of 2.2 to 2.4% regardless of the fertilizer source in 2004, but was optimum in 2005. Compared with analysis standards (Table 4-5), leaf P, K, Mg and Ca were usually within the optimum or high range in both years regardless of fertilizer treatment. CitriBlen®-treated trees (Block 5) showed numerically higher leaf P and K in both years than the conventional dry and liquid fertilization programs.

Table 4-7. Effect of a dry, liquid and controlled-release fertilization program on N, P, K, Ca, and Mg (site D).

	Mean leaf element concentration (%)									
Block	N		P		K		Mg		Ca	
	08/04	08/05	08/04	08/05	08/04	08/05	08/04	08/05	08/04	08/05
1	2.27	2.56	0.12	0.15	1.23	1.67	0.40	0.39	4.54	3.94
2	2.57	2.74	0.12	0.14	1.23	1.30	0.53	0.54	4.37	4.08
3	2.35	2.64	0.12	0.16	1.35	1.65	0.43	0.49	4.06	4.70
4	2.31	2.70	0.12	0.15	1.23	1.43	0.47	0.47	4.32	4.08
5	2.18	2.65	0.13	0.17	1.44	1.74	0.38	0.39	4.61	4.49

Economics of CitriBlen® Use on Commercial Mature Citrus Trees

Commercially-obtained fruit yield and juice quality data collected from each orchard are shown in the appendix (Table A-1). No statistical analysis was performed on these data due to the lack of replicate plots for each fertilization program. Any conclusions on yield effects from these data can be misleading since CitriBlen®-treated trees were planted on a less productive rootstock (Cleopatra) than trees subjected to a water-soluble fertilization program (Carrizo). Differences in rootstock type are likely to influence fruit yield.

A partial budget analysis was used to evaluate the effects from changes on fertilization costs on changes in net income. The partial budget, with a detailed description of the positive and negative impacts and net change in income, is shown in Table 4-8. Reduced costs listed the fertilization costs that were no longer incurred when the CitriBlen® program was initiated. Added costs included additional expenses that occurred when the CitriBlen® program took place.

Table 4-8. Partial budget for CitriBlen® fertilization program.

Proposed Change Replacing a water-soluble formulation (15-2-15-2.4Mg) with CitriBlen® (15-3-19-2.5Mg)			
POSITIVE IMPACTS		NEGATIVE IMPACTS	
	\$ per ha		\$ per ha
Reduced Costs		Added Costs	
\$0.20 kg^{-1} (15-2-15) @ 202 kg N ha^{-1}yr^{-1} - Std. Sol.	269.3	\$0.77 kg^{-1} (15-3-19) @ 101 kg N ha^{-1}yr^{-1} - CitriBlen®	518.5
\$18 ha^{-1}@ 4 applications yr^{-1}	72.0	\$18 ha^{-1} @ 1 application yr^{-1}	18.0
Total reduced costs	341.3	Total additional costs	536.5
Total positive impacts	341.3	Total negative impacts	536.5
Change in net income (Total positive impacts) minus (Total negative impacts)			(195.2)

Assuming no change in yield, economic benefits of using CitriBlen® as one application per year at half the N rate applied as opposed to applying fertilizer at the full rate over four applications were not sufficient to offset its higher cost. A study by Obreza and Rouse (2004), however, on bearing Hamlin orange trees in a commercial citrus orchard demonstrated that a resin/polymer-sulfur coated urea (Poly-S) mixture applied once per year at 101 kg N ha^{-1} $year^{-1}$ yielded about 4 pound solids per tree more than the standard water-soluble N in 5 years at the 202 kg N ha^{-1} $year^{-1}$ rate split in three applications (Figure 4-1, adapted from Obreza and Rouse (2004)). The resin/Poly-S mixture evaluated in this trial served as the forerunner to the suite of CitriBlen®.

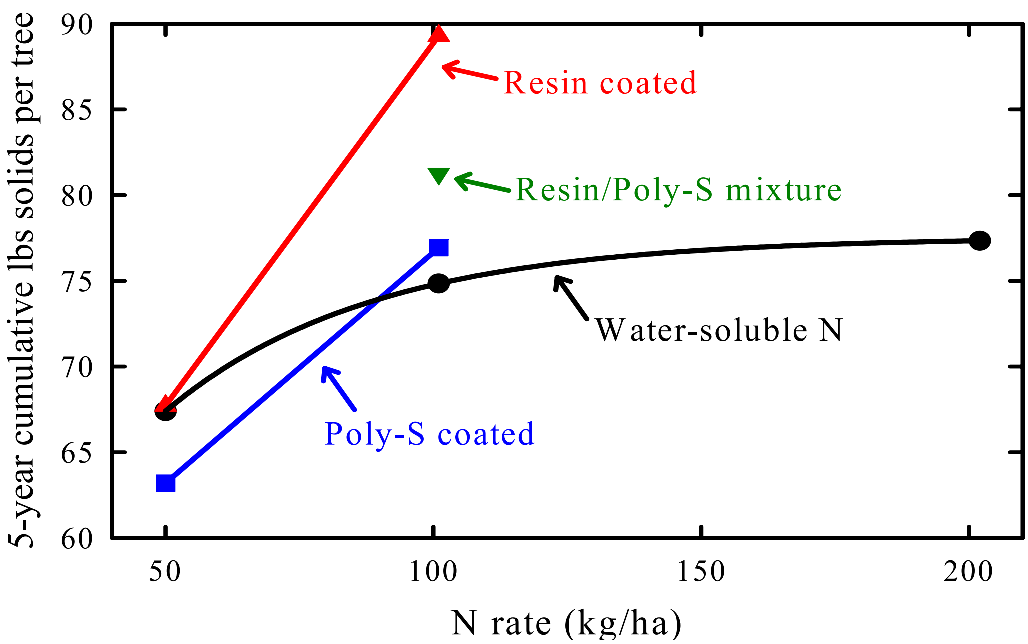

Figure 4-1. Response of Hamlin orange trees to controlled-release and water soluble fertilizers.

A partial budget analysis constructed assuming that CitriBlen® had a similar yield effect to that mentioned above when it was applied in large scale to the commercial citrus orchards is shown in Table 4-9. Since fruit production does not increase sufficiently to offset the higher cost of CitriBlen®, economic incentives will be needed to encourage growers to utilize CRF sources on mature citrus trees. One option is for state regulatory agencies to designate CRFs a Best Management Practice (BMP) and provide cost-share funds. If the cost difference ($195.20 per ha) was totally supported by regulatory agencies funds, the cost-share program would require about $13.1 million annually, assuming that the CitriBlen® fertilization program was adopted for all orange-producing orchards located in the vulnerable soils of the central Florida ridge (Polk, Highlands and Lake county). The cost-share program cost would be a relatively small cost to maintain the Florida orange production with a potential value of $508.5 million annually.

Table 4-9. Partial budget for CitriBlen® fertilization program assuming an increase in yield.

Proposed Change Replacing a water-soluble formulation (15-2-15-2.4Mg) with CitriBlen® (15-3-19-2.5Mg)			
POSITIVE IMPACTS		NEGATIVE IMPACTS	
	$ per ha		$ per ha
Reduced Costs $0.20 kg^{-1} (15-2-15) @ 202 kg N ha^{-1}yr^{-1} - Std. Sol.	269.3	Added Costs $0.77 kg^{-1} (15-3-19) @ 101 kg N ha^{-1}yr^{-1}- CitriBlen®	518.5
$18 ha^{-1} @4 applications yr^{-1}	72.0	$18 ha^{-1} @ 1 application yr^{-1}	18.0
Total reduced costs	341.3	Total additional costs	536.5
Added Returns Increase in yield 0.8 p.s. tr^{-1} @ 6 p.s. bx^{-1} 0.13 bx tr^{-1} @ $2.89 bx^{-1} $0.38 tr^{-1} @ 358 tr ha^{-1}	136.0		
Total Added Returns	136.0		
Total positive impacts	477.3	Total negative impacts	536.5
Change in net income (Total positive impacts) minus (Total negative impacts)			(59.2)

Furthermore, there are environmetnal benefits that should be considered when comparing the value of using CitriBlen® with the standard soluble fertilization practices. Those benefits include: 1) CitriBlen® gradually releases nutrients matching plant demands and consequently maximizes nutrient uptake efficiency. Therefore, there is less opportunity for nutrient losses to the environment, and 2) The CitriBlen® fertilization program requires fewer field operations and a lower N rate. One trip per year through the field may result in less soil compaction. Likewise, heavy fertilizer loads may significantly affect soil physical, chemical and biological reactions. With a reduced fertilizer load, the potential for soil degradation or structural damage is minimized.

Conclusions

Leaf Sampling of Commercial Citrus Orchards

For site B, no differences in leaf nutrient concentration were found due to N source except for K and Mg in Block 1. Variability in leaf nutrient status was found among different rootstock types regardless of N source, while the opposite was observed when the same rootstock was used. This result suggested that leaf mineral patterns might have been modified by rootstock selection. Generally, leaf N concentration was numerically higher when water-soluble fertilizers were applied compared with CitriBlen® applications. However, leaf N concentrations with the CitriBlen® treatment were usually within the optimum range according to accepted standards (Table 4-5).

Leaf P, K, Mg and Ca concentrations were always in the optimum or high range for any treatment at any given time. However, generally CitriBlen®-treated trees had numerically higher leaf P, K, and Mg than the water-soluble treated trees. This study demonstrated that CitriBlen® had the potential to maintain leaf nutrient status within the optimum range with only one application per year at a N rate reduced by one half compared with that of water-soluble fertilizer.

Economics of CitriBlen® Use on Commercial Mature Citrus Trees

Conclusions drawn from the provided yield data regarding the CitriBlen® impact on fruit production are misleading since fertilizer treatments were applied on trees that had rootstocks with different productivity potential. A partial budget analysis that compared costs between the two fertilization programs showed a negative change in net income. This finding indicated that using CitriBlen® exclusively to produce mature citrus is economically not feasible because of too high fertilizer costs.

However, if the state regulatory agencies designated CRFs a Best Management Practice (BMP) and provided cost-share funds, the implementation of a CRF program for orange production would become economically attractive for citrus growers. A cost-share program for CRF use would benefit growers and regulatory agencies by helping them meet their production and environmental goals while providing better water quality to Florida citizens and reducing environmental hazards.

CHAPTER 5
CONCLUSIONS

Providing sufficient N fertilization to citrus is critical to achieve high fruit quality and yields. However, with Florida citrus grown mainly under conditions of extremely sandy soils and high-volume rainfall, a structured fertilization program is needed to maximize N uptake efficiency and minimize environmental hazards. Excessive use of water-soluble N fertilizer can potentially lead to groundwater contamination. Controlled-release fertilizers (CRF) can be utilized as a management tool to supply nutrients during an extended period of time while reducing potential nutrient losses to the environment. Four studies were conducted to evaluate the effectiveness of polymer coated fertilizers in matching citrus nutrient requirements and achieving optimal fruit production and foliar nutrition.

CRF Incubation and Nutrient Leaching Study

The goal of this study was to determine the cumulative N, P and K released from coated fertilizers with time in a short-term laboratory incubation. Fertilizer material had an effect on the quantity of N, P and K released to the soil solution. This differential release of nutrients was likely influenced by the composition and thickness of the coating material. Rapid release of N, P and K from the Hydro® formulation was due to its high water solubility. Among the controlled-release formulations, N release followed the order: Citriblen® > Agrocote® Type C(D) > Agrocote® Type A > Agrocote® Poly-S®.

Low recovery of P (~30% of applied) from any fertilizer treatment was probably due to P fixation in the soil columns. Some retardation of P release was observed from the CRFs. Relative release of P from the fertilizers followed the same order as N release. P release patterns from Citriblen® were similar to those of its components (Agrocote® Type A, Agrocote® Type C(D) and Hydro®), with a high initial P release due to its water-soluble component and then a gradual release until termination of the experiment.

The soil used in this experiment had a great potential for K leaching due to its low CEC. Citriblen® released 85% of the applied K after 1 week of incubation and then a gradual release of the remaining portion was observed. This release pattern was likely due to the large amount (80%) of water-soluble K components present in this blend. When comparing Agrocote® Type A with Agrocote® Type C(D), similar release patterns were found, with a slower release of K from Agrocote® Type C(D) likely due to its thicker coating.

Field Mesh Bag Study

The objective of this study was to measure the N release characteristics of polymer coated fertilizers and a standard water-soluble fertilizer applied to a bearing citrus orchard. Differential N release among CRFs was likely due to differences in coating material and technology. The N release patterns measured were similar to those claimed by the manufacturer. The entire N from the water-soluble formulation was released after the first rainfall. Despite differences in total amount of N released between locations, N release patterns at both locations followed the same order: Agrocote® Type A > CitriBlen® > Agrocote® Poly-S® > Agrocote® Type C (D).

Environmental conditions were more favorable for N release at Immokalee than at Lake Alfred. Quantity and frequency of irrigation and rainfall and orchard orientation probably influenced the differential N release between locations. Slower release rates and less N released during the 1-yr field experiment at Lake Alfred were probably due to a more frequent drying of fertilizer granules between wettings by rain or irrigation.

It was found that Citriblen®, a complete N-P-K controlled- release coated blend that is made and marketed exclusively for mature Florida citrus as a one-application per year fertilizer, matched tree nutritional requirements recommended by current UF-IFAS citrus fertilizer guidelines. These recommendations indicate that 2/3 of the tree nutritional requirements should be made available between March and June 15th (105 day period), and the remaining 1/3 can be applied after September 15th. About 70 and 60% of total N applied as Citriblen® was released after 105 days in the field at Immokalee and Lake Alfred, respectively, and then a gradual release of the residual N was observed.

This finding indicated that Citriblen® can potentially increase N uptake efficiency while reducing leaching losses since only the portion of the N needed by the tree is available at a given time. Furthermore, the nutrient release mechanism of Citriblen® is temperature dependent and therefore it potentially provides nutrients to the tree anytime growth is induced as a result of warm growing conditions.

Leaf Sampling of Commercial Citrus Orchards

Three commercial citrus orchards were used to compare the effects of a CRF program with a standard water-soluble program on leaf nutrient status of mature orange trees. Leaf N, P, K, Ca and Mg concentrations were usually within the optimum or high range according to guidelines regardless the fertilization program. However, trees receiving the Citriblen® program had numerically higher leaf P, K, and Mg concentrations than the water-soluble treated trees. Furthermore, results suggested that Citriblen® can potentially produce leaf mineral concentrations within the optimum range with only one application per year at a N rate reduced by one half compared with that of conventional water-soluble fertilizer programs.

Economics of Citriblen® Use on Commercial Mature Citrus Trees

The objective of this study was to compare the costs and benefits of using Citriblen® and a conventional water-soluble fertilizer program on commercial orange orchards. A partial budget analysis used to evaluate the positive and negative impacts of using Citriblen® compared with a standard water-soluble fertilizer program indicated a negative net change in income. Break-even prices required to cover Citriblen® fertilization costs were higher than the current on-tree per box market prices.

These results suggested that using Citriblen® exclusively to produce mature citrus is economically not feasible because of excessive fertilizer costs. The use of CRFs would be unattractive to citrus growers unless they were designated as a BMP and regulatory agencies provided cost-share funds. A fully funded cost-share program would require annually about $13.1 million. This amount would be a relatively small cost to maintain the Florida orange production with a potential value of $508.5 millions annually. Environmental benefits should also be considered when evaluating the use of Citriblen® in a fertilization program. By using Citriblen®, N uptake efficiency is maximized and leaching losses to the groundwater are potentially reduced.

APPENDIX
COMMERCIAL YIELD DATA

Table A-1. Historic commercial fruit yield data for sites A, C and D.

Crop Year	Fertilizer Source					
	CitriBlen®		Std. water-soluble			
	Yield (box/ha)	Juice quality (p.s./box)	Yield (box/ha)		Juice quality (p.s./box)	
	Site A					
	Hamlin / Cleopatra		Hamlin / Carrizo			
2000-01	1,236	6.59	1,312		6.21	
2001-02	1,260	5.71	1,092		5.08	
2002-03	912	5.62	954		4.98	
2003-04	1,371	5.55	1,846		5.24	
2004-05	578	6.30	1,344		6.56	
	Site C					
	Valencia / Swingle					
1999-00	---	---	891		6.85	
2000-01	---	---	1,202		7.28	
2001-02	---	---	912		6.61	
2002-03	1,096	6.99	---		---	
2003-04	831	6.86	---		---	
2004-05	709	7.67	---		---	
	Site D					
	Valencia / Cleopatra		Val./Carr.	Val./Cleo-Carr.	Val./Carr.	Val./Cleo-Carr.
2001-02	68	5.13	78	53	5.36	5.20
2002-03	81	5.71	103	102	5.79	5.61
2004-05	96	5.48	146	128	5.43	5.39

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