EFFECT OF NITROGEN RATES AND MOWING HEIGHTS ON NITROGEN LEACHING, TURF QUALITY AND SPECTRAL REFLECTANCE IN FLORATAM ST. AUGUSTINEGRASS

By

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To my beloved husband, parents and brothers

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Abstract of Thesis Presented to the Graduate School
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EFFECT OF NITROGEN RATES AND MOWING HEIGHTS ON NITROGEN LEACHING, TURF QUALITY AND SPECTRAL REFLECTANCE IN FLORATAM ST. AUGUSTINEGRASS.

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Increasing urbanization throughout Florida is causing concerns about potential pollution of water resources from fertilization of home lawns. Best Management Practices have been developed for the commercial lawn care service in Florida to minimize any potential adverse impacts from the fertilization and lawn care activities. The objectives of this study were to evaluate the effect of nitrogen rates and mowing heights on nitrate (NO_3-N) leaching of St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze.), and to evaluate the response of N rates and mowing heights on St. Augustinegrass turf quality and physiological responses. The experiment was conducted in a greenhouse at the Turfgrass Research Envirotron Laboratory at the University of Florida in Gainesville. The grass was grown in 42.5 L poly vinyl chloride tubs in sandy loam soil (Hyperthermic, uncoated, Quartzipsamments in the Candler series). Nitrogen was applied as urea (46-0-0) at the rate of 2.5, 4.9, 7.4 and 9.8 g N m^{-2} every two month. Each interval between fertilizer applications was considered a fertilizer cycle (FC), of which there were three. Turfgrass mowing height treatments were 7.6 and 10.2 cm. Turf that was maintained at 7.6 cm was mowed once every week and turf that was maintained at 10.2 cm mowing height was mowed once every two weeks. Irrigation was applied twice a week throughout the experimental period at 1.27cm of water per application. Leachate was collected every 15 days.

Turf visual quality ratings were taken every 15 days. Multispectral reflectance, chlorophyll measurements and canopy temperature readings were taken every month. Experimental design was a randomized complete block with four replications. In FC1 and 2, there were no differences in nitrate-N leaching due to N rate; however, due to insect damage in FC3, there was greater leaching at the higher N rates. Percent of applied N leached was less than 1% throughout the study at all N rates. There were no differences in nitrate-N leaching due to mowing height in the FCs, but when data were averaged over the course of the study, greater leaching occurred at the lower mowing height. Turf visual quality and color scores increased with N rate, but were at acceptable levels at all N rates. Spectral reflectance showed some differences to N rate, but responses were not characteristic of turf responses to N rate. Where there were differences in reflectance in response to mowing height, optimal responses occurred at the higher mowing height. From results of this research, it does not appear that application of high rates of N to St. Augustinegrass will result in nitrate leaching, particularly when the grass is maintained in a healthy condition.

CHAPTER 1
INTRODUCTION

St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze) is one of the most popular choices for lawns throughout the southern United States. St. Augustinegrass represents 64.5% of all sod production in Florida, with 75% used for new residential landscapes (Haydu et al., 2002, 2005). St. Augustinegrass is believed to be native to the coastal regions of the Gulf of Mexico and the Mediterranean and performs best in well drained soils (Trenholm et al., 2000a). It has relatively good salt tolerance and certain cultivars have good shade tolerance. There are numerous cultivars of St. Augustinegrass that are produced in Florida including 'Palmetto', 'Delmar', 'Bitterblue' and 'Floratam'. Of these, Floratam is the most widely produced, comprising 75% of all St. Augustinegrass in production. Floratam is an improved St. Augustinegrass that was released jointly in 1973 by the University of Florida and Texas A & M University (Trenholm et al., 2000a). St. Augustinegrass prefers moderate cultural practices with a fertility requirement ranging from 10 to 30 g N m^{-2} yr^{-1} (Trenholm et al., 2002). In some regions, regular irrigation is needed due to poor drought tolerance (Christians 1998).

Environmental Concerns with Nitrogen Use

Increasing urbanization and an increasing number of home lawns throughout Florida may contribute to problems associated with nitrate-N (NO_3-N) contamination of water. Nitrogen is the nutrient applied to turfgrass in the greatest quantity and frequency. Nitrate nitrogen is a water soluble form of N, which may leach through the soil if applied at excessive rates especially when accompanied by excess water from either irrigation or rainfall.

In Florida, NO_3-N leaching from home lawns has been implicated as a source of N pollution to streams, lakes, springs and bays (Erickson et al., 2001, Flipse et al., 1984). Sandy soils commonly found in Florida have low water holding capacity which may increase leaching of N fertilizer from the turfgrass when water drains through the soil profile into the groundwater. Burgess (2003) said that N entering the ground and surface water can cause eutrophication, and can cause health risk where that water is used for drinking. A high uptake of NO_3-N is known to be hazardous to human health (Hornsby, 1999). Nitrate nitrogen is converted to nitrite (NO_2-N), which combines with hemoglobin in human body to form toxic methemoglobin. This decreases the ability of blood to carry oxygen, which causes the syndrome known as methemoglobinemia, also called "blue baby syndrome" (The Nitrate Elimination Co., Inc. 2001). The United States Environmental Protection Agency (EPA) limit for NO_3-N in drinking water is 10 mg L^{-1} which is easy to exceed if enough attention when applying fertilizers is not provided.

Research has shown that fertilizer management is a factor in reducing non-point source pollution (Gross et al., 1990), which has led to the development of Best Management Practices (BMPs) (Trenholm et. al. 2002). BMP's have been developed for the commercial lawn care and landscape industries in Florida to minimize any potential adverse impacts from fertilization and lawn care activities. BMP's are the guidelines for implementation of environmentally sound agronomic practices to reduce potential contamination of ground or surface water due to commercial lawn care practices. These BMPs were developed in 2002 by regulatory, academic and industry professionals and are intended to preserve Florida's water resources. Practical N management techniques such as the use of controlled-release fertilizers, fertigation, and irrigation management have been shown to provide quality turfgrass with little leaching (Snyder et al., 1984; Snyder, et al., 1989).

Annual N leaching rates for Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.) and St.Augustinegrass range from 0 to 160 kg N ha^{-1}, and represent up to 30% of fertilizer applied N (Barton and Colmer, 2006). These authors observed that pollution occurs when less than adequate management practices are used. They observed less than 5% of the applied N was lost from established turfgrass that was not over-irrigated and had received a moderate amount of N fertilizer (200–300 kg N ha^{-1} $year^{-1}$). Gross et al. (1990) studied surface runoff losses of nutrients and sediments from established tall fescue (*Festuca arundinacea* Schrub.) and Kentucky bluegrass mixed stands for two consecutive years and observed that total N loss in turf averaged 0.14 kg N ha^{-1} which was lower when compared to most agronomics row crops like tobacco (11.7 kg N ha^{-1}).

Bowman et al. (2002) compared 'Raleigh' St. Augustinegrass with five other warm season grasses (common bermudagrass [*Cynodon* dactylon (L.) Pers.], 'Tifway' hybrid bermudagrass (*Cynodon dactylon* × *transvalensis*), centipedegrass (*Eremochloa ophiuroides* (Munro) Hack.), 'Meyer' zoysiagrass (*Zoysia japonica* Steud.), and 'Emerald' zoysiagrass (*Zoysia japonica x Zoysia tenuifolia* Willd.ex Thiele) for NO_3-N leaching and N use efficiency. They applied ammonium nitrate at the rate of 50 kg N ha^{-1} and found that Raleigh St. Augustinegrass produced the highest amount of leaf tissue and root mass compared to the other species. They found differences among the species for leaching of NO_3-N ranging from a low of 24% of applied N in Raleigh St. Augustinegrass and a high of 56% in Meyer zoysiagrass. They concluded that the higher root mass might increase the ability of St. Augustinegrass to absorb NO_3-N from the soil.

In spite of some reports that propose turfgrass fertilization to be a significant contributor of NO_3-N to ground water (Flipse et al., 1984), some, research has shown that properly managed and fertilized turf is not a significant source of groundwater contamination (Erickson et al., 2001). The authors studied Floratam St. Augustinegrass vs. a mixed species (ornamental ground cover, shrubs and trees) landscape. N was applied at a rate of 50 kg N ha^{-1}per application to both plant systems for a total of 300 kg N ha^{-1} yr^{-1} to St. Augustinegrass and 150 kg N $ha^{-1}yr^{-1}$ to the mixed species landscapes. They found that more than 30% of applied fertilizer N leached from the mixed species landscapes, whereas less than 2% leached from St. Augustinegrass. Frank (2007) showed nitrate leaching from Kentucky bluegrass decreased as the turf matured. When fertilizer was applied at the rate of 196 kg N ha^{-1} in 2003, averaged NO_3-N leached was 31.6 mg L^{-1} and in 2006 averaged NO_3-N leached was 11.2 mg L^{-1}.

Leaching may also depend on the source of N fertilizer applied. Shuman (2001) determined that supplying turf with N in a controlled fashion greatly reduced the potential for leaching and runoff. According to Sartain (2002), slow-release fertilizers release their nutrient contents at more gradual rates that enhance uptake and utilization of the nutrient while minimizing losses due to leaching, volatilization or excessive turf growth. Benette (1996) verified that slow release N releases nutrients at a slower rate throughout the season, thus, less frequent application is required. The author noted that this would also reduce fertilizer burn, even when N was applied at high rates. Brown et al. (1978) studied golf greens with sandy rooting media and found that NO_3-N concentrations in leachate resulting from isobutylidene diurea (IBDU) application were low (0.2% to 1.6% of applied N) but continuous throughout the study, whereas concentrations remained above 20 mg L^{-1} up to 35 days after application of ammonium nitrate.

Saha (2004) found that St. Augustinegrass treated with of 4.9 g N m^{-2} of quick release N sources had higher visual quality scores than those that received the same amount of slow release N for the first two weeks following fertilizer application. After that, no significant differences in turf quality were found due to N source. There were no differences in leaf nutrient concentration due to N treatments in this research. Quiroga et al. (2001) applied three N sources at two rates (100 and 200 kg N ha^{-1}) and two different frequencies (every 20 or 40 days) to bermudagrass.

They found that urea and sulfur coated urea (SCU) enhanced vigor and greening and provided rapid N availability and uptake, but also increased the risk of N loss from leaching. Conversely, the sparingly soluble hydroform did not promote as much turf vigor and color but tended to minimize the risk of NO_3-N leaching loss. Other research has disagreed with these results. Park (2006) applied urea and a blend of urea and IBDU at the rate of 30 g m^{-2} yr^{-1} and 15 g $m^{-2}yr^{-1}$ and found that leaching was affected by the fertilizer rates but not by the fertilizer sources.

Previous research on N leaching from bermudagrass has shown that N rates, N sources, N application methods, and irrigation all influence the amount of NO_3-N leaching beyond the root zone and subsequently to groundwater (Snyder et al., 1989; Cisar et al., 1992).

Mowing Heights and Nitrogen Leaching

Turfgrass mowing is known to be one of the major cultural practices that can influence turf health and vigor. Turfgrass undergoes physiological stress with each mowing, particularly if too much leaf tissue is removed (Trenholm et al., 2002). These authors state that it is important to leave as much leaf surface as possible to enhance photosynthesis and to promote deep rooting. If turf is mowed too short, it tends to become denser, but has less root and rhizome growth (May et al., 2004). According to the authors, removal of excess leaf area may increase the risk of fertilizers leaching through the soil or running off and endangering water reserves. The relatively high mowing height of St. Augustinegrass compared to other grasses produces a deeper root system, which can reduce NO_3-N leaching (Bowman et al., 2002).

Clark (2006) determined that grass species like blue flag iris (*Iris virginica* L *var shrevei*), eastern gamma grass *(Tripsacum dactyloides* L.), and big blue stem (*Andropogon gerardii* Vitman.) maintained at higher heights removed more pesticides from runoff water than those maintained at lower heights. Guertal and Evans (2006) noted that bermudagrass color, rhizome and stolon weight were often reduced at a mowing height of 3.2 mm. When mowed at 3.9 mm and 4.8 mm, turf grew rapidly and maintained good stolon, rhizome, and root dry weights, as well as good total nitrogen content (TNC) and turf color.

Biran et al. (1981) found that perennial ryegrass mowed at 6 cm showed an increase in water use and yield than when mowed at 3 cm. Bermudagrass also showed a rapid and significant increase in water consumption and growth when the mowing height was increased from 3 cm to 6 cm but they slowly declined over time.

Multispectral Reflectance and Chlorophyll Measurements

Multispectral radiometry (MSR) provides a method for assessing plant light reflectance at various wavelengths of light energy where the percentage of light not reflected is either absorbed by the plant or transmitted downward to the soil surface (Trenholm et al., 1999). To assess the growth, or to compare treatment responses, qualitative responses are commonly used in turfgrass research, where quality might be expressed by visual and functional characteristics (Turgeon 1991). Qualitative responses are often described as the combination of shoot density, color, and growth habit (Beard, 1973). MSR may be used to quantify these subjective parameters and provides a reliable method for comparison of turf response to treatments (Trenholm et al., 1999).

Plants use varying amount of light at different wavelengths for physiological processes. Some of the light is assimilated for that use, while some is reflected off the leaf surface. Measurement of the amount of light reflected at various wavelengths can be correlated with crop health, chlorophyll content, fertility, and stress (Carter 1993; Carter and Miller 1994; Trenholm et al., 2000b).

Wavelengths within the visible spectrum (400–700 nm) are strongly absorbed by plant pigments. Near-infrared (NIR) radiation (700–1300 nm) is highly reflected due to low absorption (Knipling, 1970; Asrar et al., 1984). Leaf physical characteristic, such as cell structure, water content, and pigment concentration affect plant canopy reflectance, transmittance, and absorption (Maas and Dunlap, 1989). Leaf chlorophyll content was negatively correlated to green light reflection (500–600 nm) and positively correlated to NIR reflection in soybean (*Glycine max* L.) and corn (*Zea mays* L.) (Blackmer et al., 1994; Adcock et al., 1990).

Measurement of chlorophyll concentration may be used to assess plant physiological response. Chlorophyll concentration may be considered as a measure of plant vitality, or may be viewed as an indirect measure of turf color (Pocklington et al., 1974). The Field Scout CM1000 Chlorophyll Meter (Spectrum Technology, Plainfield, IL) uses ambient and reflected light at 700 nm and 840 nm to calculate a relative chlorophyll index. It senses light at wavelengths of 700 nm and 840 nm to estimate the quantity of chlorophyll in leaves. The ambient and reflected light at each wavelength is measured. Chlorophyll ***a*** absorbs 700 nm light and, as a result, the reflection of that wavelength from the leaf is reduced compared to the reflected 840 nm light. Light having a wavelength of 840 nm is unaffected by leaf chlorophyll content and serves as an indication of how much light is reflected due to leaf physical characteristics such as the presence of a waxy or hairy leaf surface. (www.specmeters.com).

Few studies have been conducted regarding the relationship of mowing height and N rate on NO_3-N leaching in warm season grasses. Therefore, the objectives of this study were to evaluate the effect of nitrogen rates and mowing heights on NO_3-N leaching of St. Augustinegrass, and to evaluate the response of N rates and mowing heights on St. Augustinegrass turf quality and physiological responses.

CHAPTER 2
MATERIALS AND METHODS

The experiment was conducted in a greenhouse at the Turfgrass Research Envirotron Laboratory at the University of Florida in Gainesville. Floratam St. Augustinegrass was harvested from the University of Florida G.C. Horn Turfgrass Research plots at the Plant Science Research and Education Unit (PSREU) located in Citra and established in poly vinyl chloride (PVC) tubs with dimensions of 0.6 m by 0.5 m and a volume of 42.5 L.

Tubs were placed on metal tables in the greenhouse. Five cm of gravel was placed at the bottom of the tubs and was covered with a mesh cloth to prevent soil migration into the gravel layer. Tubs were then filled with a sandy loam soil (Hyperthermic, uncoated, Quartzipsamments under the Candler series) obtained from the PSREU. Sod was planted on 25 September 2007. The sod was allowed to establish for two-months period before fertilizer treatments started.

Urea (46-0-0) was applied at the rate of 2.5, 4.9, 7.4 and 9.8 g N m^{-2} every two month (21 February 2008, 17 April 2008 and 26 June 2008). Each interval between fertilizer applications was considered a fertilizer cycle (FC). Turfgrass mowing height treatments were 7.6 and 10.2 cm. Turf that was maintained at 7.6 cm was mowed once every week and turf that was maintained at 10.2 cm mowing height was mowed once every two weeks.

Irrigation was applied twice a week throughout the experimental period at 1.27cm of water per application.

Leachate was collected every 15 days. To facilitate leachate collection, a hole was drilled in one side of the tub. A polyethylene tube with an internal diameter of 6.35 mm was attached to the tub to allow leachate to drain into a white 2.5 L plastic bucket. Samples were acidified with sulfuric acid (conc. 96.3%) to lower pH (<2) and were cooled to less than 4° C. Samples were submitted to the Analytical Research Laboratory (ARL) in Gainesville for NO_3-N analysis. The volume of total leachate collected was measured on each sampling date. Results are presented based on both Total Nitrogen content (TNC) leached (mg m^{-2}) and nutrient concentration in leached water (mg L^{-1}). TNC was calculated by multiplying the nutrient concentration by the corresponding leachate volume and dividing by the surface area of the tub.

Turf visual quality ratings were taken every 15 days using scale of 1 to 9, with 9 being outstanding or ideal turf and 1 being poor or dead turf. A rating of 6 or above was considered acceptable.

Reflectance measurements were taken monthly using a Cropscan model MSR 16R (CROPSCAN, Inc., Rochester, MN). Reflectance was measured at the following wave lengths: 450, 550, 660, 694, 710, 760, 835, and 930 nm. From these measurements, the following indices were used to assess turfgrass performance:

NDVI (normalized difference vegetation index) which is measured as $(R_{930}-R_{660})/(R930+R_{660})$

Stress-1, which is measured as $R_{710}/_{R760}$

Stress 2, which is measured as R_{710}/R_{835}

Chlorophyll measurements were taken monthly using a Field Scout CM-1000 Chlorophyll meter (Spectrum Technologies, Plainfield, IL). Measurements were taken holding the meter approximately 1.5 m from the turf canopy. This yielded a circular area of evaluation of approximately 180 cm^2 per measurement. All measurements were taken in full sun between 1100 and 1300 h with the meter facing away the sun.

Canopy temperature was measured monthly with a Raytek Raynger infrared thermometer (Raytek, Santa Crtuz, CA). Temperature was measured by point and shoot operation sequence by aiming the thermometer at the top of the turf canopy for couple seconds. Accurate monitoring of the difference between leaf (or canopy) temperature and air temperature has been used to indicate plant water stress (Ehrler, 1973; Idso and Ehrler, 1976).

Shoot tissue clippings were collected 4 weeks after fertilizer application for each FC. Base line clippings were collected prior to treatment initiation. Samples were dried in the oven for 48 hours at 75° C, ground, and analyzed for total nitrogen content. Analysis of N was done by total Kjeldahl nitrogen (TKN) procedure. Roots were harvested after the research was completed on 3 September 2008.

Supplemental nutrients were provided to the turfgrass during the research period. On 3 June 2008 and 18 July 2008, a micronutrient blend (Lesco Inc, Marysville, OH) (Magnesium (Mg) 1%, Sulfur (S) 5.78%, Iron (Fe) 3% and Manganese (Mn) 4%) was applied at the rate of 2.5 g m^{-2}. Phosphorous (P) was applied as 0-45-0 on 17 June 2008 at the rate of 2.5 g m^{-2}. On 5 June 2008 4.9 g m^{-2} potassium (K) was applied. Insecticides were applied as needed throughout the experiment to control scale insects and mites.

Experimental design was a randomized complete block with four replications. Data were analyzed with the SAS analytical program (SAS institute, Inc. 2008) to determine treatment differences at the 0.05 significance level by General Linear Method (GLM) and means were separated by Waller-Duncan means separation. Data are presented by FC and averaged across all FC's. Correlation analysis was done to determine degree of association between data

CHAPTER 3
EFFECT OF FERTILIZER RATES AND MOWING HEIGHTS ON NITRATE LEACHING FROM ST. AUGUSTINEGRASS

Introduction

St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze) is one of the most popular choices for lawns throughout the southern United States. St. Augustinegrass is believed to be native to the coastal regions of the Gulf of Mexico and the Mediterranean and performs best in well drained soils (Trenholm et al., 2000a). It has relatively good salt tolerance but has poor cold tolerance. St. Augustinegrass is more shade tolerant than many other warm season turfgrass species, although there is a wide range of shade tolerance within the species (Trenholm et al., 2002). St. Augustinegrass is characterized as a stoloniferous perennial, rooting at nodes, with coarse-textured leaf blades that are 6 to 8 mm wide and up to 15 cm in length (Hitchcock, 1950; Duble, 1989).

Commonly produced cultivars of St. Augustinegrass include Palmetto, Delmar, Bitterblue and Floratam, among which Floratam is the most widely produced, comprising 75% of all St. Augustinegrass in production in Florida. Floratam is an improved St. Augustinegrass that was released jointly in 1973 by the University of Florida and Texas A & M. University

While St. Augustinegrass can grow in unfertile sand soils (Chen, 1992), depending on the aesthetics and uses required, St. Augustinegrass requires fertilization to maintain a healthy turfgrass stand. St. Augustinegrass prefers moderate cultural practices with a fertility requirement ranging from 10-30 g N m^{-2} yr^{-1} (Trenholm et al., 2002). University of Florida recommendations for St. Augustinegrass fertilization vary, depending on location in the state. In northern Florida, 10-20 g N m^{-2} yr^{-1} is recommended, while in central and south Florida 10-25 g N m^{-2} yr^{-1} and 20-30 g N m^{-2} yr^{-1}, respectively, are recommended (Trenholm et al., 2002).

St. Augustinegrass does not remain green under drought conditions and may die without supplemental irrigation. When irrigating St. Augestinegrass, it is recommended that water be applied on an “as needed basis” (Trenholm et al., 2003). In some regions, St. Augestinegrass requires regular irrigation because of its poor drought tolerance (Christians, 1998).

Increasing urbanization and an increasing number of home lawns throughout Florida may contribute to problems associated with NO_3-N contamination of water. N is the nutrient applied to turfgrass in the greatest quantity and frequency to provide green color and healthy growth. NO_3-N is a water soluble form of N, which may leach through the soil if applied at excessive rates, especially when accompanied by excess water from either irrigation or rainfall.

In Florida, NO_3-N leaching from home lawns has been implicated as a source of N pollution to streams, lakes, springs and bays (Erickson et al., 2001; Flipse et al., 1984). Sandy soils commonly found in Florida have low water holding capacity, which may increase leaching of N from turfgrass when water drains through the soil profile into the groundwater. Burgess (2003) said that N entering the ground and surface water can cause eutrophication, and can cause health risk where that water is used for drinking. A high uptake of NO_3-N is known to be hazardous to human health (Hornsby, 1999). The United States Environmental Protection Agency (EPA) limit for NO_3-N in drinking water is 10 mg L^{-1}.

Bowman et al., (2002) compared ‘Raleigh’ St. Augustinegrass with five other warm season grasses (common bermudagrass, Tifway hybrid bermudagrass, centipedegrass, Meyer zoysiagrass, and Emerald zoysiagrass). They applied ammonium nitrate at the rate of 50 kg N ha^{-1} and found that Raleigh St. Augustinegrass produced the highest amount of leaf tissue and the root mass compared to the other species. They found differences among the species for leaching of NO_3-N ranging from a low of 24% of applied N in Raleigh St. Augustinegrass and a high of

56% in Meyer zoysiagrass. They concluded that the higher root mass might increase the ability of St. Augustinegrass to absorb NO_3-N from the soil.

In spite of some reports that propose turfgrass fertilization to be a significant contributor of nitrates to ground water (Flipse et al., 1984), some research has shown that properly managed and fertilized turf is not a significant source of groundwater contamination (Erickson et al., 2001). The authors studied Floratam St. Augustinegrass vs. a mixed species (ornamental ground cover, shrubs and trees) landscape. N was applied at the a of 50 kg N ha^{-1} per application to both plant types for a total of 300kg N ha^{-1} yr^{-1} to St. Augustinegrass and 150 kg N $ha^{-1}yr^{-1}$ to the mixed species landscape. They found that more than 30% of applied fertilizer N leached from the mixed species, whereas less than 2% leached from St. Augustinegrass.

Previous research on N leaching from bermudagrass golf course turf in Florida has shown that N rates, N sources, N application methods, and irrigation all influence the amount of N leached beyond the root-zone, and subsequently to groundwater (Snyder, et al., 1984; Snyder, et al., 1989; Cisar, et al., 1992). Frank (2007) showed NO_3-N leaching from Kentucky bluegrass decreased as the turf matured. When fertilizer was applied at rate of 196 kg N ha^{-1} in 2003, averaged NO_3-N leached was 31.6 mg L^{-1} and in 2006 averaged NO_3-N leached was 11.2 mg L^{-1}.

Some claim that turf use should be minimized to avoid pollution, but research has shown that properly applied fertilizer will be assimilated by the grass (Snyder et al., 1984; Erickson et al., 2001) and that proper fertilizer management is a factor in reducing non-point source pollution (Gross et al., 1990). The authors noted that application of high rates of quick release fertilizers combined with high irrigation or rainfall resulted in higher N losses due to leaching.

Leaching may also depend on the source of N fertilizer applied. Saha (2004) found that St. Augustinegrass treated with 4.9 g N m^{-2} of quick release N sources had higher visual quality scores than those that received the same amount of slow release N for the first two weeks following fertilizer application. After that, no differences in turf quality due to the N source were found. There were no differences in leaf nutrient concentration due to N treatments in this research. Shuman (2001) determined that supplying turf with N in a controlled fashion greatly reduced the potential for leaching and runoff. Similar results had previously been obtained by Killian et al. (1966), who found that concentration of NO_3-N in leachate from turfgrass was found to be dependent on N source, with greater leaching and runoff from quick release sources. Brown et al. (1982) observed NO_3-N losses of 8.6 to 21.9% in golf course greens fertilized with ammonium nitrate at the rate of 163 kg N ha^{-1}. When slow release sources [isobutylidene diurea (IBDU) and ureaformaldehyde (UF)] were used at the rate of 146 kg N ha^{-1}, only 0.2 to 1.6% NO_3-N was leached. Other research has disagreed with these results. Park (2006) applied urea and a blend of urea and IBDU at the rate of 30 g m^{-2} yr^{-1} and 15 g $m^{-2}yr^{-1}$ and found that leaching was affected by the fertilizer rates but not by the fertilizer sources.

The "Green Industries Best Management Practices" (BMPs) have been developed for the commercial lawn care service in Florida to minimize any potential adverse impacts from fertilization and lawn care activities. BMPs are the guidelines for implementation of environmentally sound agronomic practices to reduce potential contamination of ground or surface water due to commercial lawn care practices. These BMPs were developed in 2002 by regulatory, academic and industry professionals and are intended to preserve Florida's water resources. There is an outreach program for the BMPs to provide education on fertilizer management to the landscape maintenance industries of Florida. The objective of this study was to evaluate the effect of N rates and mowing heights on NO_3-N leaching and turf quality of St. Augustinegrass.

Materials and Methods

The experiment was conducted in a greenhouse at the Turfgrass Research Envirotron Laboratory at the University of Florida in Gainesville. Floratam St. Augustinegrass was harvested from the University of Florida G.C. Horn Turfgrass Research plots at the PSREU located in Citra and established in PVC tubs with dimensions of 0.6 m by 0.5 m and a volume of 42.5 L.

Tubs were placed on metal tables in the greenhouse. Five cm of gravel was placed at the bottom of the tubs and was covered with a mesh cloth to prevent soil migration into the gravel layer. Tubs were then filled with a sandy loam soil (Hyperthermic, uncoated, Quartzipsamments under the Candler series) obtained from the PSREU. Sod was planted on 25 September 2007. The sod was allowed to establish for two months period before fertilizer treatments started.

Urea (46-0-0) was applied at the rate of 2.5, 4.9, 7.4 and 9.8 g N m^{-2} every two month (21 February 2008, 17 April 2008 and 26 June 2008). Each interval between fertilizer applications was considered a fertilizer cycle (FC). Turfgrass mowing height treatments were 7.6 and 10.2 cm. Turf that was maintained at 7.6 cm was mowed once every week and turf that was maintained at 10.2 cm mowing height was mowed once every two weeks.

Irrigation was applied twice a week throughout the experimental period at 1.27cm of water per application.

Leachate was collected every 15 days. To facilitate leachate collection, a hole was drilled in one side of the tub. A polyethylene tube with an internal diameter of 6.35 mm was attached to the tub to allow leachate to drain into a white 2.5 L plastic bucket. Samples were acidified with sulfuric acid concentration to lower pH (<2) and were cooled to less than 4° C. Samples were submitted to the Analytical Research Laboratory (ARL) in Gainesville for NO_3-N analysis. The volume of total leachate collected was measured at each sampling date. Results are presented based on both nutrient concentration in leached water (mg L^{-1}) and TNC (mg m^{-2}). TNC was calculated by multiplying nutrient concentration by the corresponding leachate volume and dividing by the surface area of the tub.

Shoot tissue clippings were collected 4 weeks after fertilizer application for each FC. Base line clippings were collected prior to treatment initiation. Samples were dried in the oven for 48 hours at 75° C, ground, and analyzed for total nitrogen content. Analysis of N was done by total Kjeldahl nitrogen (TKN) procedure. Roots were harvested after the research was completed on 3 September 2008.

Turf visual quality ratings were taken every 15 days using scale of 1 to 9, with 9 being outstanding or ideal turf and 1 being poor or dead turf. A rating of 6 or above is generally considered acceptable.

Supplemental nutrients were provided to the turfgrass during the research period. On 3 June 2008 and 18 July 2008, a micronutrients blend (Lesco Inc, Marysville, OH) (Magnesium (Mg) 1%, Sulfur (S) 5.78%, Iron (Fe) 3% and Manganese (Mn) 4%) was applied at the rate of 2.5 g m^{-2}. Phosphorous (P) was applied as 0-45-0 on 17 June 2008 at the rate of 2.5 g m^{-2}. On 5 June 2008 4.9 g m^{-2} potassium (K) was applied. Insecticides were applied as needed throughout the experiment to control scale insects and mites.

Experimental design was a randomized complete block with four replications. Data were analyzed with the SAS analytical program (SAS institute, Inc. 2008) to determine treatment differences at the 0.05 significance level by General Linear Method (GLM) and means were separated by Waller-Duncan mean separation.

Results and Discussion

Nitrate Leaching (mg m^{-2})

The amount of NO_3-N leached (mg m^{-2}) is presented in Table 3-1. The amount of NO_3-N leached increased with increasing N rate in FC3 and when averaged across all three FCs (Figure 3-1). There were no differences in the NO_3-N leached due to N rate in FC1 and FC2. This result may be because the turfgrass in these two cycles was healthy and dense, and was therefore able to filter and take up N at even the high rates. Increased NO_3-N leaching in FC3 in this study is likely due to insect damage during later fertilization cycles. Loss of turf cover and density and stress due to insect (scale insects and mites) damage decreased the capacity of the turf to absorb nutrients, thus increasing the NO_3-N content in the leachate in FC3. Porter et al. (1980) hypothesized that the capacity of the soil to store fertilizer N is a function of the age of the turfgrass and that older turf sites lose the ability to store additional N in the soil, which might also account for greater leaching at higher rates. There was no difference in N leaching due to mowing heights (Table 3-1).

Nitrate-N leaching data showed increased NO_3-N in the leachate following fertilizer application in every FC for the three highest N rates (Figure. 3-2). This increase in N leaching was not seen in the samples collected at the subsequent collection dates in each FCs. Park (2006) found that regardless of season and N sources in all cycles, NO_3-N leaching peaked shortly after fertilization and did not follow any consistent trend. Other studies have also found similar results (Petrovic, 2004; Johnston et al., 2003; Geron, et al., 1993, Sheard et al., 1985). If irrigation rates and frequencies do not cause water to move beyond the active rooting zone, this will also decrease N leaching (Brown et al., 1977; Snyder et al., 1984; Morton et al., 1988).

The interaction between mowing height and N rate (fig 3-3) was significant only in FC3 (*P-value = 0.04*). At the lower mowing height, maximum NO_3-N leaching was reached at 7.3 g

N m^{-2}, and then it declined at the 9.8 g N m^{-2} level. The decrease of NO_3-N leaching at the highest N rate is hard to explain. At the higher mowing height, NO_3-N leaching was constant through the 7.3 g N m^{-2} rate and then increased sharply at the 9.8 g N m^{-2}. This means that at the higher mowing height, turfgrass filters more NO_3-N, except when N is applied at the highest rate. At the rate of 9.8 g N m^{-2} mowing height is not sufficient to effectively filter NO_3-N.

Percent of total NO_3-N leached is shown in table 3-2. The percentage of NO_3-N leached increases with increasing N rate in FC3 only. Less percentage of NO_3-N was leached from higher mowed grass when the data was averaged over all FCs. Interaction between mowing height and N-rate was found in FC3 which was very similar to fig 3-3.

Nitrate Leaching by Concentration (mg L^{-1})

Table 3-3 shows the average NO_3-N concentration (mg L^{-1}) in the leachate collected during the study period. Where there were differences in N leaching due to N rate, the most NO_3-N was leached from the highest N treatment rate and the least from the lowest N rate. There were differences due to N rate in all cycles except for FC2. There was a difference in the amount of NO_3-N leached due to the mowing height difference in FC1 and when averaged across all three FCs, with higher NO_3 leaching at the lower mowing height. An interaction was seen between the mowing heights and fertilizer rate in FC3 (figure not provided) which was very similar to the interaction of nitrate leaching (mg m^{-2}).At the lower mowing height, maximum NO_3-N leaching was reached at 7.3 g N m^{-2}, and then it declined at the 9.8 g N m^{-2} level. The decrease of NO_3-N at the highest N rate is hard to explain. At the higher mowing height, NO_3-N leaching was low and steady through the 7.3 g N m^{-2} rate and then increased at the 9.8 g N m^{-2}.This shows that turfgrass with higher mowing heights has better potential to absorb nutrients, thereby reducing the NO_3-N leaching loss.

Visual Color and Quality

Higher visual color scores (Table3-4) were obtained from the turf treated with 9.8 g N m^{-2} and lower scores were obtained from the 2.4 g N m^{-2} treated turf in all FCs and when averaged over the study period. Visual color scores of the turfgrass mowed at 10.2 cm were better in FC1 and FC3 than the turfgrass mowed at 7.6cm.

Significant differences were seen in the interaction between the mowing heights and fertilizer rates in FC1 and when averaged over all the FCs. In FC1 (fig 3-5a), whenever there was a difference, better color scores were seen in higher mowing heights and the score increased with increasing fertilizer rate for both mowing heights. This indicates the positive influence of higher mowing heights.

Similar to the visual color score, higher visual quality scores were obtained from turf treated with 9.8 g N m^{-2} than those treated with 2.4 g N m^{-2} in all three cycles and when averaged over the study period (table 3-5). There was a difference in the visual quality due to mowing height in FC1 only, with higher scores at the higher mowing height. An interaction in FC1 was also observed between mowing height and N rate with respect to turf quality (Fig 3-5b). Whenever there was a difference, better quality scores were seen in higher mowing heights and the score increases with the increase in fertilizer rate for both mowing heights.

Total Kjeldahl Nitrogen Content in Leaf Tissue

Leaf tissue nutrient analysis showed no difference in TKN in FC1 due to N treatment (Table 3-6). The TKN increased as N rate increased in all other FCs and when averaged over the study period. Higher TKN values were observed at the lower mowing height in all FCs (except FC1) and when averaged over all cycles. No interaction was seen between fertilizer rate and mowing height due to the total N content.

Shoot and Root Growth

Shoot growth differed in all FCs (except FC1) and when averaged over all cycles due to N treatment (Table 3-7). Greater shoot growth per unit area was found from 9.8 g N m^{-2} rate and the least was from the 2.4 g N m^{-2}. Trenholm et al., (1998) obtained highest shoot growth per unit area in two cultivars of bermudagrass when fertilized at a rate of 9.8 g N m^{-2} then when they were fertilized at rate of 1.2, 2.4 and 4.9 g N m^{-2}. Differences in shoot mass due to mowing height were seen in all FCs. Greater shoot tissue was harvested from the 10.2 cm mowing height in FC2 and FC3, with less growth at the higher height in FC1. This difference in FC1 may be attributed to the fact that these grasses were still establishing. There was an interaction between mowing height and N rate only in FC2 (fig 3-4). Shoot mass was always greater at the higher mowing height at all N rates, while both mowing rates showed increased shoot as N rate increased. However, shoot mass of turf mowed at 10.2 cm height reached a plateau with 7.3 g N m^{-2}, while the tissue mass of grass mowed at 7.6 cm continued to increase as N rates increased (Fig 3-4).

There were no differences in root growth due to N treatment; however, there was difference due to mowing height (Table 3-8). Root weight was 66% greater in turf maintained at 10.1 cm height than in the turf maintained at 7.6 cm height. Better root growth was supported by the higher mowing heights.

Correlation

Correlation analysis indicated that there were significant relationship between average quality and color (Table 3-9). There was no correlation between visual scores and nitrate leached. This was somewhat surprising, since the treatments with lower quality ratings tended to be those that had the most damage from insects, which would increase susceptibility to nitrate leaching.

Conclusions

From the results of this research, we conclude that even with higher N rates and lower mowing heights, healthy turfgrass can efficiently use nitrogen, allowing low levels of nitrate leaching. The turfgrass that became infested with insects had less ability to absorb nitrogen as efficiently and increased the potential of leaching, particularly at the higher N rates. The higher mowing heights lessened nitrate-N leaching when insect damage became a factor. High nitrate leaching peaks were observed after the fertilization events, which supports the potential for higher N leaching with quick-release urea nitrogen if applied at higher N rates.

Higher nitrogen rates and higher mowing heights produced better quality turfgrass and increased shoot mass. Additionally, higher NO_3-N leaching losses may occur at lower mowing heights due to less shoot and root tissue to take up the nitrogen. Recommended mowing heights should be followed for optimal turfgrass health and mitigation of nutrient leaching.

From this greenhouse research, it appears that healthy St. Augustinegrass provides an excellent filter to absorb applied N and that, proper cultural practices to ensure turf vigor is an important factor in reducing NO_3-N leaching. Field plot research should be conducted to determine if similar results would be found outside of a controlled greenhouse setting.

Table 3-1. Nitrate leaching (mg m^{-2}) from Floratam St. Augustinegrass in response to N rates and mowing heights in a greenhouse experiment

N-rate (g N m^{-2})	FC1	FC2	FC3	Average
2.4	0.58	2.69	2.69	1.98b*
4.9	8.61	3.43	11.64	7.90b
7.3	10.61	7.21	51.25	23.02ba
9.8	16.44	36.95	66.95	40.11a
Mow Ht (cm)				
7.6	17.36	22.42	40.07	26.61
10.2	0.76	2.72	26.21	9.90
ANOVA				
N-rate	NS	NS	0.01	0.02
Mow Ht	NS	NS	NS	NS
N- rate×Mow Ht	NS	NS	0.04	NS

*Means followed by the same letter do not differ significantly at the 0.05 probability level. Means are averaged for fertilizer cycles.

Table 3-2. Percentage Nitrate leached from Floratam St. Augustinegrass in response to N rates and mowing heights in a greenhouse experiment

N-rate (g N m^{-2})	FC1	FC2	FC3	Average
2.4	0.02	0.11	0.11	0.08
4.9	0.17	0.07	0.23	0.16
7.3	0.14	0.10	0.70	0.31
9.8	0.17	0.38	0.68	0.40
Mow Ht (cm)				
7.6	0.24	0.27	0.55	0.36a*
10.2	0.01	0.05	0.31	0.13b
ANOVA				
N-rate	NS	NS	0.01	NS
Mow Ht	NS	NS	NS	0.02
N-rate×Mow Ht	NS	NS	0.01	NS

*Means followed by the same letter do not differ significantly at the 0.05 probability level. Means are averaged for fertilizer cycles.

Table 3-3. Nitrate leaching (mg L^{-1}) from Floratam St. Augustinegrass in response to N rates and mowing heights in a greenhouse experiment

N-rate (g N m^{-2})	FC1	FC2	FC3	Average
2.4	0.08b*	0.12	0.13	0.11b
4.9	0.73ba	0.13	0.38	0.41b
7.3	0.88ba	0.47	1.61	0.99b
9.8	2.40a	1.60	2.81	2.27a
Mow Ht (cm)				
7.6	1.95a	0.99	1.32	1.42a
10.2	0.10b	0.16	1.15	0.47b
ANOVA				
N-rate	NS	NS	0.0005	0.0008
Mow Ht	0.004	NS	NS	0.009
N- rate×Mow Ht	NS	NS	0.003	NS

*Means followed by the same letter do not differ significantly at the 0.05 probability level. Means are averaged for fertilizer cycles.

Table 3-4. Visual color score of Floratam St. Augustinegrass in response to N rates and mowing heights in a greenhouse experiment

N-rate (g N m^{-2})	FC1	FC2	FC3	Average
2.4	6.5	6.3c*	6.5d	6.4
4.9	6.6	6.4b	6.5c	6.5
7.3	6.8	6.6a	6.6b	6.7
9.8	7.0	6.7a	6.7a	6.8
Mow Ht (cm)				
7.6	6.6	6.5	6.6a	6.6
10.2	6.8	6.5	6.5b	6.6
ANOVA				
N-rate	<0.0001	<0.0001	<0.0001	<0.0001
Mow Ht	0.011	NS	0.019	NS
N- rate×Mow Ht	0.033	NS	NS	0.04

*Means followed by the same letter do not differ significantly at the 0.05 probability level. Means are averaged for fertilizer cycles.

Table 3-5. Visual quality score of Floratam St. Augustinegrass in response to N rates and mowing heights in a greenhouse experiment

N-rate (g N m^{-2})	FC1	FC2	FC3	Average
2.4	6.4	6.2d*	6.4c	6.4b
4.9	6.5	6.4c	6.5bc	6.5b
7.3	6.7	6.5b	6.5ba	6.5ba
9.8	6.8	6.6a	6.6a	6.6a
Mow Ht (cm)				
7.6	6.5	6.5	6.5	6.5
10.2	6.7	6.4	6.5	6.5
ANOVA				
N-rate	<0.0001	<0.0001	0.0006	0.009
Mow Ht	0.002	NS	NS	NS
N- rate×Mow Ht	0.04	NS	NS	NS

*Means followed by the same letter do not differ significantly at the 0.05 probability level. Means are averaged for fertilizer cycles.

Table 3-6. Total Kjeldahl Nitrogen percentage Floratam St. Augustinegrass in response to N rates and mowing heights in a greenhouse experiment

N-rate (g N m^{-2})	FC1	FC2	FC3	Average
2.4	1.00	1.08c*	1.50b	1.20c
4.9	1.06	1.30b	1.74ba	1.36b
7.3	1.22	1.60a	1.86a	1.54a
9.8	1.07	1.61a	1.91a	1.53a
Mow Ht (cm)				
7.6	1.18	1.47a	1.87a	1.50a
10.2	1.00	1.30b	1.66b	1.31b
ANOVA				
N-rate	NS	<.0001	0.01	<.0001
Mow Ht	NS	0.0004	0.02	0.0006
N- rate×Mow Ht	NS	NS	NS	NS

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 3-7. Turf shoot weight (g m^{-2}) Floratam St. Augustinegrass in response to N rates and mowing heights in a greenhouse experiment

N-rate (g N m^{-2})	FC1	FC2	FC3	Average
2.4	2.75	4.65	9.07b*	5.49c
4.9	3.35	4.66	12.40a	6.80b
7.3	2.88	6.06	12.26a	7.07b
9.8	3.08	6.43	14.20a	7.91a
Mow Ht (cm)				
7.6	3.47a	4.59	10.65b	6.24b
10.2	2.56b	6.31	13.31a	7.39a
ANOVA				
N-rate	NS	<.0001	0.0006	0.0006
Mow Ht	0.0004	<.0001	0.001	0.0008
N- rate×Mow Ht	NS	0.02	NS	NS

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 3-8. Turf root weight (g m^{-2}) Floratam St. Augustinegrass in response to N rates and mowing heights in a greenhouse experiment

N-rate (g N m^{-2})	root wt (gm)
2.4	20.47
4.9	18.78
7.3	21.81
9.8	17.59
Mow Ht (cm)	
7.6	14.78a*
10.2	24.55b
ANOVA	
N rate	NS
Mow Ht	0.004
N- rate×Mow Ht	NS

*Means followed by the same letter do not differ significantly at the 0.05 probability level.

Table 3-9. Correlation matrix of average color, average quality and average nitrate leached from Floratam St. Augustinegrass in response to N rates in a greenhouse experiment

	Average color	Average quality	Average N leached
Average color	1	0.96	0.23
Average quality	0.96	1	0.18
Average N leached	0.23	0.18	1

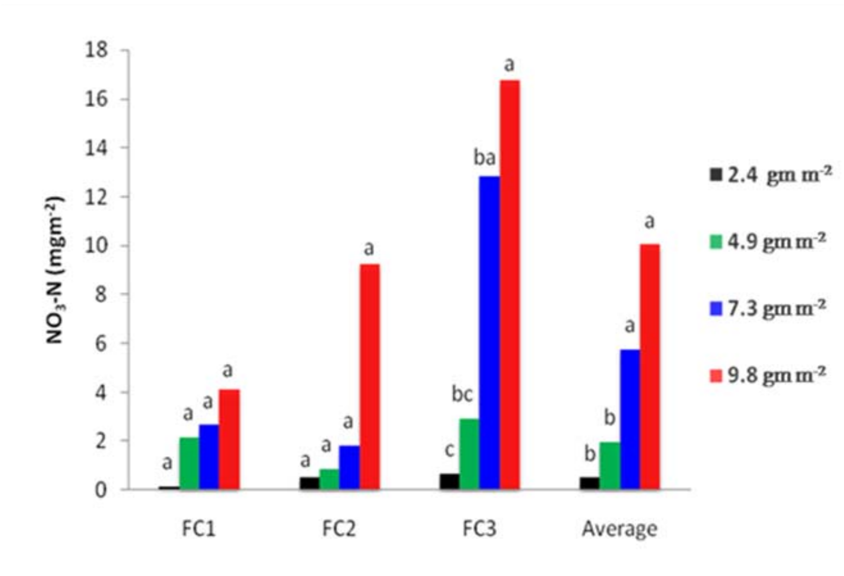


Figure 3-1. Average NO_3-N leached from the turf at different fertilization cycles. Means are averaged for fertilizer cycles

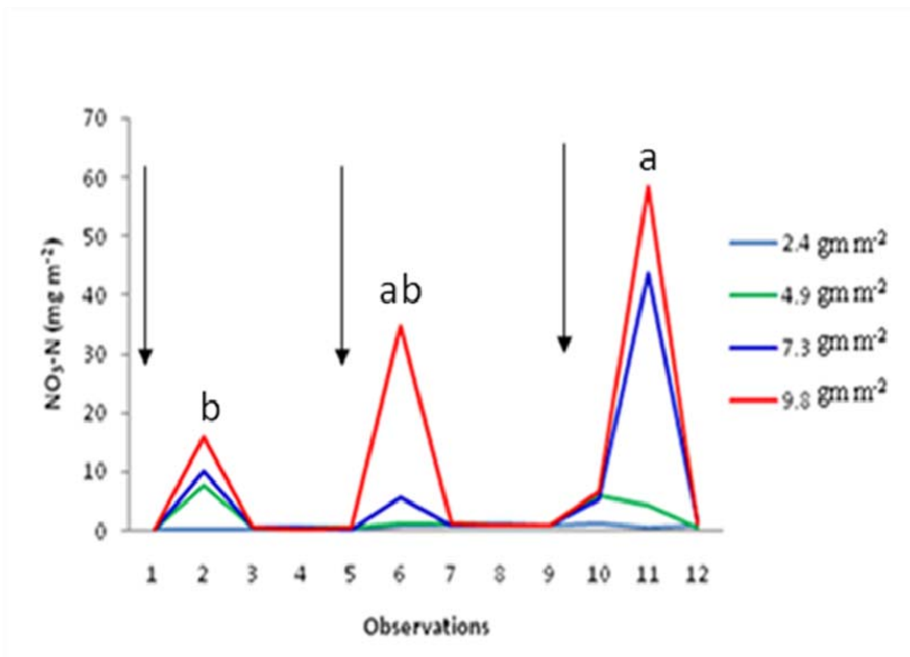


Figure 3-2. Observations NO_3-N (mg m^{-2}) leaching with respect to the three fertilization dates. Black arrows indicate fertilizer application dates

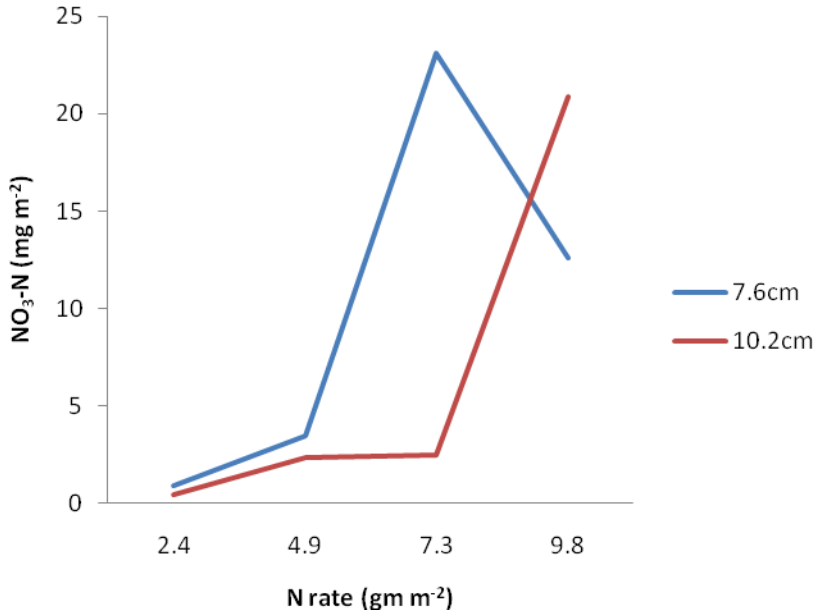


Figure 3-3. Interaction between mowing height and N rate with respect to NO_3-N leaching from Floratam St. Augustinegrass in FC3

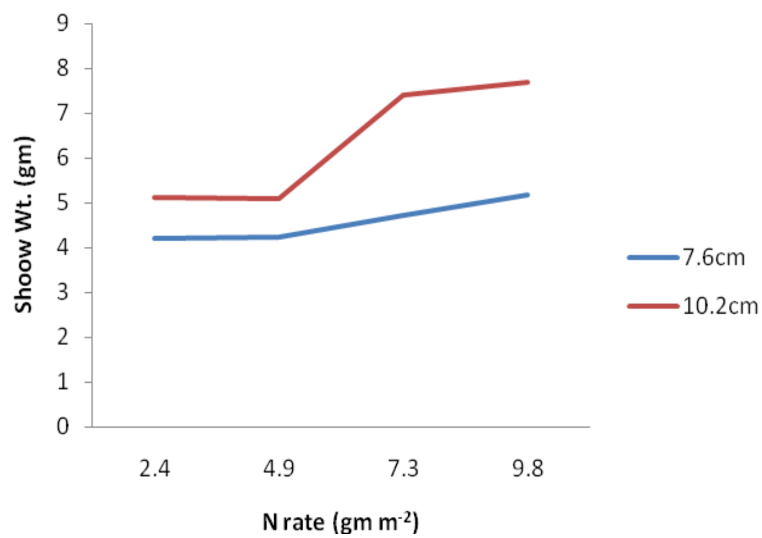
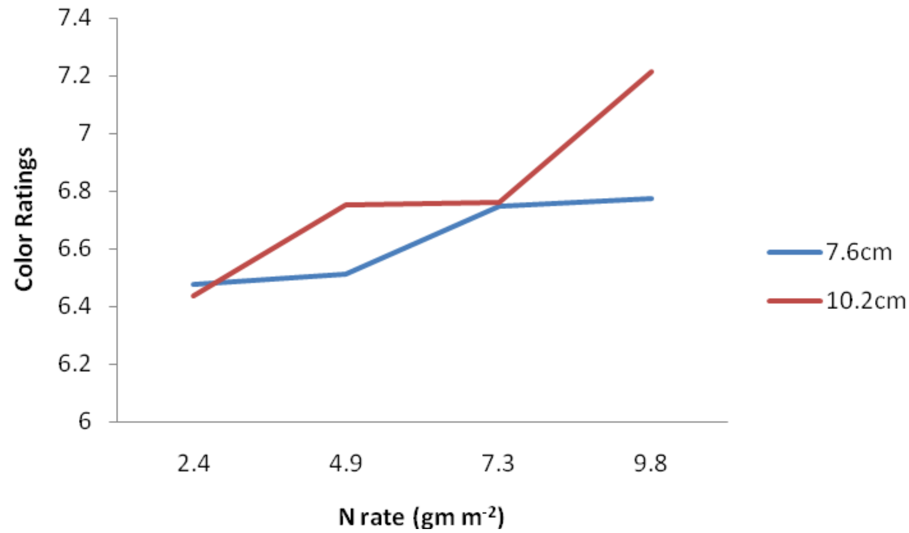
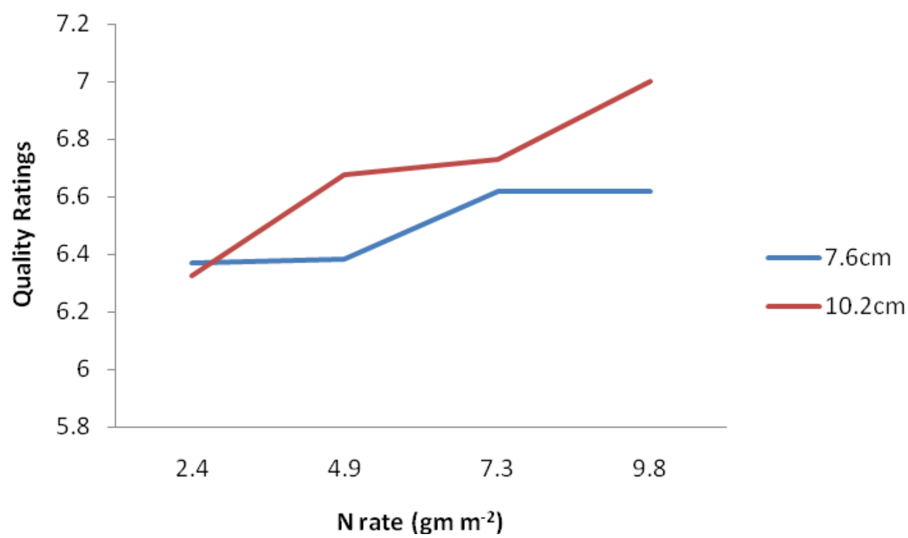


Figure 3-4. Interaction between mowing height and N rate with respect ot shoot growth of Floratam St. Augustinegrass



(a)



(b)

Figure 3-5. Interaction between mowing height and N rate with respect to visual color (a) and quality (b) ratings at FC1.

CHAPTER 4
EFFECT OF FERTILIZER RATES AND MOWING HEIGHTS ON SPECTRAL REFLECTANCE OF ST. AUGUSTINEGRASS

Introduction

St. Augustinegrass is one of the most popular choices for lawns throughout the southern United States. St. Augustinegrass is believed to be native to the coastal regions of the Gulf of Mexico and the Mediterranean and performs best in well drained soils (Trenholm et al., 2000). It has relatively good salt tolerance but has poor cold tolerance. St. Augustinegrass is more shade tolerant than many other warm season turfgrass species, although there is a wide range of shade tolerance within the species (Trenholm et al., 2002). St. Augustinegrass is characterized as a stoloniferous perennial, rooting at nodes, with coarse-textured leaf blades that are 6 to 8 mm wide and up to 15 cm in length (Hitchcock, 1950; Duble, 1989).

Commonly produced cultivars of St. Augustinegrass include Palmetto, Delmar, Bitterblue and Floratam, among which Floratam is the most widely produced, comprising 75% of all St. Augustinegrass in production in Florida. Floratam is an improved St. Augustinegrass that was released jointly in 1973 by the University of Florida and Texas A & M University.

While St. Augustinegrass can grow in unfertile sand soils (Chen, 1992), depending on the aesthetics and uses required, St. Augustinegrass requires fertilization to maintain a healthy turfgrass stand. St. Augustinegrass prefers moderate cultural practices with a fertility requirement ranging from 10-30 g N m^{-2} yr^{-1} (Trenholm et al., 2002). University of Florida recommendations for St. Augustinegrass fertilization vary, depending on location in the state. In northern Florida, 10-20 g N m^{-2} yr^{-1} is recommended, while in central and south Florida 10-25 g N m^{-2} yr^{-1} and 20-30 g N m^{-2} yr^{-1}, respectively, are recommended (Trenholm et al., 2002).

St. Augustinegrass does not remain green under drought conditions and may die without supplemental irrigation. When irrigating St. Augestinegrass, it is recommended that water be applied on an "as needed basis" (Trenholm et al., 2003). In some regions, St. Augestinegrass requires regular irrigation because of its poor drought tolerance (Christians 1998).

Increasing urbanization and an increasing number of home lawns throughout Florida may contribute to problems associated with NO_3-N contamination of water. N is the nutrient applied to turfgrass in the greatest quantity and frequency to provide green color and healthy growth. NO_3-N is a water soluble form of N, which may leach through the soil if applied at excessive rates especially when accompanied by excess water from either irrigation or rainfall.

Turfgrass mowing is known to be one of the major cultural practices that can influence turf health and vigor. Turfgrass undergoes physiological stress with each mowing, particularly if too much leaf tissue is removed (Trenholm et al., 2002). These authors state that it is important to leave as much leaf surface as possible so that photosynthesis can occur and to promote deep rooting. If turf is mowed too short, it tends to become denser, but has less root and rhizome growth (May et al., 2004). According to the authors, removal of excess leaf area may increase the risk of fertilizers leaching through the soil or running off and endangering water reserves.

To assess the growth, or to compare treatment responses, qualitative responses are commonly used in turfgrass research, where quality might be expressed by visual and functional characteristics (Turgeon 1991). Qualitative responses are often described as the combination of shoot density, color, and growth habit (Beard 1973). Multispectral radiometry (MSR) may be used to quantify these subjective values and provides a reliable method for comparison of turf response to treatments (Trenholm et al., 1999).

Plants use varying amount of light at different wavelengths for physiological processes. Some of the light is assimilated for that use, while some is reflected off the leaf surface. Measurement of the amount of light reflected at various wavelengths can be correlated with crop health, chlorophyll content, fertility, and stress (Carter 1993; Carter and Miller 1994; Trenholm et al., 2000). Wavelengths in the visible range (400–700 nm can be absorbed by plant pigments. Near-infrared (NIR) radiation (700–1300 nm) is highly reflected due to low absorption (Knipling, 1970; Asrar et al., 1984). Leaf physical characteristics such as cell structure, water content, and pigment concentration affect plant canopy reflectance, transmittance, and absorption (Maas and Dunlap, 1989). Leaf chlorophyll content was negatively correlated to green light reflection (500–600 nm) and positively correlated to NIR reflection in soybean and corn (Blackmer et al., 1994; Adcock et al., 1990).

Measurement of chlorophyll concentration may be used to assess plant physiological response. Chlorophyll concentration may be considered as a measure of plant vitality, or may be viewed as an indirect measure of turf color (Pocklington et al., 1974). The Field Scout CM1000 Chlorophyll Meter (Spectrum Technology, Plainfield, IL) uses ambient and reflected light at 700 nm and 840 nm to calculate a relative chlorophyll index. It senses light at wavelengths of 700 nm and 840 nm to estimate the quantity of chlorophyll in leaves. The ambient and reflected light at each wavelength is measured. Chlorophyll ***a*** absorbs 700 nm light and, as a result, the reflection of that wavelength from the leaf is reduced compared to the reflected 840 nm light. Light having a wavelength of 840 nm is unaffected by leaf chlorophyll content and serves as an indication of how much light is reflected due to leaf physical characteristics such as the presence of a waxy or hairy leaf surface. (www.specmeters.com).

The objective of this study was to evaluate the physiological responses of St. Augustinegrass as measured through various instrumentation in response to N rates and mowing heights.

Materials and Methods

The experiment was conducted in a greenhouse at the Turfgrass Research Envirotron Laboratory at the University of Florida in Gainesville. Floratam St. Augustinegrass was harvested from the University of Florida G.C. Horn Turfgrass Research plots at the PSREU located in Citra and established in PVC tubs with dimensions of 0.6 m by 0.5 m and a volume of 42.5 L.

Tubs were placed on metal tables in the greenhouse. Five cm of gravel was placed at the bottom of the tubs and was covered with a mesh cloth to prevent soil migration into the gravel layer. Tubs were filled with a sandy loam soil (Hyperthermic, uncoated, Quartzipsamments under the Candler series) obtained from the PSREU. Sod was planted on 25 September 2007. The sod was allowed to establish for two months before fertilizer treatments started.

Urea (46-0-0) was applied at the rate of 2.5, 4.9, 7.4 and 9.8 g N m^{-2} every two month (21 February 2008, 17 April 2008 and 26 June 2008). Each interval between fertilizer applications was considered a fertilizer cycle (FC). Turfgrass mowing height treatments were 7.6 and 10.2 cm. Turf that was maintained at 7.6 cm was mowed once every week and turf that was maintained at 10.2 cm mowing height was mowed once every two weeks.

Irrigation was applied twice a week throughout the experimental period at 1.27cm of water per application.

Chlorophyll measurements were taken monthly using Field Scout CM-1000 Chlorophyll meter (Spectrum Technologies, Plainfield, IL). Measurements were taken holding the meter approximately 1.5 m from the turf canopy. This yielded a circular area of evaluation of approximately 180 cm^2 per measurement. All measurements were taken in full sun between 1100 and 1300 h with the meter facing away from the sun.

Canopy temperature was measured monthly with a Raytek Raynger infrared thermometer (Raytek, Santa Crtuz, CA). Temperature was measured by point and shoot operation sequence by aiming the thermometer at the top of the turf canopy for couple seconds. Accurate monitoring of the difference between leaf (or canopy) temperature and air temperature has been used to indicate plant water stress (Ehrler, 1973; Idso and Ehrler, 1976).

Reflectance measurements were taken monthly using a Cropscan model MSR 16R (CROPSCAN, Inc., Rochester, MN). Reflectance was measured at the following wave lengths: 450, 550, 660, 694, 710, 760, 835, and 930 nm. From these measurements, the following indices were used to assess turfgrass performance:

NDVI (normalized difference vegetation index) which is measured as $(R_{930}-R_{660})/(R_{930}+R_{660})$

Stress-1, which is measured as R_{710}/R_{760}

Stress 2, which is measured as R_{710}/R_{835}

Visual quality measurements were taken every other week (data in Chapter 3). These measurements were used for correlation analysis with instrumentation data collected here. Supplemental nutrients were provided to the turfgrass during the research period. On 3 June 2008 and 18 July 2008, micronutrients blend (Lesco Inc.) (Magnesium (Mg) 1%, Sulfur (S) 5.78%, Iron (Fe) 3% and Manganese (Mn) 4%) was applied at the rate of 2.5 g m^{-2}. Phosphorous (P) was applied as 0-45-0 on 17 June 2008 at the rate of 2.5g m^{-2}. On 5 June 2008 4.9g m^{-2} potassium (K) was applied. Insecticides were applied as needed throughout the experiment to control scale insects and mites.

Experimental design was a randomized complete block with four replications. Data were analyzed with the SAS analytical program (SAS institute, Inc. 2008) to determine treatment differences at the 0.05 significance level by General Linear Method (GLM) and means were separated by Waller-Duncan mean separation.

Results and Discussion

Multispectral Reflectance

There were no differences in reflectance values due to N rate in FC1 but there were differences in indices NDVI, Stress 1 and Stress 2 (Table 4-1). Reflectance values at 450 nm and 660 nm were lower, indicating greater plant assimilation of light, at 10.2 cm mowing height than at 7.6 cm. Trenholm et al. (1999) showed that reflectance in the visible range (400-700 nm) is relatively low due to increased chlorophyll absorptance in this range. There was an interaction between N rate and mowing height for NDVI, Stress 1 and Stress 2 (fig 4-1)

In FC2, there were differences due to N rate for all the wavelengths and indices excluding Stress 2 (Table 4-2). Although no difference was found in FC2 due to mowing height, there was an interaction between N rate and mowing height for wavelengths 450, 660, 694, and 710 nm (fig 4-2). At 450 nm, reflectance from the turf at 10.2 cm height decreased when N rate was increased from 2.4 g N m^{-2} to 7.3 g N m^{-2}, while for 7.6 cm, reflectance increased from 2.4 to 4.9 g N m^{-2} and declined from 4.8 to 7.3 g N m^{-2}. Reflectance at 450 nm increased for both mowing heights when N rate was increased to the highest rate but the increase was much greater for 7.6 cm as compared to the 10.1 cm height.

In FC3 there were no differences due to N rate, with the exception of Stress2 index, where better values were seen at the lower N rates (Table 4-3). Thisresult may be due to the insect damage in FC3. In the NIR range of 710 to 935 nm, reflectance is typically increased across the visible range because of internal scattering of light within the leaf that results in greater reflective surfaces (Gupta and Woolley, 1971; Knipling, 1970). If stress is sufficient to inhibit chlorophyll production, increased reflectance becomes detectable first as chlorophyll content decreases. Thus, reflectance sensitivity to stress-induced chlorosis is high in the 690-700 nm range (Cibula and Carter, 1992; Carter, 1993)

Canopy Temperature

Canopy temperature decreased with increasing N rate in all FCs (Table 4.4). No difference was seen due to mowing height except for in FC1, where temperature was higher at the lower mowing height. Interaction between mowing height and N rate was seen only in FC3 (fig 4.3). At the lower mowing height, canopy temperature increased as the N rate increased from 2.4 to 4.9 g N m^{-2} and then steadily decreased as the N rate increased. At the higher mowing height, canopy temperature decreased when N rate increased from 2.4 to 7.3 g N m^{-2} but increased slightly when the N rate was increased to 9.8 g N m^{-2}. These responses are not unexpected, since evapotranspiration (ET) in a turf system has been shown to have a cooling effect and this would be expected to increase as shoot growth is increased, either due to N or mowing height (Fig 4-4). In addition, poor turf often did not fill the whole tub leaving exposed soil which would lead to increased canopy temperature. Throssell et al. (1987) found that well-watered Kentucky bluegrass turf had lower canopy temperature than slightly stressed turf and that moderately stressed turf had the highest temperatures.

Chlorophyll Index

The Chlorophyll Index (CI) increased with increasing N rates (Table 4.5). In all FCs, chlorophyll readings were highest for the turf that received 9.8 g N m^{-2} and lowest in the turf receiving 2.4 g N m^{-2} treated turf (Fig.4.5). This response to N is logical, since higher N rates produce more chlorophyll, which is the green pigment that induces green-up of turf. This research agrees with Madison and Anderson (1963), who reported that increasing N rate, increased the chlorophyll index significantly in Seaside bentgrass (*Agrostis palustris* Huds “Seaside”).

There were differences in CI due to mowing height in FC1 and when averaged throughout the cycles. Chlorophyll index increased at higher mowing heights.

Correlation

Growth index NDVI had strong associations with color (*r* = 0.73) (Table 4.6 and Fig. 4.6) and quality (*r* = 0.75). Stress2 had strong negative associations with color and quality with limited association between Stress1 and quality and color. Previous research has shown that Stress2 is the more reliable indicator of quality and color in bermudagrass and seashore paspalum (Trenholm et al., 1999). These results indicate that these indices, particularly Stress2, can alternatively be used to indicate qualitative factors as well as responses to stress (Carter, 1994; Carter and Miller, 1994).

NDVI had strong negative associations with canopy temperature and CI (*r = -0.68* and *r = 0.77* respectively) (Table 4.7 and Fig. 4.7). There was a slight association between canopy temperature and Stress1 (*r=0.43*) and stronger association with Stress2 (*r=0.73*).

Conclusions

From the results of this research, we conclude that some instrumentation may provide an indication of the physiological functioning of the turfgrass. Spectral reflectance readings at some of the visible range wavelengths can be useful in determining health, cover, and stress level of the turfgrass. Indices NDVI and Stress2 appear to have the best potential for determination of stress symptoms. Canopy temperature and chlorophyll may have some ability to indicate stress or health in a turfgrass system.

Field plot research should be conducted to determine if similar results would be found outside of a controlled greenhouse setting.

Table 4-1. Multispectral reflectance values of Floratam St. Augustinegrass in a greenhouse experiment in response to N rates and mowing heights in FC1.

N-rate	WV450	WV550	WV660	WV694	WV710	NDV1	Stress1	Stress2
2.4	2.54	7.88	5.51	7.75	9.36	0.73	0.35	0.31
4.9	3.00	9.59	6.62	9.44	12.23	0.78	0.31	0.28
7.3	2.66	8.93	5.81	8.06	10.61	0.79	0.27	0.24
9.8	3.00	9.29	6.44	8.88	12.58	0.80	0.27	0.24
Mow Ht								
7.6	3.24a*	9.86	7.33a	9.70	13.18	0.74	0.32	0.29
10.2	2.35b	7.98	4.86b	7.37	9.20	0.81	0.30	0.25
ANOVA								
N-rate	NS	NS	NS	NS	NS	0.0003	<.0001	<.0001
Mow Ht	0.03	NS	0.04	NS	NS	<.0001	<.0001	0.0003
N-rate×Mow Ht	NS	NS	NS	NS	NS	0.03	0.002	0.001

*Means followed by the same letter do not differ significantly at the 0.05 probability level. Means are averaged for fertilizer cycles.

Table 4-2. Multispectral reflectance values of Floratam St. Augustinegrass in a greenhouse experiment in response to N rates and mowing heights in FC2

N-rate	WV450	WV550	WV660	WV694	WV710	NDV1	Stress1	Stress2
2.4	4.62	12.15b*	9.79	12.63	18.89	0.64b	0.47	0.46a
4.9	4.05	10.71b	7.87	10.53	17.19	0.70a	0.41	0.46a
7.3	3.30	9.33b	6.08	8.24	13.71	0.73a	0.50	0.37ba
9.8	5.53	17.95a	13.99	18.69	24.66	0.73a	0.39	0.33b
Mow Ht								
7.6	4.65	12.69	10.09	13.06	19.14	0.68b	0.45	0.43
10.2	4.09	12.38	8.78	11.98	18.08	0.72a	0.43	0.38
ANOVA								
N-rate	0.014	0.002	0.002	0.006	0.042	0.0006	NS	0.01
Mow Ht	NS	NS	NS	NS	NS	0.03	NS	NS
N- rate×Mow Ht	0.03	NS	0.02	0.05	0.03	NS	NS	NS

*Means followed by the same letter do not differ significantly at the 0.05 probability level. Means are averaged for fertilizer cycles.

Table 4-3. Multispectral reflectance values of Floratam St. Augustinegrass in a greenhouse experiment in response to N rates and mowing heights in FC3

N-rate	WV450	WV550	WV660	WV694	WV710	NDV1	Stress1	Stress2
2.4	3.83	11.23	9.70	13.60	16.57	0.69	0.41	0.43a*
4.9	3.99	12.31	11.14	15.15	18.08	0.70	0.55	0.36b
7.3	3.32	10.71	8.64	11.75	15.96	0.75	0.39	0.31b
9.8	3.51	10.68	8.69	12.32	15.92	0.74	0.44	0.34b
Mow Ht								
7.6	3.84	11.35	10.05	14.20	16.69	0.72	0.47	0.36
10.2	3.49	11.11	9.03	12.21	16.56	0.73	0.43	0.36
ANOVA								
N-rate	NS	NS	NS	NS	NS	NS	NS	0.005
Mow Ht	NS	NS	NS	NS	NS	NS	NS	NS
N- rate×Mow Ht	NS	NS	NS	NS	NS	NS	NS	NS

*Means followed by the same letter do not differ significantly at the 0.05 probability level. Means are averaged for fertilizer cycles.

Table 4-4. Canopy temperature reading (°C) of Floratam St. Augustinegrass in a greenhouse experiment in response to N rates and mowing heights

N-rate	Cycle 1	Cycle 2	Cycle 3	Average
2.4	32.2a*	32.2a	36.7	34.0a
4.9	31.5b	32.1a	36.4	33.4ba
7.3	30.8b	30.8b	36.0	32.5bc
9.8	30.9b	30.5b	35.8	32.4c
Mow Ht				
7.6	32.2a	31.1	36.4	33.3
10.2	30.9b	31.6	36.1	32.9
ANOVA				
N-rate	0.017	0.014	0.011	0.001
Mow Ht	0.034	NS	NS	NS
N- rate×Mow Ht	NS	NS	0.02	NS

*Means followed by the same letter do not differ significantly at the 0.05 probability level. Means are averaged for fertilizer cycles.

Table 4-5. Chlorophyll reading Floratam St. Augustinegrass in a greenhouse experiment in response to N rates and mowing heights

N-rate	Cycle 1	Cycle 2	Cycle 3	Average
2.4	218.37b*	156.43c	201.00b	191.93b
4.9	226.43b	190.06b	215.75b	210.75b
7.3	288.68a	241.56a	240.5a	256.91a
9.8	296.00a	256.06a	254.81a	268.96a
Mow Ht				
7.6	230.81b	211.09	223.75	221.88b
10.2	283.93a	210.96	232.28	242.39a
ANOVA				
N-rate	<0.0001	<0.0001	0.0004	<0.0001
Mow Ht	<0.0001	NS	NS	0.012
N- rate×Mow Ht	NS	NS	NS	NS

*Means followed by the same letter do not differ significantly at the 0.05 probability level. Means are averaged for fertilizer cycles.

Table 4-6. Correlation matrix of visual color and quality (from chapter 3) with reflectance values of Floratam St. Augustinegrass in a greenhouse experiment

	Color	Quality	WV 450	WV 550	WV 660	WV 694	WV 710	NDVI	Stress1	Stress2
Color	1.00	0.96	-0.12	0.09	-0.09	-0.03	-0.03	0.73	-0.27	-0.75
Quality	0.96	1.00	-0.11	0.11	-0.09	-0.02	-0.01	0.75	-0.25	-0.75

Table 4-7. Correlation matrix of canopy temperature (CT) and chlorophyll index (CI) with reflectance values of Floratam St. Augustinegrass in a grass experiment

	CT	CI	WV 450	WV 550	WV 660	WV 694	WV 710	NDVI	Stress1	Stress2
CT	1.00	-0.81	0.34	0.16	0.27	0.18	0.21	-0.68	0.43	0.63
CI	-0.81	1.00	-0.21	0.01	-0.19	-0.13	-0.08	0.77	-0.37	-0.76

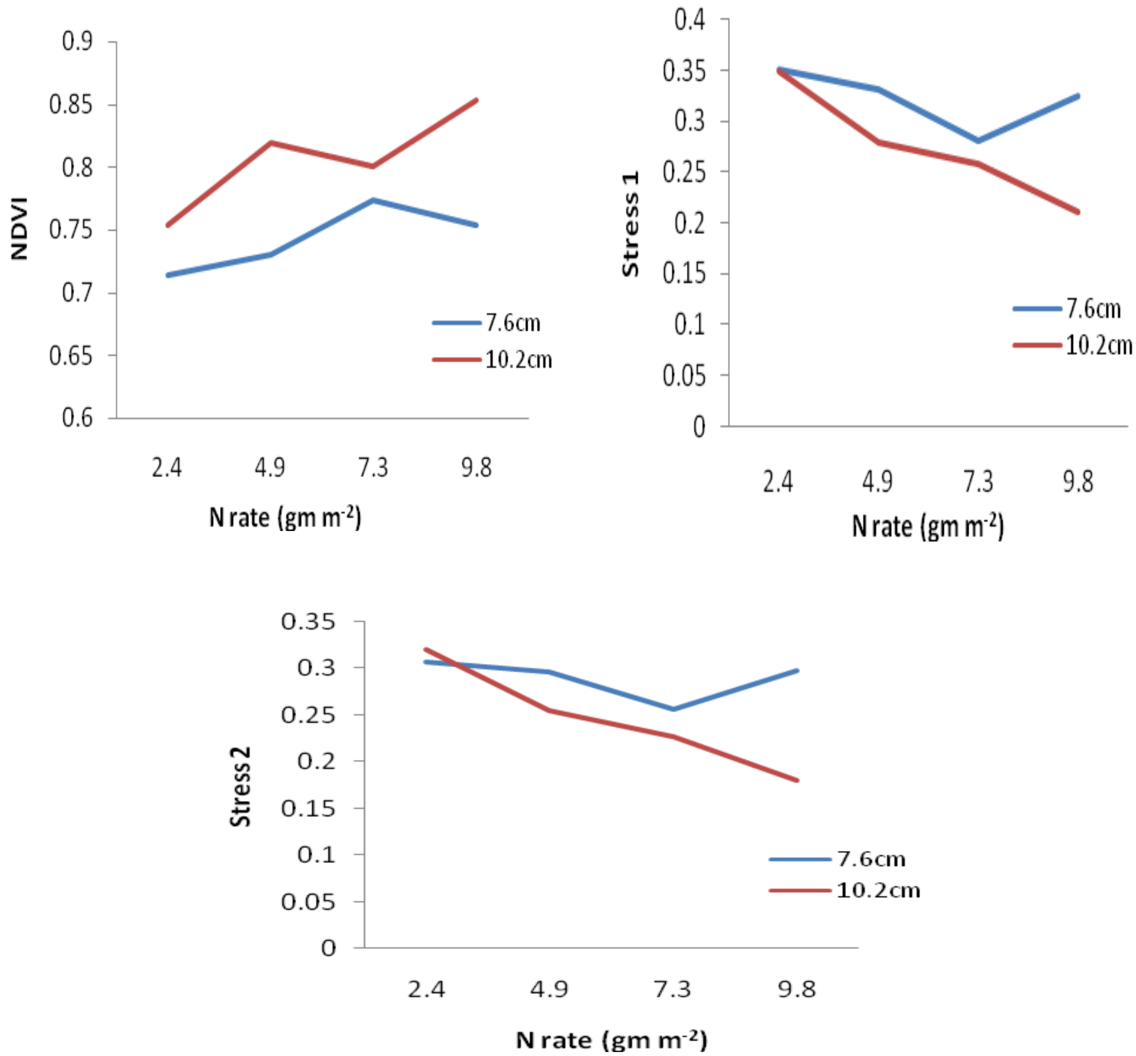


Figure 4-1. Interaction between N rate and mowing height of Floratam St. Augustinegrass in a greenhouse experiment with respect to (a) NFVI (b) Stress1 (c) Stress2 during FC1

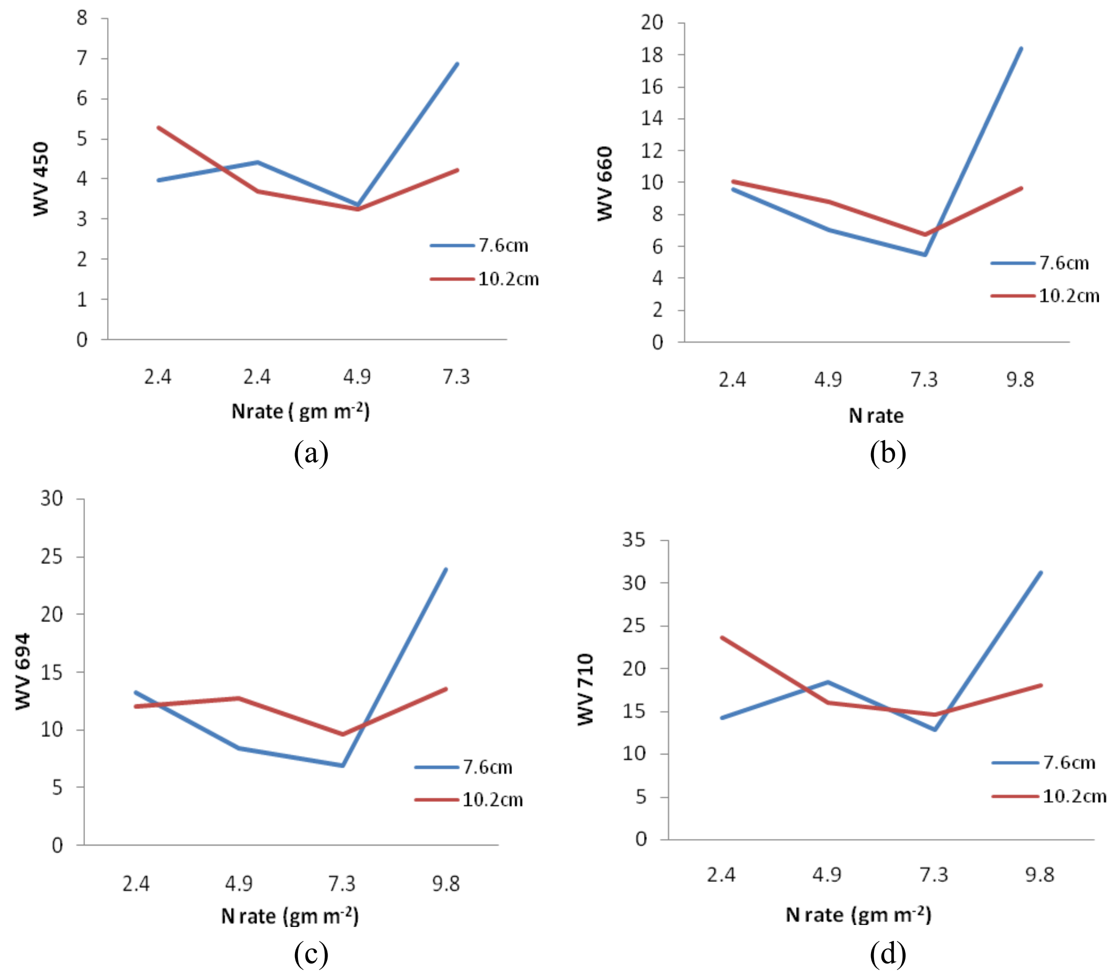


Figure 4-2. Interaction between N rate and mowing height of Floratam St. Augustinegrass in a greenhouse experiment with respect to MSR at different wavelengths in FC2. (a) 450nm (b) 660nm (c) 694nm (d) 710nm

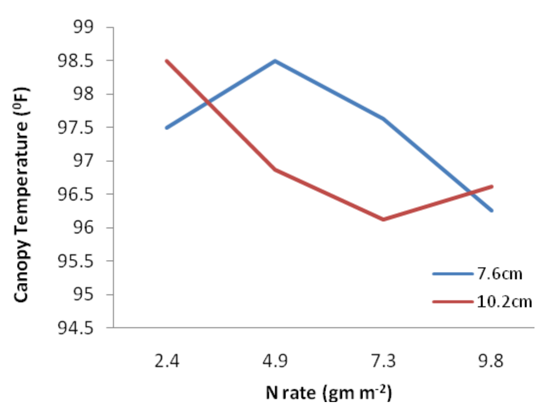


Figure 4-3. Interaction between N rate and mowing height of Floratam St. Augustinegrass in a greenhouse experiment with respect to canopy temperature during FC3

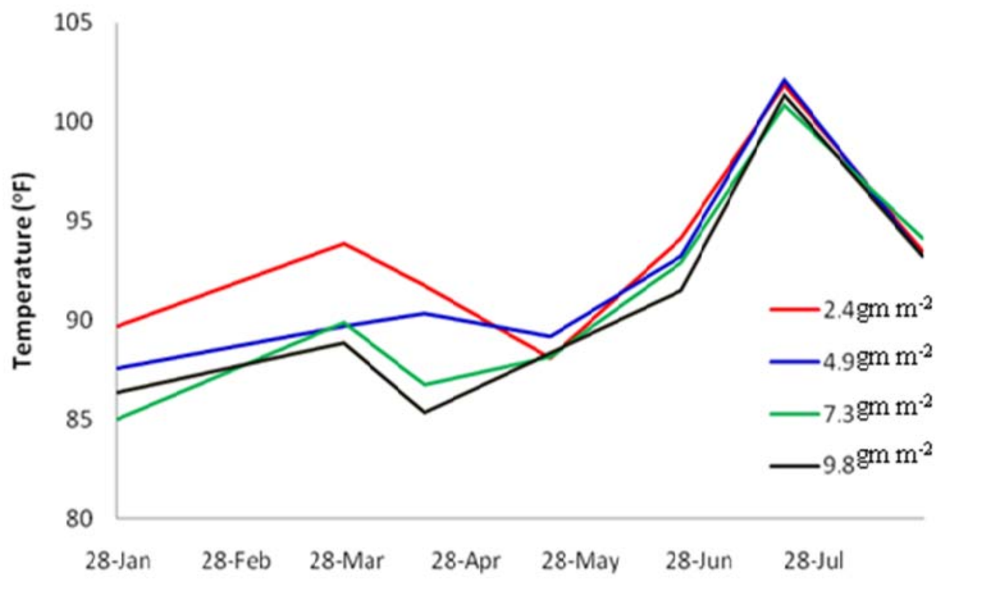


Figure 4-4. Average canopy temperature (°F) of Floratam St. Augustinegrass in a greenhouse experiment with different N treatments during the study period

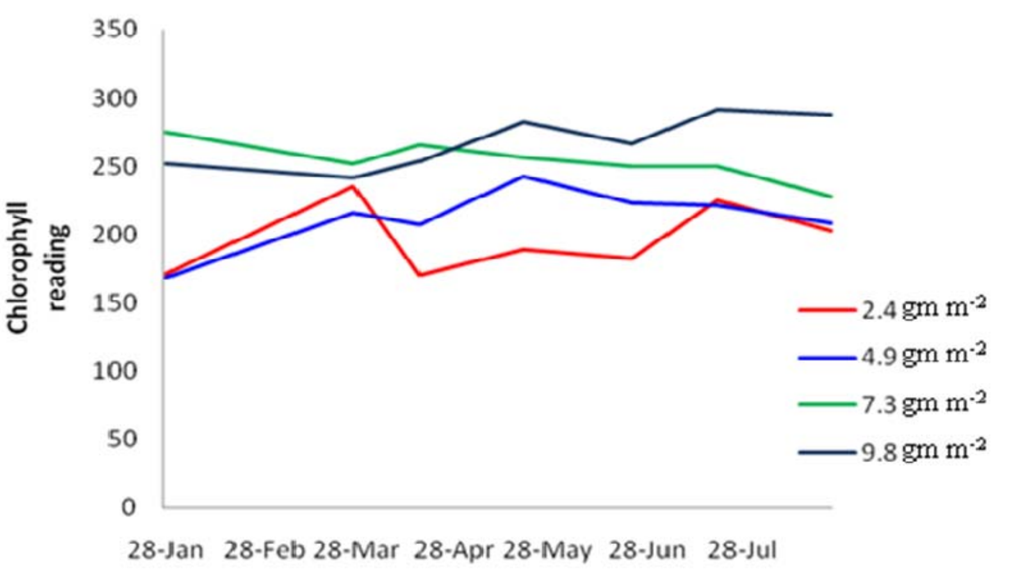


Figure 4-5. Average chlorophyll readings of Floratam St. Augustinegrass in a greenhouse experiment with different N treatments during the study period

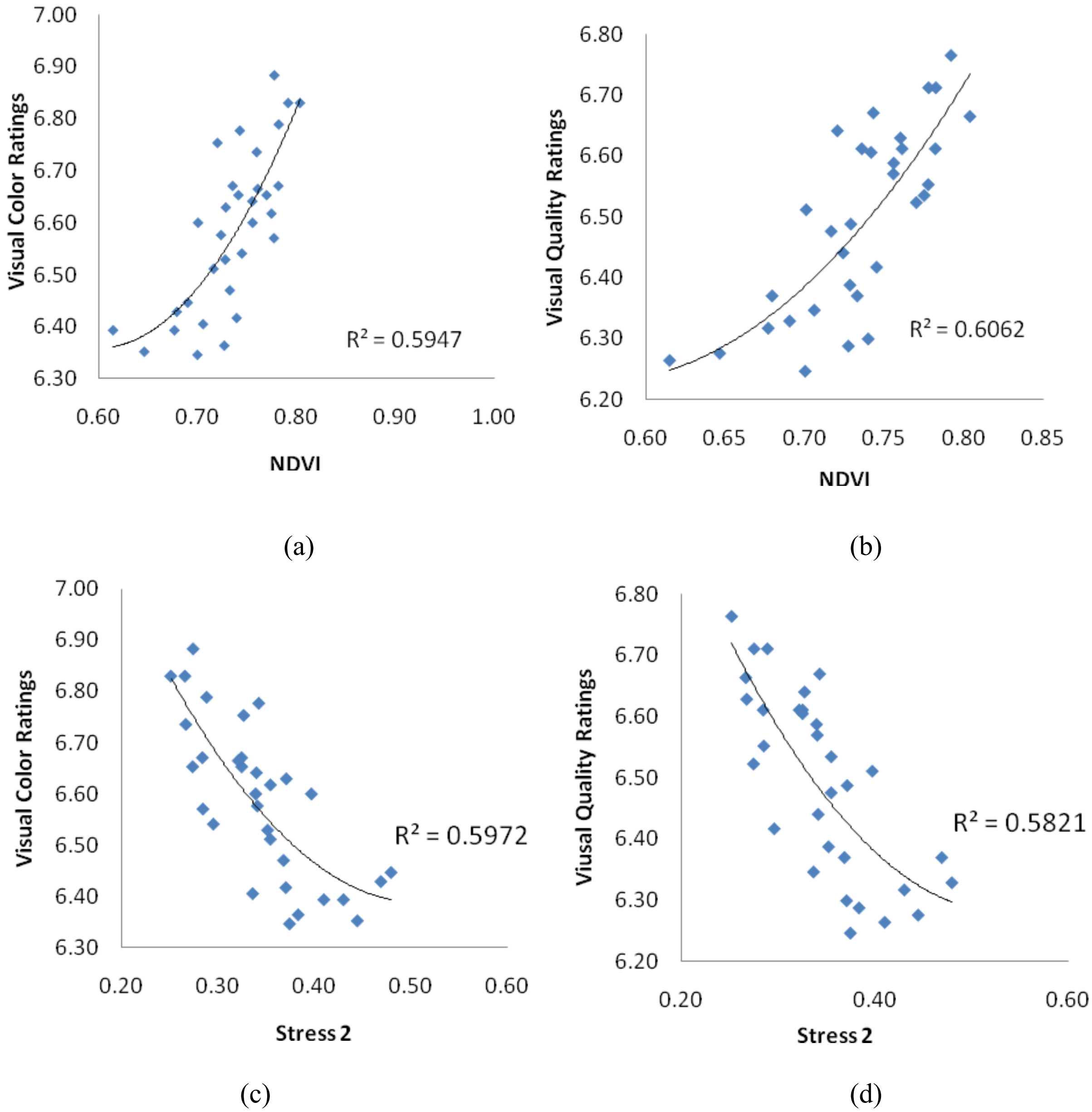
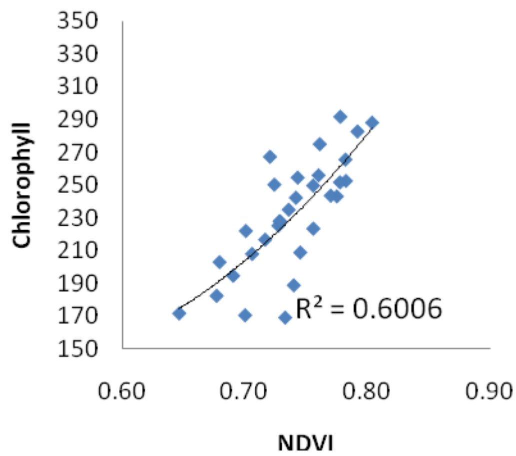
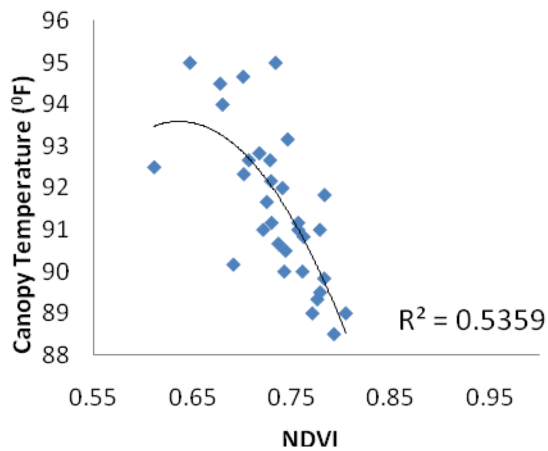
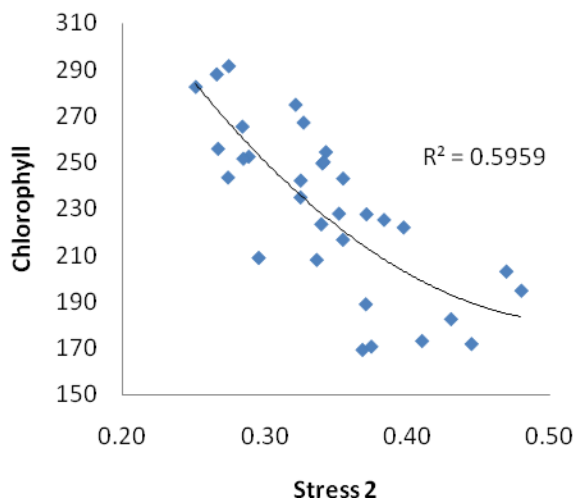


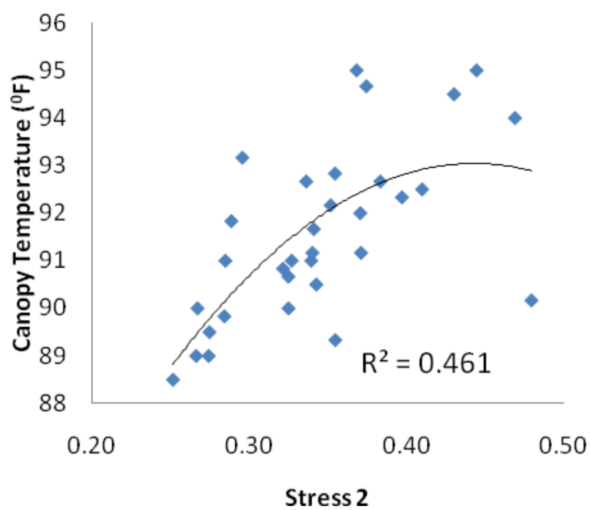
Figure 4-6. Relationships between visual color and quality of Floratam St. Augustinegrass in a greenhouse experiment with different reflectance ratios. (a)NDVI and color (b) NDVI and quality (c) Stress2 and color (d) Stress2 and quality





(a) (b)





(c) (d)

Figure 4-7. Relationship of canopy temperature and chlorophyll index with reflectance ratios of Floratam St. Augustinegrass in a greenhouse experiment (a) NDVI and chlorophyll (b) NDVI and canopy tempertature (c) Stress2 and chlorophyll (d) Stress2 and canopy temperature

CHAPTER 5
CONCLUSIONS

Four different N rates and two mowing height treatments were studied for their effects on NO_3-N leaching, turf visual color and quality, chlorophyll index, canopy temperature, and multispectral reflectance in Floratam St. Augustinegrass. From the results of this research, we conclude that even at high N rates and low mowing heights, healthy turfgrass can absorb virtually the entire applied N, with very low NO_3-N leaching rates. When the turfgrass was in poor condition and injured by insects in FC3, it did not absorb N as well as when it was growing in a healthy condition.

Grass maintained at a higher mowing height leached less N than when mowed at a lower height. High NO_3-N leaching peaks were observed after the fertilization events, which supports the potential for leaching of quick release fertilizers such as urea if applied at higher N rates. Higher N rates and higher mowing heights produced better quality turfgrass and increased shoot growth but do not compensate enough to reduce NO_3-N leaching. Additionally, higher NO_3-N leaching losses may occur at lower mowing heights due to less shoot and root tissue to take up the N. Recommended mowing heights should be followed for optimal turfgrass health and mitigation of nutrient leaching.

Some instrumentation may provide an indication of the physiological functioning of the turfgrass. Spectral reflectance readings at some of the visible range wavelengths can be useful in determining health, cover, and stress level of the turfgrass. Indices NDVI and Stress2 appear to have the best potential for determination of stress symptoms in turfgrass. Canopy temperature and CI may have some ability to indicate stress or health in a turfgrass system.

The results obtained from this study indicate responses under controlled environmental conditions. Therefore, recommendations for a natural landscape cannot be made based solely on these findings. However, these results indicate that the amount of N loss from St. Augustinegrass can be lowered or minimized if they are maintained at higher mowing heights and lower N levels.

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BIOGRAPHICAL SKETCH

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