ROLE OF NITROGEN AND CLIPPING-RETURN ON TURF GROWTH AND NITRATE LEACHING IN ZOYSIAGRASS (*Zoysia japonica* Steud.)

By

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To My Lovely Wife

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ROLE OF NITROGEN AND CLIPPING-RETURN ON N BALANCE AND NITRATE LEACHING IN ZOYSIAGRASS (*Zoysia japonica* Steud.)

By

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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 clipping management on nitrate (NO_3-N) leaching of Empire zoysiagrass and to evaluate the response of N rates and clipping management on the turf quality and physiological responses.

The field experiment was conducted at the University of Florida Plant Science Research and Education Center in Citra, Florida on Empire zoysiagrass. The grass was established in March 2008 in sandy loam soil (Hyperthermic, uncoated, Quartzipsamments in the Candler series) and the study was conducted from June to October 2008.

This research provides information about the effect of CM and N rate on NO_3-N leaching, shoot growth, TKN concentration, N uptake, quality, and chlorophyll level.

Returning clippings decreased turf quality, chlorophyll content than removing clippings. Empire zoysiagrass showed higher NO_3-N leaching than St. Augustinegrass from previous research (Sharma el al., 2009). Total NO_3-N leachate from CRT ranged 114.6 to 7379.1 mg m^{-2}

and 123.1 to 1537.6 mg m^{-2} from CRM. The average concentration of NO_3-N leaching ranged 0.23 to 6.47 mg L^{-2}. The highest N rate (294 kg N ha^{-1}) produced significantly greater NO_3-N leaching compared to the other N rates. To avoid NO_3-N leaching, it is important to apply N at rates below 196 kg N ha^{-1} at each application.

In addition, NO_3-N leaching was significantly correlated with rainfall. These results would indicate that exceeding the currently recommended N fertilization rates may contribute to NO_3-N leaching during raining summer season (June to Aug) in Florida.

MSR data at varying wavelengths did not differ due to CM. However, responses of growth and stress indices were significant due to CM. The CRT showed less turf growth and higher stress than CRM treatment through entire experiment period. Stress indices were also lower under higher N rates throughout the experiment. Growth and stress indices such as NDVI, Stress, and IR/R showed significant and consistent linear correlation with all evaluations used in this study.

These results generally contradict previous studies on CM, which reported positive results of clipping-return on NO_3-N leaching in research conducted on cool-season grasses.

CHAPTER 1
INTRODUCTION

Nitrogen Physiology in Turf

There are many sources of nitrogen (N) in our environment, some of which are available for plant use. The atmospheric is about 80% N, although it is not readily usable by plants in the element form. The N content of surface mineral soil ranges from 0.02 to 0.5% (Brady, 1990), and may be available to plants, depending on the form in which it is stored in the soil. Nitrogen is one of the major mineral nutrients required by plants, providing the building blocks for growth and physiological functioning. Nitrogen is a component of amino acids, nucleic acids, chlorophyll, and enzymes. Nitrogen also stimulates plant shoot and root growth and development, and is essential for carbohydrate use in plants. In general, higher rates of fertilization with N deliver better quality of turf, regardless of fertilizer sources (Heckman et al., 2000). Both organic and inorganic fertilizers have similar effects on warm-season turfgrass systems (Trenholm and Unruh, 2005b).

Turfgrass absorbs N as ammonium (NH_4^+) or nitrate (NO_3^-). Nitrate and NH_4^+ are typically present at similar concentrations in soil (Hull and Liu, 2005). However, in soil water, NO_3^- concentration is five to ten times higher than that of NH_4^+ (Bowman et al. 1989; Hull and Liu, 2005). Because soil is negatively charged, the cationic NH_4^+ ions are attracted to cation exchange sites, and remain at a relatively lower rate in the soil solution. The NO_3^- ions move freely in the solution due to the repulsion by soil particles. Thus, turfgrass roots absorb less NH_4^+ because of the immobility of NH_4^+ in soil (Below, 2001) and primarily take up N as the NO_3^- form.

Both NO_3^- and NH_4^+ forms are rapidly absorbed by plant roots. Bowman et al. (1989) demonstrated this by applying 5 g N m^{-2} of NO_3^- and NH_4^+ to separate field plots of Kentucky bluegrass (*Poa pratensis* L.). After 24 hours, only 20 to 30% of both NO_3^- and NH_4^+ could be extracted from the soil-thatch phase of the turf. None of the N applied could be extracted in either form after 48 hours.

Uptake of most nutrients, including nitrogen, occurs mainly through root hairs, which can effectively absorb water and nutrients via their enlarged surface area (Bloom et al., 2003). Root hairs enhance root capacity to take up immobile nutrients such as phosphate and NH_4^+ (Hull and Liu, 2005). A dense of fibrous root, which can improve competition for N against soil microbes, is also an important strategy for uptake of immobile ions in soil (Jackson et al., 2008)

Water and Nitrogen Leaching

Water is essential for the survival and maintenance of life. Fresh water consists of surface and groundwater, the latter constituting 97% of the sources for global drinking water.

According to the US Environmental Protection Agency (EPA), excessive nitrate concentration in drinking water has caused severe illness and even death in infants less than six months of age (EPA, 2006). Nitrate is converted to nitrite in the mammalian body, and this process rapidly reduces the oxygen-carrying capacity in the blood stream of children. A 'blue baby' syndrome occurs. Thus, EPA set the drinking water standard at 10 ppm for nitrate and 1 ppm for nitrite (EPA, 2006). Elevated levels of nitrate in drinking water can also cause serious health issues in adults. Some of these include methemoglobinemia, cancer, neurological effects, or abortion (Gupta et al., 2008; EPA, 2006). Nitrate levels in groundwater remain stable over time and a measurement of nitrate in water can indicate longer periods of exposure (Ruckart et al., 2008). Thus, this stable nature of nitrate causes a reduction in the safety of our environment and health. In addition, nitrogen is one of the nutrients most often identified in stormwater runoff, which picks up surface pollutants and carries them along as the water reenters the ground or surface water system (FDEP, 2007). In surface waters, nitrogen in stormwater can also lead to heavy algae growth, eutrophication and low dissolved oxygen levels as a non-point source pollution (Shaver et al., 2007), which has led to the initiation of Best Management Practices (BMPs) (Trenholm et. al., 2002). The Florida Green Industries BMPs have been developed to minimize nonpoint source pollution resulting from fertilization while providing education on fertilizer management to the landscape maintenance industries of Florida since 2003. The program funded by the Florida Department of Environmental Protection (FDEP) helped the commercial lawn and landscape industry to increase awareness regarding nutrient leaching and runoff. (FDEP, 2007; Trenholm, 2007).

Fertilizers, when used properly, can maintain the health and quality of turf. Nitrogen is the element required in greatest quantity by turf for healthy growth and functioning (Trenholm and Unruh, 2005a). In most cases, slow-release N sources can reduce the potential loss of N relative to water-soluble, quick-release N sources (Saha et al, 2007; Heckman et al., 2000).

Rooting patterns (depth) can reduce the total amount of NO_3^-N leachate from the soil. Deep-rooted turf absorbs N more efficiently than shallow-rooted turf (Bowman el al. 1998). Nitrate leaching from turf has been shown to increase as rates of applied N become excessive (Morton et al., 1988; Kopp and Guillard, 2005; Frank et al., 2006).

Lee et al. (2003) evaluated the influence of fertilization and mineralization on soil nitrate level in bermudagrass (*Cynodon spp.*) systems established on 50- and 70-year-old golf courses. Results indicated that NO_3-N levels were consistently low (below 4 mg kg^{-1} soil) and similar to the N level of an adjacent natural area. They also found that soil nitrate levels under different fertilization regimes were not significantly different from those in adjacent, nonfertilized areas.

Bowman et al. (2002) compared NO_3-N leaching and N use efficiency among six warm-season grasses under greenhouse condition for one year. They analyzed NO_3-N and NH_4-N in samples of leachate and clippings. St. Augustinegrass (*Stenotaphrum secundatum* (Walt.) Kuntze) was most efficient at minimizing NO_3-N leaching, and 'Meyer' Zoysiagrass (*Zoysia japonica* Steud) was least efficient at minimizing NO_3^-N leaching. Species selection is thus an important factor for reduction of NO_3^-N leaching from turfgrass systems. The N leaching rate also depends on plant species. Erickson et al. (2001) reported the difference of N leaching between St. Augustinegrass and a mixed-species landscape. They concluded that N leaching loss was significantly greater on the mixed-species landscape (48.3 kg N ha^{-1}) than St. Augustinegrasss (4.1 kg N ha^{-1}). On the contrary, there is a study to suggest that management practices is more important than species composition for reducing N leaching from residential land use (Erickson et al., 2008). Through St. Augustinegrass (SA) and a mixed-species landscape (MS), Erickson et al.(2008) observed that cumulative N leaching for 3 yr was 4.1 kg ha–1 and 7.4 kg ha–1 for the SA and MS landscapes, respectively. The MS had significantly greater inorganic-N leaching (5.2 kg ha^{-1}) in year 1 of the study compared to the SA landscape (1.3 kg ha^{-1}). However, after year 1, inorganic-N leaching was comparable on both landscapes, and was low (<2% of applied N) on both landscapes following establishment.

The ability of grass to take up N depends on age. Miltner et al. (1996) examined the fate of heavy isotope ^{15}N applied to Kentucky bluegrass, which had been established one year before the experiment. Urea-N was applied at an annual total rate of 196 kg N ha^{-1}. In general, the NO_3-N in leachate was below 1 mg N L^{-1}, and only 0.23% of applied labeled fertilizer N was collected in leachate. Frank et al. (2006) conducted an experiment similar to that of Miltner et al. (1996), but modified the design by using 10-year-old Kentucky bluegrass and two fertilizer treatments with an annual rate of 98 and 245kg N ha^{-1}. The NO_3-N in the leachate at the low rate (98 kg N ha^{-1}) was typically below 5 mg L^{-1}, whereas the NO_3-N concentration at the high rate

(245 kg N ha^{-1}) was often greater than 20 mg L^{-1}. The latter value is 2 times greater than the EPA standard for drinking water.

Empire Zoysiagrass

Zoysiagrass (*Zoysia* spp. Willd.) originated from the Orient (Christians, 2007) with ten species, which include Korean (or Japanese) lawngrass (*Zoysia japonica* Steud.), which is the most widely used species in the United States (Christians, 2007). *Zoysia japonica* is well adapted to use on golf courses fairways and tees as well as homelawns, because it has excellent cold tolerance (Trenholm and Unruh, 2005a), fair shade, and salinity tolerance (Christians, 2007). It also grows well to traffic and droughty conditions while maintaining relatively low level of disease and insect damage (Christians, 2007). 'Empire' zoysiagrass is a native proprietary selection of *Zoysia japonica*. It has performed well in sandy and clay soils with dark and green in color and a wide leaf blade (Trenholm and Unruh, 2005a).

Clipping Management

Turf shoot clippings have often been considered a nuisance product to dispose of, although the clippings contain abundant nutrients and are a source of organic matter. Removing clipping from turf causes N loss from the system. Starr and DeRoo (1981) examined the various effects of clipping-return while evaluating the fate of N fertilizer with Kentucky bluegrass mix (*Poa pratensis* L.) and creeping red fescue (*Festuca rubra* L.). The study spanned 3 years and used a suction lysimeter with ^{15}N labeling to trace the fate of N from clippings and fertilizer. Return of clippings to the turf increased the total N uptake of the harvested grass by 19, 41, and 74% for the 3 consecutive years of the experiment. In the clipping returned treatment, yield and growth of the grass increased by about 30%. The tissue N concentration from clipping-removed treatment was derived equally from soil and fertilizer, whereas the tissue N concentration from clipping-returned treatment was derived from equal amounts of N from soil, fertilizer, and clipping-return. Nitrate-nitrogen concentrations in the leachate on average were 1.9 mg L^{-1} for clipping-removed and 2.0 mg L^{-1} for clipping-returned treatment, indicating that NO_3-N leaching was not significantly reduced by clipping treatments.

To reduce nitrate leaching, returning clipping has potential importance in turf management. Liu and Hull (2006) investigated overall growth and N recovery from clippings using 10 cultivars each of three cool-season grasses (kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), and tall fescue (*Festuca arundinacea* Schreb.) under field condition. All turf was maintained under an N fertilization rate of 147 kg N ha^{-1} $year^{-1}$ for two growing seasons (May through October). Clipping yields ranged from 5,152 kg dry weight ha^{-1} for tall fescue and 3,680 kg ha^{-1} for perennial ryegrass. In terms of N recovery, Kentucky bluegrass had greater recovery than tall fescue, and perennial ryegrass. Total N recovered from clippings exceeded the amount of N applied as fertilizer, ranging from 260 to 111 kg N ha^{-1} yr^{-1}.

Clippings alone were shown to be an effective N source for turf maintenance when clippings were provided from well fertilized turf (Bigelow et al., 2005). Tall fescue (*Festuca arundinacea* 'Rebel') was treated with 0, 1, 2, 3, or 4 plot-equivalents of clippings from adjacent donor plots treated with 220 kg N ha^{-1} $year^{-1}$ for two growing seasons. During the first year of the research, N recovery from clippings was linear, and all turf plots showed N deficiency, regardless of how many clippings were returned. However, in the second year, N recovery demonstrated a quadratic response, with tissue N maintained adequately in instances where clippings applications were highest.

Little research has been directed towards the ‘clipping-return’ effect on turf quality or N-use efficiency. Heckman et al. (2000) examined the effect of returning clippings to Kentucky bluegrass by using a mulching mower for 4 years (1994-1997). Results suggested that clipping-return treatment improved color of the turf and reduced need for N fertilization by 50%. In addition, Heckman et al. (2000) found that the use of slow-release fertilizer reduced the problem of turf quality such as unsightly clippings or undesirable growth surge. Kopp and Guillard (2002a) examined the response of turf growth and quality to clipping-return at varying rates of N fertilization. Two clipping management strategies (removed or returned) and four N fertilization rates (0, 98, 196, and 392 kg N ha^{-1}) were compared. The clipping-returned treatment enhanced clipping dry matter from 30 to 72%, and increased total N uptake from 48 to 60%. Also, N-use-efficiency increased from 52 to 71%. The authors concluded that N fertilization rate could be reduced at least 50% while maintaining turf quality if grass clippings were returned.

The question of whether clippings contribute to thatch was considered a negative effect of clipping-return. Research has shown that thatch is accumulated not by grass clippings, but rather, from roots, horizontal stems (stolons and rhizomes), and mature sheaths and blades (McCarty et al., 2007). Soper et al. (1998) found that returning clippings increased thatch by 3.4% and decreased the tiller density by 12% in ‘Meyer’ Zoysiagrass (*Zoysia japonica* Steud). The reduction of tiller density may be due to shading effects of clippings within the turf canopy. Clipping removal was not recommended for thatch control because of the benefits provided by clippings as a nutrient source. (Soper et al. 1998)

Qian et al. (2003) applied an ecosystem model, and used this to predict long-term effects of clipping management and NO_3-N leaching. Prior to long-term prediction, 3 years of field research with Kentucky bluegrass (*Poa pratensis* L.) was used to generate the predictions. Results indicated that when the clippings were returned, N fertilizer requirements would be reduced by 25% during the first of 10 years after turf establishment, by another 50% from 25 to 50 years, and by 60% after 50 years.

Most studies on the effects of clipping-return have focused on cool-season grasses, with comparatively little work on warm-season grasses. Sartain (1993) conducted a 3-year comparison of response to clipping-return by ‘Tifway’ bermudagrass (*Cynodon dactylon* (L.) Pers. X *Cynodon transvaalensis* Burtt Davy) overseeded with ‘Pennant’ perennial ryegrass (*Lolium perenne* L.). When clippings were returned, the clipping yield of both species increased, but turf quality was enhanced only in bermudagrass. Thatch accumulation was not affected by clipping-return (Sartain, 1993).

Kopp and Guilard (2005) examined the relationship between clipping treatment and NO_3-N leaching over a 30-week period for creeping bentgrass (*Agrostis stolonifera* L.) under greenhouse conditions. Treatments consisted of four rates of N fertilization (equivalent to 0, 98, 196, and 392 kg N ha^{-1}), two clipping management strategies (removed or returned), and two irrigation regimes (standard or standard + precipitation). Clipping-return treatments increased both NO_3-N concentration and mass losses of N in percolating soil water. Effects were greater with increased rates of N application and irrigation. When clippings were removed, the percentage loss for applied N was 0.9 to 7.6% for the standard irrigation treatment, and 14.3 to 41.8% for the (standard + precipitation) irrigation treatment. However, when clippings were returned, the percentage loss of applied N was 12.8 to 23.6% for standard irrigation and 39.2 to 62.9 % for the (standard + precipitation) irrigation. The authors did not report on effects of clipping management on turfgrass quality and growth.

This result was contrary to that of Starr and DeRoo (1981) who concluded that the effect of clipping treatments on NO_3-N leaching was negligible. The fertilizer used in the experiment by Kopp and Guillard (2005) was water-soluble inorganic NH_4NO_3,, while Starr and DeRoo (1981) used ureaformaldehyde, an organic, slow release N source. The different N sources may have contributed to the difference in NO_3-N leached.

Apparently, clipping-return can play a substantial role in reducing N fertilizer use in cool-season turfgrasses and maximizing the efficiency of N use in turf. Returning clippings to turfgrass can be a solution for more efficient, environmentally-sound fertilizer use when applied with adequate amount of N fertilizer.

The majority of the research looking at clipping effects has focused on cool-season grasses rather than warm-season grasses. Thus, the objective of this research was to evaluate the NO_3-N leaching, turf growth, quality, and spectral reflectance of 'Empire' zoysiagrass due to N rate and clipping management.

MultiSpectral Reflectance (MSR)

Qualitative measurement such as quality and color are commonly utilized in turfgrass research to compare or assess turf growth and health (Turgeon, 1991; Heckman *et al*., 2000). Recently multispectral radiometry has been used to quantitatively distinguish between stressed and non-stressed plants (Carter, 1993; Carter and Miller, 1994) including turfgrass (Trenholm *et al*., 1999a and 1999b). Thus, multispectral radiometry can quantitatively provide information on overall health, growth and vigor of turfgrass. A multispectral radiometer measures the amount of light plant absorb at particular wavelengths, thereby indicating how the plant effectively uses photosynthetically active radiation (PAR).

Visible (VIS) and near infrared (NIR) regions of spectrum are useful range for determining plant response when a treatment applies. Leaf reflectance of PAR (400 to 700nm) is highly negatively correlated (r^2>0.97) with concentration of chlorophyll, so a healthy plant has relatively low reflectance of PAR (Trenholm, 2000). However, more than 700nm of reflectance is positively correlated with cellular water concentration in the leaf cell. Thus, a stressed plant has high reflectance value at the PAR range, and low reflectance value above 700nm (Trenholm et al, 1999a; Trenholm, 2000).

Asrar et al. (1984) showed that the ratios normalized difference vegetation index (NDVI), which computed as $(R_{935}-R_{661})/(R_{935}+R_{661})$, correlated well ($r^2=0.97$) with absorbed photosynthetically active radiation (APAR) in wheat (*Triticum aestivum* L.).

Trenholm et al. (1999a) reported the significance of spectral data as quantitative tool on seven seashore paspalum (*Paspalurn vaginaturn* Swartz) ecotypes and three hybrid bermudagrass *(Cynodon dactylon* L. X *C. trunsvaalensis* Burtt-Davy) cultivars. They concluded that NDVI, infrared/red (IR/R), Stress I (ST-1) (R_{706}/R_{760}) and Stress II (ST-2) (R_{706}/R_{813}) were highly correlated with visual quality, shoot density, and shoot tissue injury rating except with shoot growth (Trenholm et al. 1999a).

Relatively little information is available on the spectral responses for turfgrass system. Moreover, because of lack of research on the effect of clipping-return in warm-season grasses, the objectives of this study were to evaluate responses of zoysiagrass to N rate and clipping treatment using spectral data and to determine correlation between value of multispectral radiometer and other measurements such as quality, color and shoot growth.

CHAPTER 2
MATERIALS AND METHODS

A field experiment was conducted at the University of Florida Plant Science Research and Education Center in Citra, Florida on 'Empire' zoysiagrass (*Zoysia japonica* Steud.). The grass was established in March 2008 in sandy loam soil (Hyperthermic, uncoated, Quartzipsamments in the Candler series) and the study was conducted from June to October 2008.

Plots measured 4.0m x 4.0m. High-density polyethylene (HDPE) lysimeters were installed in the center of each plot, approximately 10 cm below the soil surface. Lysimeters measured 57 cm diam. and 88 cm in height with a volume of 168 L. Lysimeters were assembled by placing cylinders into a single piece galvanized steel base unit measuring 25.4 cm in height. A bulkhead fitting was inserted into the base of each unit, to which collection tubing (0.95 cm low density polyethylene) was attached. The tubing was run underground to central aboveground collection portals. Lysimeters were installed by boring and removing soil in 15.2 cm sections to a depth of 107 cm. Lysimeters were placed in holes and bases of the units were filled with washed egg rock (1.9 – 6.4 cm) for a volume of 38 L. The gravel was covered with fitted non-woven polyolefin cloth that was secured with a hoop of 1.3 cm HDPE tubing to reduce soil intrusion into the reservoir. Soil was replaced into the lysimeters as it had been removed from the soil profile. Soil was gently tamped with a tamping tool (17 kg and 858 cm^2) to approximate original soil bulk density.

Clipping-management (CM) and nitrogen (N) fertilizer treatments were as follows:

- CM #1 consisted of clipping-return, in which clippings were left in the experimental field after mowing with a conventional rotary mower.

- CM#2 consisted of clipping-removal, in which clippings were taken from the field by attaching a collection bag to the mower.

Mowing height was set at 6.3 cm (2.5 inches). The plots were mowed once a week throughout the study period.

Fertilizer treatments consisted of six levels of total N rates (equivalent to 0 lbs, 1 lbs, 2 lbs, 3 lbs, 4 lbs or 6lbs N 1,000 ft^{-2} yr^{-1} or 0 kg, 49 kg, 98 kg, 147 kg, 196 kg, or 294 kg N ha^{-1} yr^{-1}). Treatments were applied at 2-mo intervals for a total of two treatment applications. A 50% quick-release fertilizer (QRF) and 50% slow-release fertilizer (SRF) of 15N-0P-15K were used. The area was irrigated to replace evapotranspiration (ET) as needed to maintain healthy turf.

Turf was evaluated visually for quality and color, which was rated immediately after mowing. A scale of 1 to 9 was used, in which 9 represents optimal, dark green color and 1 represents dead, brown turf. A rating of 6 was considered minimally acceptable for a home lawn.

Soil moisture (SM), canopy temperature (CT), chlorophyll content (CC), and multispectral reflectance (MSR) were also measured. Soil moisture content was quantified weekly using a Time Domain Reflectometer (TRD) (IMIKO Micromodule Technik GmbH; Ettingen, Germany).

The CC was taken weekly using Field Scout CM-1000 Chlorophyll meter (Spectrum Technologies, Plainfield, IL). The measurement was taken at approximately 1.2 m from the turf canopy. This provided an evaluation of circular area approximately 144 cm^2 per measurement.

The CT was also taken weekly with a Raytek Raynger infrared thermometer (Raytek, Santa Cruz, CA). Temperature was averaged with three random points in each plot.

The MSR was measured six times at 1, 3, and 6 weeks after first N treatment, and at 1, 3, and 5 weeks after second N treatment using a Cropscan model MSR 16R (CROPSCAN, Inc., Rochester, MN). The radiometer was fitted with filter wavelengths to measure reflectance at 450, 550, 660, 694, 710, 760, 810, and 930 nm. In addition, the following growth and stress indices were evaluated:

- NDVI (normalized difference vegetation index) growth index computed as R_{930} -R_{660}/R_{930} + R_{660}. Best = highest value.
- IR/R (leaf area index) growth index computed as R_{930}/R_{660}. Best = highest value.
- Stress1 index computed as R_{710}/R_{760}. Best = lowest value.
- Stress2 index computed as R_{710}/R_{810}. Best = lowest value.

Clippings were collected to determine shoot growth once a month and dried at 75ºC for 48h. They were ground in a Wiley mill and then weighed. Clippings were analyzed for total Kjeldahl nitrogen (TKN). Roots were sampled by taking three 3.8-cm diameter root cores per plot once a year. Root weight and length were measured after washing soil from them. Total N uptake (TNU) was also calculated from the TKN (%) and dry weight of clippings (DWC) (g m^{-2}).

$$\text{TNU (mg m}^{-2}) = \text{DWC (g m}^{-2}) \times \text{TKN (\%)} \times 1000\text{mg g}^{-1} \quad \text{(Eq.2-1)}$$

Samples were collected by applying a vacuum to the collection tubing and withdrawing percolate from the reservoir of the lysimeter until dry. 20-ml aliquots of the leachate were transferred to collection vials and placed on ice in the field and then frozen at 0^{O} C until nitrate analysis was done. Nitrate concentration was measured using an AutoAnalyzer 3 continuous segmented flow analyzer (Seal Analytical, Mequon, WI) at the UF Analytical Research Laboratory in Gainesville. Leachate volumes were also calculated for each plot. Nitrate leaching data are presented as total cumulative nitrate-N leached over the study period and percent of applied N leached. Minimum detection limit (MDL) for the flow analyzer was 0.05. A baseline leachate sample was collected prior to first treatment application yearly, those values were used to correct for all other N mass values for each sampling event.

- TNC (mg) = Nitrate concentration (mg L^{-1}) × Leached water volume (L). (Eq.2-2)

This experiment was arranged as a nested design by CM, with fertilizer treatments randomized within. There were three replications. Data were analyzed with the SAS procedure ANOVA (SAS Institute Inc., Cary, NC). Significance was determined at the 0.05 probability level.

CHAPTER 3
EFFECT OF CLIPPING MANAGEMENT ON NITRATE LEACHING AND TURF QUALITY AND GROWTH IN EMPIRE ZOYSIAGRASS.

Introduction

Water is essential for survival and maintenance of life. For humans, 97% fresh drinking water comes from a combination of surface and groundwater. However, excessive or improper use of nitrogen (N) fertilizer may increase nitrate leaching that could potentially lead to nonpoint source pollution of ground or surface waters. Nitrate-N (NO_3-N) in water bodies causes eutrophication, which can produce detrimental toxins and lower the oxygen concentration in water (Glass, 2003). In addition, the USEPA reports that excessive nitrate concentration in drinking water may cause severe illness and even death in infants less than six months of age (EPA, 2006). Nitrate is converted to nitrite in the body, and this conversion leads to a rapid reduction in the oxygen-carrying capacity of blood especially in young children. A 'blue baby' syndrome or methemoglobinemia can result. Elevated levels of nitrate in drinking water can cause serious health issues in adults as well such as cancer, neurological effects, or abortion.

While urban turfgrass fertilization is often considered a major source of potential pollution to water bodies, numerous reports indicate that a mature turfgrass system leaches very low levels of nitrate-N (Geron et al., 1993; Lee et al., 2003; Qian et al., 2003). Nitrate leaching from turfgrass can be increased due to excessive N application rate (Morton et al., 1988; Kopp and Guillard, 2005; Frank et al., 2006), excessive irrigation or rainfall (Morton et al., 1988; Kopp and Guillard, 2005), timing (Bowman et al., 1998), N source (Snyder et al., 1984; Heckman et al., 2000 ; Guillard and Kopp, 2004; Saha et al, 2007), root density (Bowman el al. 1998), soil depth (Gross et al., 1990), turf establishment (Geron, 1993), turf species (Bowman et al., 2002) and other factors. These reports, however, indicate that when fertilizer is applied at the appropriate rates, timings, and with the correct irrigation, virtually all of the N is used by the turfgrass with very little lost to leaching. Gross et al. (1990) showed that there was no difference in leaching whether nitrogen was applied as liquid or granule. However, concerns over nitrogen leaching in Florida have led to numerous local ordinances and a state law requiring certification and licensing of all commercial fertilizer applicators.

Reducing potential nonpoint source pollution from urban turfgrass involves more than just fertilizer management. For example, turfgrass clippings may contribute to nutrient movement if left on impervious surfaces or if deposited incorrectly. Clippings produced from mowed grass retain considerable levels of nutrients such as N, P, K, and are easily decomposed (Sartain, 2004). Decomposition rate is related to turf species due to different content of lignin and cellulose in clippings (Sartain, 2004). It is also possible that returning clippings to turf may reduce fertilizer requirements. Research has reported that recycling grass clippings can help maintain high quality turf characteristics while reducing fertilizer use in bermudagrass (Sartain, 1993 and 2004), Kentucky bluegrass (Heckman et al., 2000) and a mixture of Kentucky bluegrass (*Poa pratensis* L.)-perennial ryegrass (*Lolium perenne* L.)- red fescue (*Festuca rubra* L.) (Kopp and Guillard, 2002a).

'Empire' zoysiagrass (*Zoysia japonica* Steud.) is increasingly used as a home lawn grass throughout Florida. Recommendations from the University of Florida for fertilization of zoysiagrass vary, depending on location in Florida, from 147 to 294 kg N ha^{-1} yr^{-1} (Unruh et al., 2006). In north Florida, 147 to 245 kg N ha^{-1} yr^{-1} is recommended, while in central and south Florida 147 to 294 kg N ha^{-1} $yr^{-1}$and 196 to 294 kg N ha^{-1} yr^{-1}, respectively, are recommended (Unruh et al., 2006). However, research (Trenholm and Unruh, 2009) has indicated that the cultivar Empire may perform best with lower rates of N than those suggested in the official recommendations. There are currently no other published reports on responses of Empire to fertilization rates.

The Florida Green Industries Best Management Practices (BMPs) were developed in 2002 to minimize nonpoint source pollution resulting from fertilization and to provide education on fertilizer management to the landscape maintenance industries of Florida. Use of grass clippings may represent a source of critical nutrients and can also provide organic matter. Due to lack of information regarding the effect of clipping-return on nitrate leaching in Empire zoysiagrass, the objectives of this study were to determine the effects of N rate and clipping management on NO_3-N leaching and turf quality of Empire zoysiagrass.

Materials and Methods

The field experiment was conducted at the University of Florida Plant Science Research and Education Center in Citra, Florida on Empire zoysiagrass. The grass was established in March 2008 in sandy loam soil (Hyperthermic, uncoated, Quartzipsamments in the Candler series) and the study was conducted from June to October 2008.

Plots measured 4.0m x 4.0m. High-density polyethylene (HDPE) lysimeters were installed in the center of each plot, approximately 10 cm below the soil surface. Lysimeters measured 57 cm diam. and 88 cm in height with a volume of 168 L. Lysimeters were assembled by placing cylinders into a single piece galvanized steel base unit measuring 25.4 cm in height. A bulkhead fitting was inserted into the base of each unit, to which collection tubing (0.95 cm low density polyethylene) was attached. The tubing was run underground to central aboveground collection portals. Lysimeters were installed by boring and removing soil in 15.2 cm sections to a depth of 107 cm. Lysimeters were placed in holes and bases of the units were filled with washed egg rock (1.9 – 6.4 cm) for a volume of 38 L. The gravel was covered with fitted non-woven polyolefin cloth that was secured with a hoop of 1.3 cm HDPE tubing to reduce soil intrusion into the reservoir. Soil was replaced into the lysimeters as it had been removed from the soil profile. Soil was gently tamped with a tamping tool (17 kg and 858 cm^2) to approximate original soil bulk density.

Clipping-management (CM) and nitrogen (N) fertilizer treatments were as follows:

- CM #1 consisted of clipping-return (CRT), in which clippings were left in the experimental field after mowing with a conventional rotary mower.
- CM#2 consisted of clipping-removal (CRM), in which clippings were taken from the field by attaching a collection bag to the same rotary mower.

Mowing height for both management strategies was set at 6.3 cm (2.5 inches). The plots were mowed once a week during the growing season.

Fertilizer treatments consisted of six levels of total N rates applied over the study period that were equivalent to 0 lbs, 1 lbs, 2 lbs, 3 lbs, 4 lbs or 6lbs N 1,000 ft^{-2} (0 kg, 49 kg, 98 kg, 147 kg, 196 kg, or 294 kg N ha^{-1}). Treatments were applied at 2-mo intervals for a total of two treatment applications. A 50% slow-release N fertilizer (Urea N) with an analysis of 15N-0P-15K was used. The area was irrigated to replace evapotranspiration (ET) as needed to maintain good quality turf.

Turf was evaluated visually for quality and color, immediately after mowing every week. A scale of 1 to 9 was used, in which 9 represents optimal, dark green color and 1 represents dead, brown turf. A rating of 6 was considered minimally acceptable for a home lawn.

Soil moisture (SM), canopy temperature (CT), and chlorophyll content (CC) were also measured. The SM was quantified weekly using a Time Domain Reflectometer (TRD) (IMIKO Micromodule Technik GmbH; Ettingen, Germany).

Chlorophyll content of the leaf tissue was measured weekly using a Field Scout CM-1000 Chlorophyll meter (Spectrum Technologies, Plainfield, IL). The measurement was taken at approximately 1.2 m from the turf canopy

Turf CT was also taken weekly with a Raytek Raynger infrared thermometer (Raytek, Santa Cruz, CA). Temperature was averaged from reading of three random points in each plot.

Clippings were collected to determine shoot growth once a month and dried at 75ºC for 48h. They were ground in a Wiley mill and then weighed. The total N concentration was analyzed with 0.2 g of dried clippings by the total Kjeldahl N (TKN) procedure. Roots were sampled by taking three 3.8-cm diameter root cores per plot once a year. Root weight and length were measured after washing them free of soil. Total N uptake (TNU) was also calculated from the TKN (%) and dry weight of clippings (DWC) (g m^{-2}).

Nitrate-N leachate samples were collected by applying a vacuum to the collection tubing and withdrawing percolate from the reservoir of the lysimeter until dry. 20-ml aliquots of the leachate were transferred to collection vials and placed on ice in the field and then frozen at 0^{O} C until nitrate analysis was done. Nitrate concentration was measured using an AutoAnalyzer 3 continuous segmented flow analyzer (Seal Analytical, Mequon, WI) at the UF Analytical Research Laboratory in Gainesville. Leachate volumes were also calculated for each plot. Nitrate leaching data are presented as total cumulative NO_3-N leached over the study period and percent of applied NO_3-N leached. Minimum detection limit (MDL) for the flow analyzer was 0.05. A baseline leachate sample was collected prior to first treatment application yearly, with those values used to correct for all other N mass values for each sampling event.

This experiment was arranged as a nested design by CM, with fertilizer treatments randomized within. There were three replications. Data were analyzed with the SAS procedure

ANOVA (SAS institute Inc., Cary. NC) and means were separated by Tukey's method. Significance was determined at the 0.05 probability level.

Results and Discussion

Nitrate Leaching

In all evaluation periods, there were differences due to N rates (Table 3-1). Greater amounts of NO_3-N leached from the 294 kg N ha^{-1} rate than from the other rates. High N rate has previously been shown to increase nitrate-N leaching (Morton et al., 1988; Kopp and Guillard, 2005; Frank et al., 2006) in other grass species. The highest rate applied here (294 kg N ha^{-1}) represents a 3-fold increase in recommended application rates from the University of Florida. Even at the next highest rate of 196 kg N ha^{-1}, nitrate-N leaching did not differ from the lower rates or from the control.

There were also differences in NO_3-N leaching due to CM and the interaction of N rate and CM for all month with exceptions of Aug and Sep (Table 3-1 and Fig 3-1). The amount of NO_3-N leaching for CRT plots dramatically increased at 294 kg N ha^{-1} rate during June to Aug. There was no increase in NO_3-N leaching from CRM plots, regardless of N rate during June to Aug. In contrast to this, in Oct there was no difference between N rates for CRT and NO_3-N leached in CRM plots increased remarkably over CRT plots (Fig 3-1).

These results of high NO_3-N leached for the highest N rate in CRT plots were correlated with the amount of monthly rainfall (Table 3-2). The peak of NO_3-N leaching was in June (2867.7 mg m^{-2}) and the lowest was in October (84.2 mg m^{-2}) (Table 3-3, Fig 3-2). This is positively correlated with rainfall during this study period (r^2=0.372, p=0.0157) (Table 3-2), with approximately 78% of the rain received was during the first three months (June to Aug) (Table 3-3). Heavy rainfall has previously been shown to increase leaching (Kopp and Guillard, 2005). This shows that heavy rainfall in Florida can accelerate the risk of NO_3-N leaching combined with high N rate. This field was established 3 months before this research. Root system of the zoysiagrass was not fully established and grown during June to Aug, when N from CRT may be mobilized quickly under rainfall. There was no correlation in NO_3-N leaching (mg m^{-2}) at any N rate for CRM (Data not shown).

Starr and DeRoo (1981) reported no response of NO_3-N leaching due to CM in a mixture of Kentucky bluegrass and creeping red fescue. They applied N fertilizer at a rate of 195 kg N ha^{-1} in the first 2 years and 180 kg N ha^{-1} in the 3rd year. Their research result was similar to this research when compared with the rate of 194 kg N ha^{-1} or less in this research.

There were differences in the percent of total applied N that leached over the trial period due to N rate and interaction between CM and N rate (Table 3-4), with means ranging from 0 to 11.97% for CRT and 0.09 to 2.16 % for CRM. Percentage loss of applied fertilizer N was less than 0.84 and 2.08 %, respectively, for CRT and CRM except at the 294 kg N ha^{-1}, which had leaching percentages of 11.97 and 2.16, respectively.

Nitrate-N leaching by concentration (mg L^{-1}) also peaked at the highest N rate (Table 3-5), similar to NO_3-N leaching (mg m^{-2}). The concentration of NO_3-N leached ranged from 0.15 to 28.1 mg L^{-1}. These NO_3-N concentrations were less than the USEPA drinking water standard of 10 mg L^{-1} (10 ppm) with the exception of the highest N rate in June (28.1 mg L^{-1}), July (18.5 mg L^{-1}) and August (11.0 mg L^{-1}) only for CRT plots. There were differences in concentration of NO_3-N leached due to N rate and CM (Table 3-5). The interaction between N rate and CM was also significant in June (p=0.0007), July (p=<.0001), August (p=0.0003) and October (p=0.0027). The concentration of NO_3-N leachate dramatically increased when the highest N rate (294 kg N ha^{-1}) was combined with CRT treatment during June to August, resulting in NO_3-N leaching exceeding the USEPA standard (Fig. 3-3).

There are a limited number of studies on the effect of N rate on NO_3-N leaching in warms-season grasses. Sharma et al. (2009) observed very low levels of NO_3-N leaching in healthy St. Augustinegrass even at the highest N rate of 296 kg N ha^{-1}. At four different N rates (75, 147, 222, and 294 kg N ha^{-1}), there were no differences in NO_3-N leaching due to N rate during the first and second fertilizer cycle (FC) because of the healthy condition of the turf. However, during the third FC, when there was injury due to mite and scale insects, higher N rate caused higher NO_3-N leaching. The NO_3-N concentrations of percolate ranged from 0.58 to 66.95 g N m^{-2}, and an average of 0.08 to 0.40 % of applied N leached. The range of application rates of N fertilizer used in this previous research study was similar to this study's; however, the previous research was done on St. Augustinegrass, rather than zoysiagrass. The reduction in NO_3-N leaching previously reported in St. Augustinegrass may be due to the deeper and better developed root system of. St. Augustinegrass as compared to zoysiagrass.

Saha et al. (2007) compared nitrate leaching from 'Floratam' St. Augustinegrass with a mix of common Florida ornamentals, including canna (*Canna generalis* L.H. Bailey), nandina (*Nandina domestica* Thunb.), ligustrum (*Ligustrum japonicum* Thunb.), and allamanda (*Allamanda cathartica* L.). Less NO_3-N leached from St. Augustinegrass than from ornamentals, and more NO_3-N leached from quick-release fertilizer than from slow-release fertilizer when applied at a rate of 294 kg N ha^{-1}. The NO_3-N concentration from the turf ranged from 0.11 to 0.21 mg L^{-1} and from ornamentals ranged 0.23 to 0.52mg L^{-1}.

Erickson et al. (2001) observed that a greater amount of NO_3-N was leached from ornamentals (1.46 mg L^{-1}) in comparison to newly established turf (<0.2 mg L^{-1}) when a fertilizer was applied at a rate of 300 kg N ha^{-1} for turf and 150 kg N ha^{-1} for ornamentals. In 2008, Erickson et al. (2008) reported that NO_3-N concentration of ornamental (0.44±0.12 mg L^{-}

^{1}) was higher than St. Augustinegrass (0.05 ± 0.01 mg L^{-1}). In all of these previous reports, less nitrate-N leached from St. Augustinegrass than was reported here from zoysiagrass,

Kopp and Guillard (2005) also reported that there were interactions between CM and N rate on NO_3-N leaching in creeping bentgrass. They applied N fertilizer at a rate of 0 to 392 kg N ha^{-1}. Clipping-return plots (CRT) had greater nitrate-N leaching than clipping-remove plots (CRM) as N rate increased. Cumulative NO_3-N mass losses from the creeping bentgrass were 1.9 to 85.4 mg L^{-1} when clippings were removed, and 10.1 to 171mg L^{-1} when clippings were returned.

Results reported here are similar to NO_3-N leaching results in cool-season grasses. In creeping bentgrass (Kopp and Guillard, 2005) and Kentucky bluegrass (Morton et al., 1988; Frank et al., 2006), the amount of NO_3-N leached increased as N rate increased. Morton et al. (1988) observed that the average NO_3-N concentration in leachate for three N rates (0, 97, and 244 kg N ha^{-1}) was 0.51, 087, and 1.24 mg L^{-1} with scheduled irrigation, and 0.36, 1.77, and 4.02 mg L^{-1} with overwatered irrigation in average. Frank et al. (2006) used two N rates (98 and 245 kg N ha^{-1}) to investigate NO_3-N leaching of mature Kentucky Bluegrass. They reported that NO_3-N concentration for 98 kg N ha^{-1} were typically below 5 mg $L^{-1}$and for 245 kg N ha^{-1} were often greater than 20 mg L^{-1}. In creeping bentgrass, NO_3-N concentration ranged from 0.13 to 21.0mg L^{-1} for four N rates of 0, 98, 196, and 392 kg N ha^{-1} and the percent of applied N lost due to nitrate-N leaching ranged from 0.9 to 63% (Kopp and Guillard, 2005).

There were differences in NO_3-N leaching (mg L^{-1}) at 294 kg N ha^{-1} rate for CRT plots by month (Table 3-5). The peak of NO_3-N leachate was in August (28.1 mg L^{-1}) and the lowest was in September and October (0.8 to 1.2 mg L^{-1}). This is directly correlated with rainfall during this study period (r^2=0.331, p=0.0307) (Table 3-2). This pattern of NO_3-N leaching (mg L^{-1}) at the highest N rate for CRT was similar to that of mass of NO_3-N leaching (mg m^{-2}) (Table 3-2 and 3-3). There was no correlation in NO_3-N leaching (mg L^{-1}) at any N rate for CRM (Data not shown).

Shoot and Root Growth

There were differences in shoot growth due to N rate for all months and the average of the harvests (Table 3-6). In July, Aug, and Sept, there were differences in shoot growth due to CM, with more clippings in July and Sept when clippings were removed. The response in July and Sept are most probably due to N treatment application 2 wks prior to harvest, while in Aug, there was no N treatment application. The response may also have been related to limited rainfall during Sept and Oct (Table 3-3). Less rainfall resulted in less NO_3-N leaching, which resulted in production of maximum shoot growth in Oct (Table 3-1 and 3-6).

There was an interaction of N rate and CM in Aug (Fig 3-4). CRT treatment produced greater clippings than CRM treatment as N rates increased. These results were similar to previous reports on shoot growth in cool-season grasses. Shoot growth from CRT treatment exceeded the amount of clippings from CRM (Liu and Hull, 2006; Kopp and Guillard, 2002a). Ten cultivars of three cool-season grasses produced clippings ranged from 515g dry weight m^{-2} for tall fescue and 368g m^{-2} for perennial ryegrass while applied 15g N m^{-2} in a year for two growing season (Liu and Hull, 2006). CRT treatment enhanced clipping dry matter from 30 to 72%, and increased total N uptake from 48 to 60% with a cool-season grass mixture for 2-year (Kopp and Guillard, 2002a). There was no difference in root weight due to any treatment effect.

Tissue N concentration

Leaf TKN differed due to N rate in Sept and Oct and due to CM in Oct only (Table 3-7). This may indicate that CRT increasingly affects tissue N concentration over time. There were no interactions for TKN. There were differences of N uptake due to N rate in every month and for the average of the trial period and due to CM in July, Aug, and Sept. There was an interaction for N uptake between N rate and CM in Sept (Table 3-7; Fig. 3-5). Both CRT and CRM treatment increased N as N rates increased. However, N uptake was steeply increased in CRT plots.

Visual Quality and Color

Turf visual quality and color differed due to N rate for each month and when averaged over the entire trial period (Table 3-8). Average quality ranged from 6.75 to 8.20, and average color from 6.67 to 7.92, with higher scores as N rate increased. There were also differences in quality due to CM in June through Aug and for color in June and July, where CRM plots had better quality and color than CRT plots. Average quality was 7.41 for CRT and 7.67 for CRM. This result was contrary to Sartain (1993 and 2004), who found increased visual quality of bermudagrass when clippings were returned over a 3-yr period. The author reported no difference of quality for ryegrass due to CM. Similar results were reported by Kopp and Guillard (2002a, 2002b) with a bluegrass–ryegrass–fescue mixture, and Heckman et al. (2000) with Kentucky bluegrass. Turf color was generally better where clippings were returned (Heckman et al., 2000). Kopp and Guillard (2002) also reported that clipping-return may reduce more than 50% of N fertilization use without negative effect on turf quality.

The reason that quality and color rating decreased may be from clipping size, which can cause delay of clipping decomposition. The rotary mower used in this research had less efficiency to chop clippings rather than the mulching mower used by Heckman et al. (2000). Bigger clippings remain on the turf surface longer, covering the surface and reducing photosynthesis activity of turf. This is likely to reduce quality and color as well as chlorophyll level in shoot.

Chlorophyll Content (CC)

Chlorophyll index ranged from 216.8 to 303.1 (Table 3-9; Fig 3-6), with higher levels occurring at the higher N rates. There were also differences due to CM for Sept, Oct, and when averaged over the trial period (Table 3-9). Higher chlorophyll level was found when clippings were removed (Fig.3-7). Chlorophyll level is related to photosynthesis activity in leaf tissue. Photosynthesis may be reduced due to shading effect of clippings left on leaf tissue, resulting in lower CC levels observed here. Use of a mulching mower may reduce this shading effect and increase CC.

Correlation between N rate vs. CM vs. Quality vs. Color vs. Chlorophyll Level vs. NO_3-N leaching vs. Shoot Growth.

Nitrogen rate was correlated with quality, color, chlorophyll, NO_3-N leaching, and shoot growth (Table 3-10). The strongest associations (*r* values ranging from 0.736 – 0.875) occurred in correlation with quality, color, chlorophyll and shoot growth (Table 3-10). There was no significant correlation between CM and other evaluations (Table 3-10). The strongest correlation ($r = 0.93$) occurred between visual quality and color ratings (Table 3-10).

Chlorophyll level was positively correlated with N rate, quality, color and shoot growth (Table 3-10). Correlation of chlorophyll level and shoot growth were generally high ($r = 0.645$) with significantly correlated evaluations. NO_3-N leaching was also correlated with N rate, quality, color, and shoot growth. When shoot growth increased, the NO_3-N leaching decreased in general. This not surprising, as more shoot growth provides more ground cover more tissue to absorb applied N.

Conclusions

This research provides information about the effect of CM and N rate on NO_3-N leaching, shoot growth, TKN concentration, N uptake, quality, and chlorophyll level.

Returning clippings resulted in lower turf quality and chlorophyll index than removing clippings. Total NO_3-N leached from CRT ranged from 114.6 to 7379.1 mg m^{-2} , while the range was from 123.1 to 1537.6 mg m^{-2} under CRM. The average concentration of NO_3-N leached ranged 0.23 to 6.47 mg L^{-2}, with significantly higher NO3-N leached From the highest N rate (294 kg N ha^{-1}). From the results of this research, it is important to apply N at rates below 196 kg N ha^{-1} per application to avoid NO_3-N leaching in Empire zoysiagrass. The potential for leaching was greater under a combination of CRT and high N rates, particularly under heavy rainfall.

These results generally contradict previous studies on clipping-return effect, which showed reduced NO3-N leaching under CRT in cool-season grasses. Thus, further research is required to verify verify the effect of clipping management and N rate on NO3-N leaching and turf quality in Empire zoysiagrass.

Table 3-1. N leaching (mg m^{-2}) of Empire Zoysiagrass in response to N rates and Clipping Management (CM)

N-rate (kg ha^{-1})	June		July		Aug		Sep	Oct		Total	
	CRT†	CRM‡	CRT	CRM	CRT	CRM		CRT	CRM	CRT	CRM
0	9.8b	20.5	3.7b	5.6	3.5b	11.2b	1.6 b[§]	0.8b	2.7b	114.6 b	242.5 b
49	5.7b	12.8	2.3b	3.2	4.6b	3.7b	1.3 b	3.7b	1.3b	121.2 b	123.1 b
98	10.0b	12.8	1.9b	7.5	3.1b	5.2b	2.6 b	4.2b	9.2b	131.0 b	261.5 b
147	20.1b	16.0	2.1b	18.1	4.6b	6.8b	2.0 b	2.6b	5.5b	146.3 b	363.0 b
196	85.8b	75.6	11.7b	7.6	16.9b	3.1b	2.1 b	5.1ab	13.6b	530.2 b	412.6 b
294	1307.7a	32.3	225.4a	30.5	206.6a	50.9a	12.6 a	9.6a	60.6a	7379.1 a	1537.6 a

ANOVA	June	July	Aug	Sep	Oct	Total
N-rate (N)	0.0067	<.0001	<.0001	<.0001	0.0010	<.0001
CM	0.0220	0.0375	NS	NS	0.0247	NS
N × CM	0.0073	<.0001	0.0160	NS	0.0218	0.0061

[§]Means followed by the same letter within each column for each N rate and clipping management are not significantly different at P=0.05. NS= not significant

†CRT-Clippings returned. ‡CRM-clippings removed.

Table 3-2. Correlation (r^2) between NO_3-N leaching of 294 kg N ha^{-1} rate for CRT plots vs. Rainfall during trial period

		Rainfall	
		r^2	p-value
NO_3-N Leaching	mg m^{-2}	0.372	0.0157*
	mg L^{-1}	0.331	0.0307*

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 3-3. NO_3-N leaching mass (mg m^{-2}) and concentration (mg L^{-1}) of 294 kg N ha^{-1} rate for CRT and Rainfall* (mm) during trial period.

		Jun	Jul	Aug	Sep	Oct
NO_3-N leaching	(mg m^{-2})	2867.7	2493.3	1812.3	121.6	84.2
	(mg L^{-1})	28.1 a[§]	18.5 ab	11.0 ab	1.2 b	0.8 b
Rainfall	(mm)	91.9	102.6	116.1	44.5	43.9

*Data from Florida Automated Weather Network (FAWN) were edited
[§]Means followed by the same letter within each column for each N rate and clipping management are not significantly different at P=0.05.

Table 3-4. Percentage loss of applied fertilizer N from Zoysiagrass soil under varying N rates, and Clipping Management (CM).

N Rate	Percentage Loss of Applied N	
	CRT	CRM
Kg N ha^{-1}	%	
49	-0.19	0.09
98	-0.01	2.08
147	0.26	1.97
196	0.84	1.47
294	11.97	2.16
ANOVA		
N-rate (N)	0.0037	
CM	NS	
N × CM	0.0119	

Table 3-5. N leaching (mg L^{-1}) of Empire Zoysiagrass in response to N rates and Clipping Management (CM)

N-rate (kg ha^{-1})	Jun		Jul		Aug		Sep	Oct		Average
	CRT	CRM	CRT	CRM	CRT	CRM		CRT	CRM	
0	0.21	0.92	0.52	1.01	0.22	0.56	0.15 b	0.15	0.37	0.41 b
49	0.18	0.36	0.31	0.23	0.21	0.15	0.17 b	0.41	0.15	0.23 b
98	0.29	0.26	0.19	0.83	0.15	0.22	0.30 b	0.81	1.37	0.52 b
147	0.45	0.44	0.28	1.74	0.18	0.51	0.25 b	0.32	0.68	0.53 b
196	2.52	4.12	1.06	0.88	0.71	0.19	0.31 b	0.73	1.19	0.73 b
294	28.07	1.81	18.50	3.29	10.96	2.30	1.75 a	1.18	8.47	6.47 a
ANOVA										
N-rate (N)	0.0003		<.0001		<.0001		0.0003	<.0001		0.0002
CM	0.0065		0.0038		0.0337		NS	0.0168		NS
N × CM	0.0007		<.0001		0.0003		NS	0.0027		NS

§Means followed by the same letter within each column for each N rate and clipping management are not significantly different at *p*=0.05.
NS= not significant

Table 3-6. Turf shoot and root growth in response to N rates and Clipping Management (CM).

N-rate (kg ha^{-1})	Shoot growth (g m^{-2} day^{-1})					Root Weight (g)
	Jul	Aug	Sep	Oct	Average	
0	3.26 c	0.91 d	3.31 d	8.37 c	3.96 d	1.03
49	6.55 c	1.65 d	6.67 cd	17.18 bc	8.01 cd	0.62
98	7.83 c	2.38 cd	11.04 c	22.48 bc	10.93 bcd	0.80
147	23.13 b	3.77 bc	19.74 b	28.94 b	18.89 b	0.72
196	16.14 b	4.37 ab	19.52 b	27.72 b	16.94 bc	0.77
294	41.84 a	5.88 a	29.65 a	47.32 a	31.18 a	0.53
CM						
Return	11.11 b	4.52 a	12.42 b	24.39	13.11	0.69
Remove	21.81 a	1.80 b	17.55 a	26.29	16.86	0.80
ANOVA						
N-rate (N)	<0.0001	<0.0001	<0.0001	0.0050	<0.0001	NS[§]
CM	<0.0001	<0.0001	0.0062	NS	NS	NS
N × CM	NS	0.0026	NS	NS	NS	NS

[§]Means followed by the same letter within each column for each N rate and clipping management are not significantly different at P=0.05.
NS= not significant

Table 3-7. Total Kjeldahl Nitrogen percentage and N uptake of Empire Zoysiagrass in response to N rates and Clipping Management.

N-rate	% TKN					N uptake‡ (mg m^{-2})				
(kg ha^{-1})	Jul	Aug	Sep	Oct	Average	Jul	Aug	Sep	Oct	Average
0	1.55	1.70	1.48 b§	1.43 ab	1.54	50.5 d	13.9 d	50.8 c	127.9 c	60.8 c
49	1.73	1.67	1.53 ab	1.37 b	1.58	102.2 cd	25.7 d	104.7 c	268.2 bc	125.2 bc
98	1.72	1.69	1.53 ab	1.42 ab	1.59	123.7 cd	37.8 cd	174.7 bc	354.1 bc	172.6 bc
147	1.45	1.78	1.58 ab	1.45 ab	1.57	365.8 b	58.3 bc	313.1 b	447.4 b	296.1 b
196	1.62	1.83	1.75 ab	1.41 ab	1.65	264.6 bc	74.9 ab	322.6 b	457.6 b	279.9 b
294	1.59	1.79	1.80 a	1.59 a	1.70	709.3 a	99.9 a	503.9 a	804.2 a	529.3 a
Clipping Management										
Return	1.56	1.74	1.57	1.52 a	1.60	182.3 b	74.4 a	202.9 b	398.4	214.5
Remove	1.66	1.75	1.65	1.38 b	1.61	356.4 a	29.1 b	287.0 a	421.4	273.5
ANOVA										
N-rate (N)	NS	NS	0.0185	0.0233	NS	<0.0001	<0.0001	<0.0001	0.0033	<0.0001
Clipping (C)	NS	NS	NS	0.0004	NS	<0.0001	<0.0001	0.0142	NS	NS
N × C	NS	NS	NS	NS	NS	NS	0.0035	NS	NS	NS

§Means followed by the same letter within each column for each N rate and clipping management are not significantly different at P=0.05.

‡N uptake (mg m^{-2}) = Dry Shoot growth × % TKN

Table 3-8. Visual quality and color score of Empire Zoysiagrass in response to N rates and Clipping Management (CM) in a field experiment

N-rate	Quality						Color					
(kg ha^{-1})	Jun	Jul	Aug	Sep	Oct	Average	Jun	Jul	Aug	Sep	Oct	Average
0	5.78d[§]	6.55d	7.03d	7.01c	7.32d	6.75d	6.02d	6.57c	6.83d	7.01d	6.87d	6.67c
49	6.40c	7.05c	7.68bc	7.57b	7.95c	7.33c	6.43c	7.10b	7.47c	7.70c	7.30c	7.18b
98	6.32c	7.03c	7.65c	7.80b	8.02bc	7.35c	6.45c	7.23b	7.62bc	7.90b	7.50bc	7.33b
147	7.10b	7.72b	8.07a	8.10a	8.28ab	7.87b	7.13b	7.87a	7.88ab	8.20a	7.70ab	7.73a
196	6.63c	7.75ab	8.02ab	8.12a	8.30ab	7.75b	6.77bc	7.88a	7.87ab	8.17a	7.72ab	7.68a
294	7.90a	8.13a	8.25a	8.28a	8.43a	8.20a	7.65 a	8.05a	7.93a	8.22a	7.73a	7.92a
CM												
Return	6.57b	7.17b	7.58b	7.78	7.98	7.41 b	6.60 b	7.28 b	7.58	7.89	7.52	7.36
Remove	6.81a	7.57a	7.98a	7.87	8.12	7.67 a	6.88 a	7.62 a	7.62	7.86	7.42	7.48
ANOVA												
N-rate (N)	***	***	***	***	***	***	***	***	***	***	***	***
CM	*	***	***	NS	NS	**	*	**	NS	NS	NS	NS
N × CM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively. / NS: Not Significant

[§]Means followed by the same letter within each column for each N rate and clipping management are not significantly different at P=0.05.

NS= Not Significant at P=0.05

Table 3-9. Chlorophyll Index of Empire Zoysiagrass in response to N rates and Clipping Management (CM).

N-rate (kg ha^{-1})	Chlorophyll Index				
	Jul	Aug	Sep	Oct	Average
0	236.5 c[§]	220.50 d	213.2 c	197.2 c	216.8 d
49	306.3 b	271.8 bc	253.4 b	209.8 bc	260.2 c
98	323.5 b	299.92 a	273.1 ab	227.1 ab	280.9 b
147	374.8 a	285.0 ab	276.9 ab	230.5 a	291.8 ab
196	381.2 a	303.08 a	287.27 a	240.6 a	303.1 a
294	381.9 a	257.08 c	274.4 ab	231.0 a	286.1 ab
CM					
Return	330.01 a	279.1 a	238.9 b	212.8 b	265.2 b
Remove	338.04 a	266.5 a	287.2 a	232.6 a	281.1 a
ANOVA					
N-rate (N)	<0.0001	<0.0001	<0.0001	0.0015	<0.0001
CM	NS	0.0509	<0.0001	0.0015	0.0047
N × CM	NS	NS	NS	NS	NS

[§]Means followed by the same letter within each column for each N rate and clipping management are not significantly different at P=0.05.

Table 3-10. Correlation coefficients for N rate, clipping management, quality, color, chlorophyll, NO_3-N Leaching, and Shoot growth.

		N-rates	CM	Quality	Color	Chlorophyll	NO_3-N Leaching	Shoot growth
N-rates	*r*	-	0.000	**0.858**	**0.875**	**0.736**	**0.519**	**0.812**
	P	-	1.000	**<0.0001**	**<0.0001**	**<0.0001**	**0.0012**	**<0.0001**
CM	*r*	0.000	-	-0.255	-0.128	-0.247	0.24	-0.183
	P	1.000	-	0.134	0.4557	0.1472	0.1587	0.286
Quality	*r*	**0.858**	-0.255	-	**0.93**	**0.823**	**0.382**	**0.866**
	P	**<0.0001**	0.134	-	**<0.0001**	**<0.0001**	**0.0214**	**<0.0001**
Color	*r*	**0.875**	-0.128	**0.93**	-	**0.824**	**0.443**	**0.859**
	P	**<0.0001**	0.4557	**<0.0001**	-	**<0.0001**	**0.0069**	**<0.0001**
Chlorophyll	*r*	**0.736**	-0.247	**0.823**	**0.824**	-	0.082	**0.645**
	P	**<0.0001**	0.1472	**<0.0001**	**<0.0001**	-	0.6358	**<0.0001**
NO_3-N Leaching	*r*	**0.519**	0.24	**0.382**	**0.443**	0.082	-	**0.51**
	P	**0.0012**	0.1587	**0.0214**	**0.0069**	0.6358	-	**0.0015**
Shoot growth	*r*	**0.812**	-0.183	**0.866**	**0.859**	**0.645**	**0.51**	-
	P	**<0.0001**	0.286	**<0.0001**	**<0.0001**	**<0.0001**	**-0.0015**	-

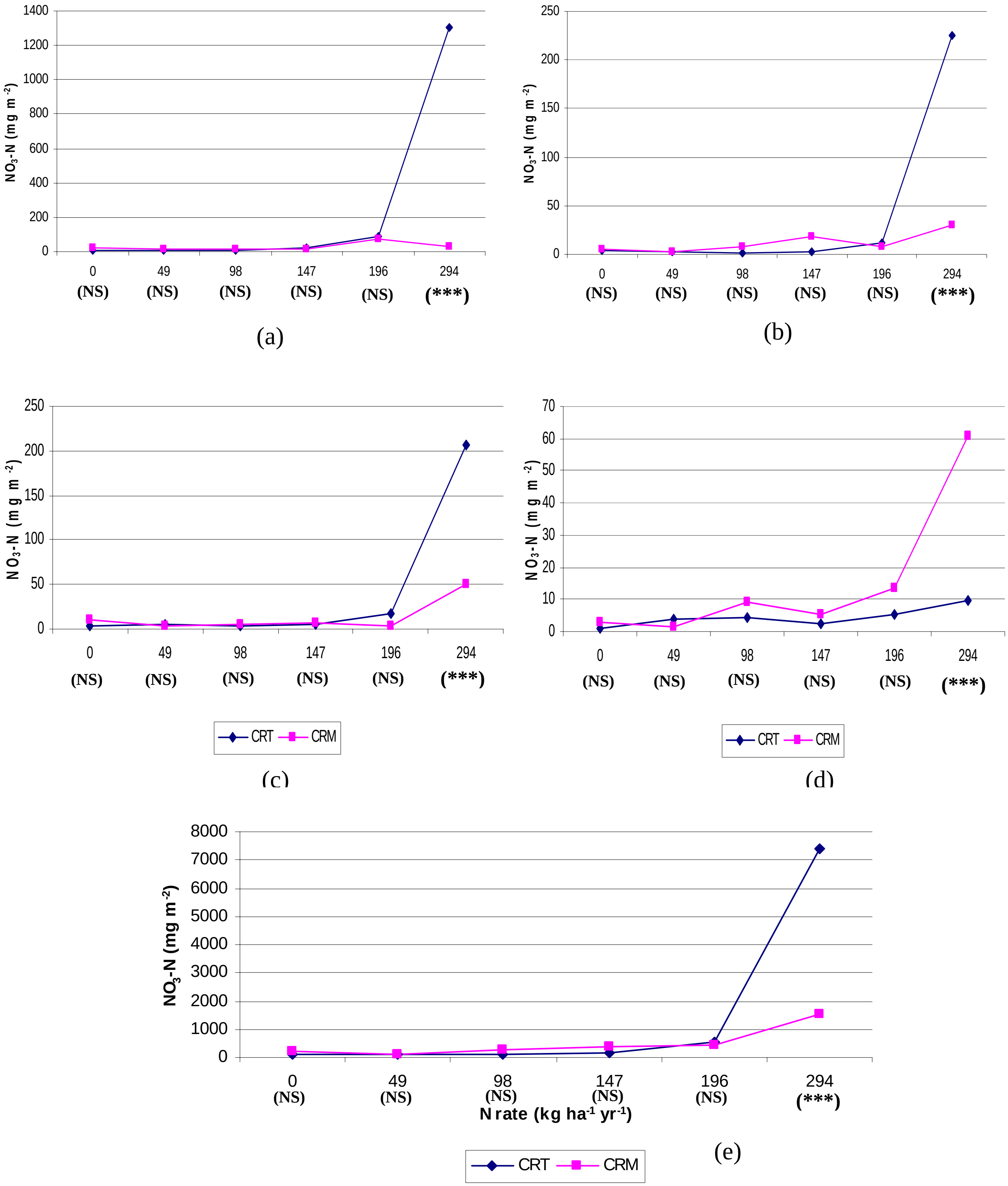

Figure 3-1. Interaction between clipping management (CM) and N rate with respect to NO_3-N leaching (mg m-^{2}) from Empire Zoysiagrass in June (a), July (b), August (c), October (d), and total (e). (NS: Not significant, ***: Significant at *p*=0.05 between N rates)

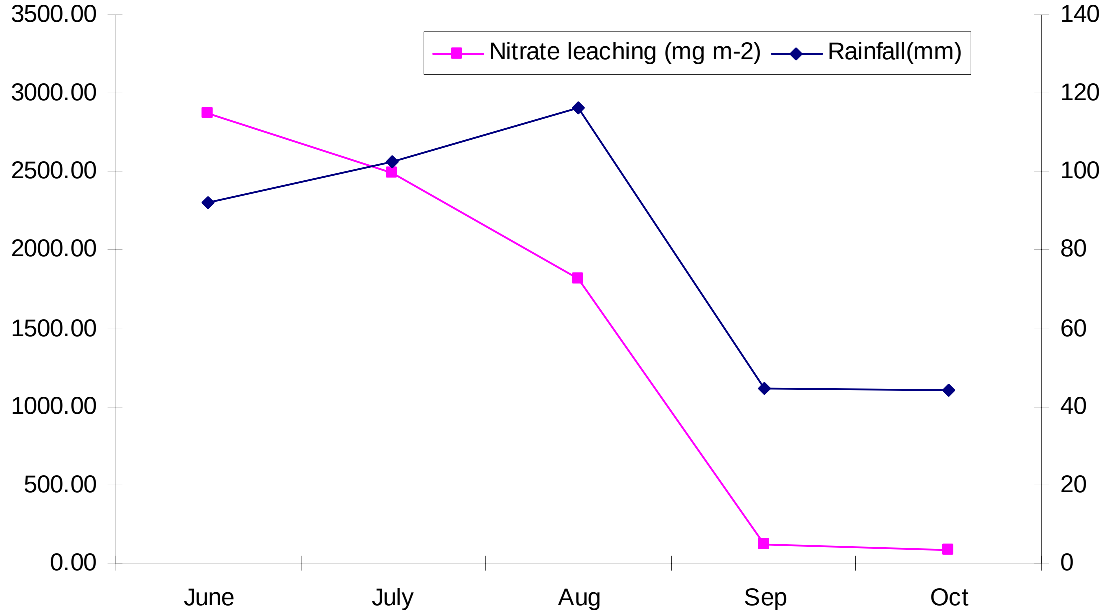

Fig. 3-2. Comparison of monthly rainfall and nitrate (NO_3-N) leaching.

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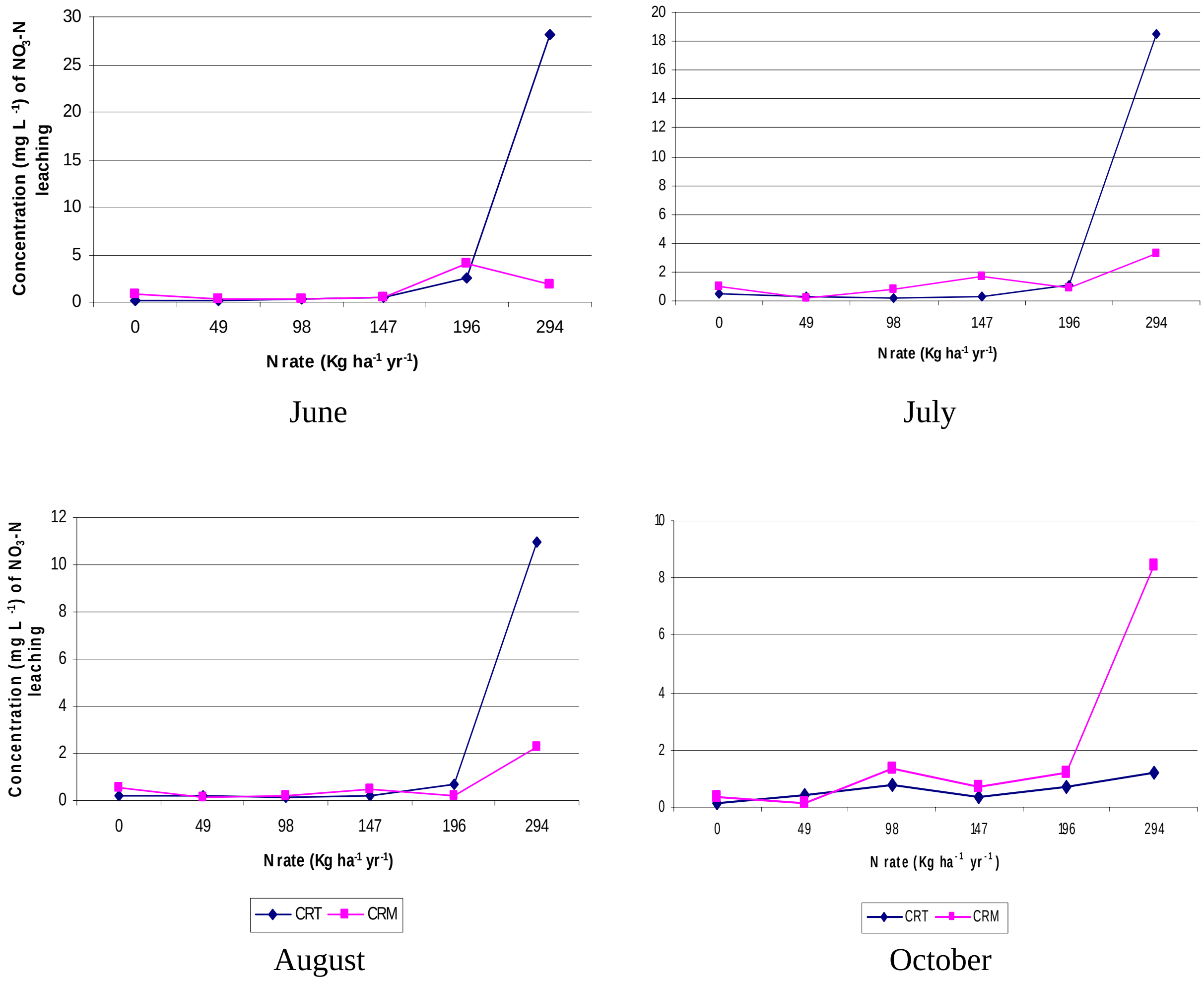

Figure 3-3. Interaction between clipping management (CM) and N rate with respect to NO_3-N leaching (mg L^{-1}) from Empire Zoysiagrass in June (upper left), July (upper right), August (bottom left), and October (bottom right).

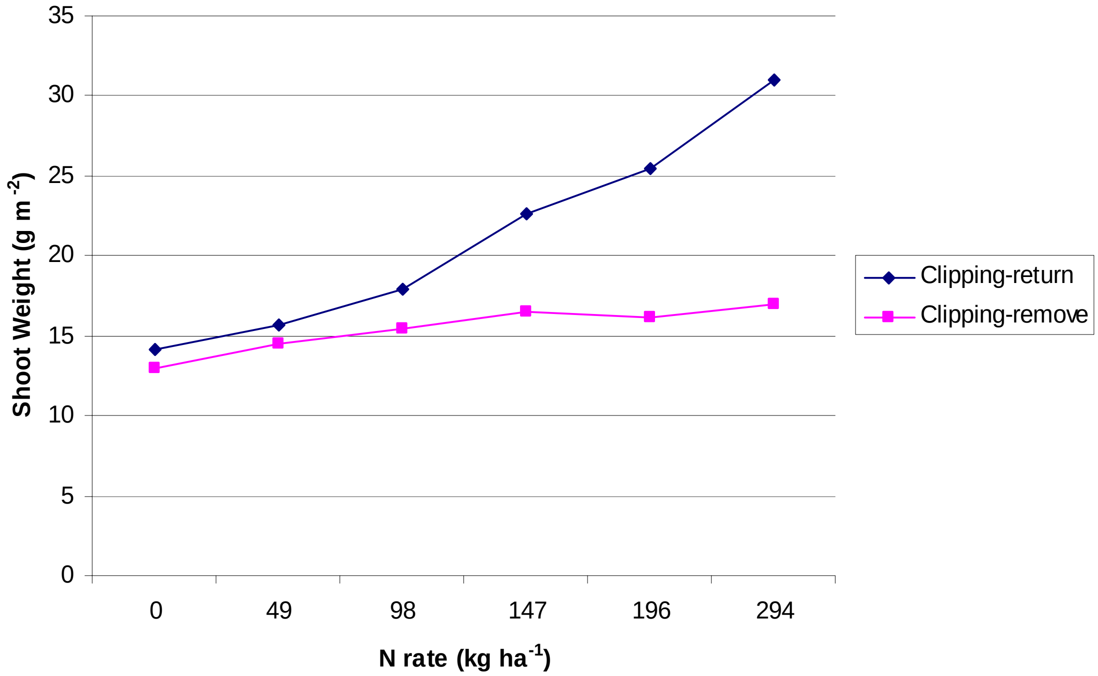

Figure 3-4. Interaction between clipping management (CM) and N rate with respect to shoot weight (g m-^{2}day^{-1}) from Empire Zoysiagrass in August

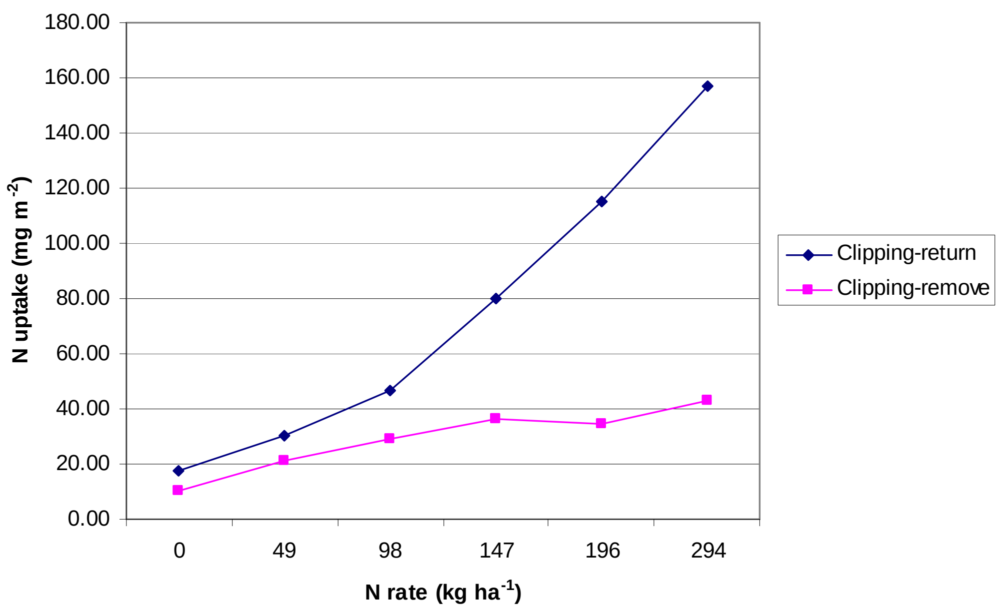

Figure 3-5. Interaction between clipping management (CM) and N rate with respect to N uptake (g m-^{2}) from Empire Zoysiagrass in August

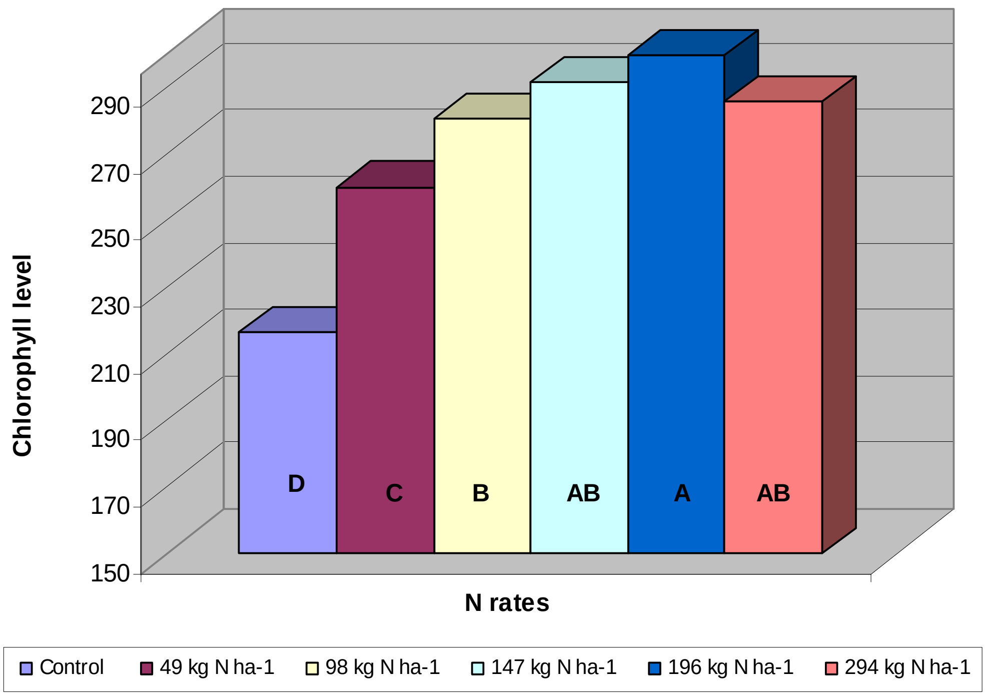

Figure 3-6. Chlorophyll level by N rate treatment for 'Empire' Zoysiagrass

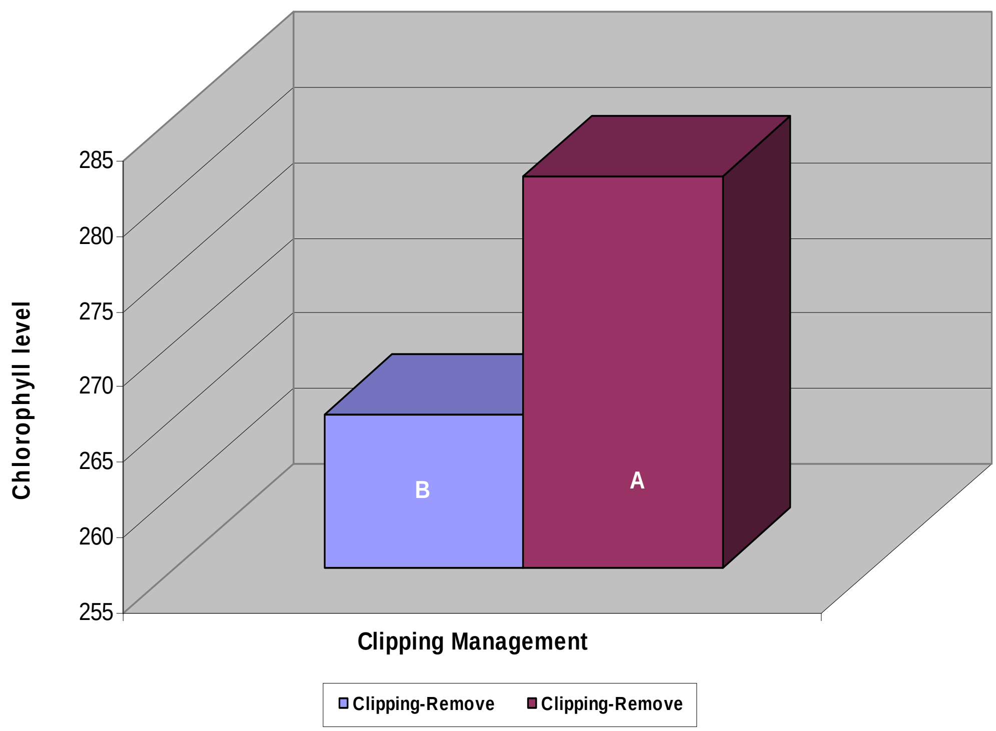

Figure 3-7. Chlorophyll level by Clipping treatment for 'Empire' Zoysiagrass

CHAPTER 4
EFFECT OF MULTISPECTRAL REFLECTANCE AND CORRELATION OF QUALITY AND LEACHING IN EMPIRE ZOYSIAGRASS

Introduction

Turfgrass research typically uses qualitative visual measurements to compare effects of treatments. These measurements include over all turf quality and may often include related parameters such as turf color, density, percent green or injured, etc. While these ratings may produce solid statistical data, technology has been developed to determine ability to quantify these subjective ratings. Use of multispectral reflectance has been used by a number of researchers in turf systems. Trenholm et al. (1999a) observed that reflectance at particular wavelengths throughout the visible spectrum was highly correlated with visual turf quality scores, shoot density, and shoot tissue injury in seashore paspalum (*Paspalum vaginatum* Swartz.) and hybrid bermudagrass (*Cynodon dactylon* x *C. transvaalensis* Burtt-Davy). Reflectance at 661 and 813 nm had the strongest correlations, as did several growth and stress indices using both visual spectrum and near infrared (NIR) wavelengths. Trenholm et al. (1999b) further observed that reflectance could be reliably used to discriminate between wear injury. Spectral reflectance was also used to distinguish between N application, herbicide stress, and C3 vs. C4 grasses (Trenholm et al., 2000). Higher reflectance in the visible range (400-700 nm) indicates less plant light attenuation and utilization at those wavelengths and has been associated with stress or nutritional deficiency. Growth indices NDVI (normalized difference vegetation index)and LAI (leaf area index) have been associated with crop growth and yield (Asrar et al., 1984) and with healthy turfgrass growth and shoot density (Trenholm, et al., 1999). Higher values indicate optimal performance, and Stress1 (reflectance at wavelength 710/wavelength 760) and Stress2 (reflectance at wavelength

710/wavelength 810) indices are associated with turf stress response, where lower values indicate lower stress levels and better performance.

There are at least 10 species of zoysiagrass (*Zoysia* spp. Willd.), all of which have originated from the Orient (Christians, 2007). They include Korean (or Japanese) lawngrass (*Zoysia japonica* Steud.), which is the most widely used species in the United States (Christians, 2007). *Zoysia japonica* is well adapted to use on golf courses fairways and tees and some cultivars appear to be well suited to home lawn use (Trenholm and Unruh, 2005a), fair shade, and salinity tolerance (Christians, 2007). It also stands up well to traffic and has been reported to tolerate drought while maintaining relatively low levels of disease and insect damage (Christians, 2007). 'Empire' zoysiagrass is a native proprietary selection of *Zoysia japonica*. It has performed well in trials in Florida and appears to require less nitrogen than other zoysiagrass cultivars (Trenholm and Unruh, 2009). It is currently being used increasingly in home lawns throughout Florida.

Turf shoot clippings have often been considered a nuisance product to dispose of, although the clippings contain abundant nutrients and are a source of organic matter. Removing clippings from turf causes N loss from the system. Starr and DeRoo (1981) examined the various effects of clipping-return while evaluating the fate of N fertilizer with Kentucky bluegrass mix (*Poa pratensis* L.) and creeping red fescue (*Festuca rubra* L.). The study spanned 3 years and used a suction lysimeter with ^{15}N labeling to trace the fate of N from clippings and fertilizer. Return of clippings to the turf increased the total N uptake of the harvested grass by 19, 41, and 74% for the 3 consecutive years of the experiment. In the clipping returned treatment, yield and growth of the grass increased by about 30%. The tissue N concentration from clipping-removed treatment was derived equally from soil and fertilizer, whereas the tissue N concentration from clipping-returned treatment was derived from equal amounts of N from soil, fertilizer, and clipping-return.

No information is available on the spectral responses for turfgrasses due to clipping management. Therefore, the objectives of this study were to evaluate responses of zoysiagrass to N rate and clipping treatment using spectral reflectance data and to determine the degree of association between reflectance values and other measurements such as nitrate leaching, quality, color and shoot growth.

Materials and Methods

The field experiment was conducted at the University of Florida Plant Science Research and Education Center in Citra, Florida on ‘Empire’ zoysiagrass (*Zoysia japonica* Steud.). The grass was established in March 2008 and the study was conducted from June to October 2008.

Clipping-management (CM) and nitrogen (N) fertilizer treatments were as follows:

- CM #1 consisted of clipping-return, in which clippings were left in the experimental field after mowing with a conventional rotary mower.
- CM#2 consisted of clipping-removal, in which clippings were taken from the field by attaching a collection bag to the mower.

Mowing height was set at 6.3 cm (2.5 inches). The plots were mowed once a week throughout the study period.

Fertilizer treatments consisted of six levels of total N rates (equivalent to 0 lbs, 1 lbs, 2 lbs, 3 lbs, 4 lbs or 6lbs N 1,000 ft^{-2} or 0 kg, 49 kg, 98 kg, 147 kg, 196 kg, or 294 kg

N ha^{-1}). Treatments were applied at 2-mo intervals for a total of two treatment applications. A 50% quick-release fertilizer (QRF) and 50% slow-release fertilizer (SRF) of 15N-0P-15K were used. The area was irrigated to replace evapotranspiration (ET) as needed to maintain healthy turf.

Turf was evaluated visually for quality and color, which were rated immediately after mowing. A scale of 1 to 9 was used, in which 9 represents optimal, dark green color and 1 represents dead, brown turf. A rating of 6 was considered minimally acceptable for a home lawn.

Soil moisture (SM), canopy temperature (CT), chlorophyll content (CC), and multispectral reflectance (MSR) were also measured. Soil moisture content was quantified weekly using a Time Domain Reflectometer (TRD) (IMIKO Micromodule Technik GmbH; Ettingen, Germany).

Multispectral reflectance readings were taken every 7-10 days with a Cropscan MSR16 radiometer (Cropscan, Inc., Rochester, MN); The radiometer was fitted with filter wavelengths to measure reflectance at 450, 550, 660, 694, 710, 760, 810, and 930 nm. In addition, the following growth and stress indices were evaluated:

- NDVI (normalized difference vegetation index) growth index computed as $R_{930} - R_{660}/R_{930} + R_{660}$. Best = highest value.
- IR/R (leaf area index) growth index computed as R_{930}/R_{660}. Best = highest value.
- Stress1 index computed as R_{710}/R_{760}. Best = lowest value.
- Stress2 index computed as $R_{71}0/R_{810}$. Best = lowest value.

Nitrate leaching and shoot growth collection methodologies were previously described in Chapter 3.

This experiment was arranged as a nested design by CM, with fertilizer treatments randomized within. There were three replications. Data were analyzed with the SAS procedure ANOVA or CORR (SAS institute Inc., Cary. NC). Significance was determined at the 0.05 probability level.

Results and Discussion

MultiSpectral Reflectance (MSR)

There were few differences in reflectance scores due to CM f in the weeks following the first fertilizer treatment (WAFT), (Table 4-1). There were differences in reflectance at all wavelengths and in all indices (P<0.001) at 1 week after second treatment (WAST), with better values occurring in CRM plots (Table 4-2), which means that CRT plots had more stress than CRM plots (Table 4-2). At 3 WAST, stress indices also showed that the CRT plots had more stress than the CRM plots (data not shown). Reflectance at 450 nm at 5 WAST consistently showed that the CRT plots had more stress than the CRM plots (data not shown).

In general, N treatment had significant difference at PAR range (450-710) and growth (NDVI, and IR/R) and stress (ST-1, and ST-2) indices at between 1 WAFT and 1 WAST (Table 4-1). At 3 WAST, stress indices showed that lower N rate plots had higher reflectance and therefore less ability to assimilate and use light at the various wavelengths measeured than higher rate plots (data not shown). Throughout the evaluation period, higher N rate plots generally had lower reflectance than lower N rate (Table 4-1 and 4-2). Similar results were reported by Trenholm et al. (2000). They observed that there were consistent differences due to N rate throughout the visible range wavelengths. The reflectance was consistently greater at the lowest N.

Correlation between Multispectral Reflectance (MSR) vs. N rate, CM, Growth, and Quality.

N Rate vs. Reflectance

N rate was correlated with spectral reflectance at 450 and 550 nm and the ratios NDVI, ST-1, ST-2, and IR/R (Table 4-3). Highest r values (0.490-0.638) were obtained from 450 nm, NDVI, ST-1, ST-2, IR/R (Table 4-3). Lower N rate indicated higher reflectance and stress (ST-1, and ST-2) caused by N deficiency (Table 4-3).

CM vs. Reflectance

There was no correlation between any of the wavelengths evaluated and CM (Table 4-4). However, response of CM to growth and stress indices was significant (r = 0.383-0.458), with lowest vales seen with IR/R and highest with NDVI (Table 4-4). The negative correlation between CM and growth indices (NDVI and IR/R) and positive correlation between CM and Stress indices implies that CRT had less turf growth and higher stress than CRM treatment (Table 4-4). This was different from the result of Heckman *et a*l.(2000) who reported a productive effect of CRT on shoot growth and turf quality.

There are several possibilities about the effect of CRT on turf health. First possibility was evaluation timing for MSR, which was evaluated immediately after mowing event. Clippings in CRT plots possibly affected reflectance readings.

Second, for zoysiagrass, CRT may require longer time periods for satisfactory effect on turf growth and health due to their physiological difference from cool-season grasses. Sartain (1993) reported that the clipping yield and quality of one warm-season grass ('Tifway' bermudagrass) species and one cool-season grass ('Pennant' perennial ryegrass) increased when clippings were returned for three years. The other possibility may result from mower difference. Regular rotary mower was used rather than mulching mower Heckman *et al* (2000) used. In general, warm-season grasses grow faster and more active in summer than cool-season grasses. We mowed weekly with cutting height of 6.3 cm regardless of growing status. Clippings may cover turf effectively from sunlight while reducing chlorophyll level of tissue. NDVI is related to chlorophyll concentration (Filella et al., 1995). The NDVI index (-0.458) showed that CRT treatment had less chlorophyll concentration (Table 4-3).

Visual Quality and Color vs. Reflectance

Similar responses were seen for visual quality and color at varying reflectance. Quality and color were negatively correlated with reflectance at 450 and 660 nm, (Table 4-3). The correlation coefficient ranged from -0.358 to -0.702 for quality, and -0.335 to -0.627 for color (Table 4-3). Turf quality and color were highly correlated with all growth and stress indices (Table 4-3). Correlation coefficients all showed a high degree of association with quality (0.698-0.804) and color (0.639-0.762); relations were positively associated for growth indices NDVI and IR/R and were negatively for the stress indices (Table 4-3).

NO_3-N Leaching vs. Reflectance

Reflectance was not correlated with NO_3-N leaching data at any individual wavelength or indices (Table 4-3). This is somewhat surprising, since NO_3-N leaching was positively correlated with N rate, quality, color, and chlorophyll level (r=0.382 to 0.519) (Table 3-9) and it could be speculated that stronger, more dense grass associated with increased N rate, quality, and color would reduce leaching.

Shoot Growth vs. Reflectance

Reflectance at 450 nm was correlated with shoot growth (Table 4-3). In this study, highest values were found in reflectance at wavelength 450nm, NDVI, ST-1, ST-2, and IR/R (r = -0.529, 0.548, -0.655, -0.656, and 0.661, respectively) (Table 4-3).

Conclusions

This research provides information about the effect of CM and N rate on spectral reflectance responses of Empire zoysiagrass. There was very little response to any reflectance values to CM, except for the values taken the week following the second fertilizer application. Reflectance values did vary due to N rate and showed several strong associations with other measured parameters.

From the results of this research, it appears that CM has little effect on turf light attenuation through the visible range wavelengths and that it has little effect on the associated physiological functions. Results also indicate that it is not practical to use this methodology to predict nitrate leaching from Empire zoysiagrass

Further research should be done to determine if multiple years will provide similar results regarding nitrate leaching and spectral reflectance correlations and responses.

Table 4-1. Reflectance by clipping practice and varying N rate 6 weeks after first fertilizer treatment (6 WAFT‡).

N-rate (kg ha^{-1})	Wavelength (nm)								
	450	**550**	**660**	**694**	**710**	**NDVI**	**Stress-1**	**Stress-2**	**IR/R**
0	4.5a	13.5a	7.1a	10.0 a	19.4 a	0.81 b	0.37 a	0.33 a	9.2 b
49	3.9bc	11.5b	5.8bc	8.2 bc	16.5 b	0.83 ab	0.33 bc	0.30 bc	11.1 a
98	3.8bc	11.0bc	5.6 b-d	7.8 cd	15.8 bc	0.84 ab	0.32 bc	0.29 bc	12.3 a
147	3.7bc	10.6cd	5.5cd	7.8 cd	15.5 bc	0.84 ab	0.32 bc	0.29 bc	11.3 a
196	3.6c	10.2d	5.1d	7.1 d	14.7 c	0.85 a	0.30 c	0.27 c	12.6 a
294	4.1ab	11.1bc	6.3b	8.7 b	16.6 b	0.81 b	0.35 ab	0.32 ab	9.3 b
CM									
Return	3.9	11.1 b	5.8	8.1	16.0 b	0.83	0.33	0.30	10.7
Remove	4.0	11.5 a	6.0	8.4	16.8 a	0.83	0.33	0.30	10.9
ANOVA									
N-rate (N)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0016	0.0001	0.0001	<0.0001
CM	NS	0.0017	NS	NS	0.0016	NS	NS	NS	NS
N × CM	NS	NS	NS	NS	NS	NS	NS	NS	NS

‡WAFT: Week(s) After First Treatment

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

§NS= not significant

Table 4-2. Reflectance by clipping practice and varying N rate 1 week after second fertilizer treatment (1 WAST).

N-rate	Wavelength (nm)								
(kg ha^{-1})	450	550	660	694	710	NDVI	Stress-1	Stress-2	IR/R
0	4.3 a	13.8 a	8.4 a	12.2 a	22.1 a	0.75	0.43 a	0.41 a	6.3 b
49	3.6 b	11.5 b	6.8 ab	10.1ab	18.9 b	0.77	0.40 ab	0.38 ab	7.7 ab
98	3.4 b	10.6bc	6.7 ab	9.7 b	17.9 bc	0.77	0.40 ab	0.37 ab	8.0 ab
147	3.3 b	10.1b-d	6.3 b	9.0 b	16.8 b-d	0.78	0.37 ab	0.35 ab	8.5 ab
196	3.0 b	9.3 d	5.4 b	7.9 b	15.2 d	0.81	0.33 b	0.31 b	10.1 a
294	3.3 b	9.6 d	6.2 b	8.7 b	15.7 cd	0.78	0.37 ab	0.34 ab	9.1 a
CM									
Return	3.8 a	11.5 a	7.5 a	10.8 a	19.2 a	0.74 b	0.43 a	0.41 a	6.8 b
Remove	3.2 b	10.2 b	5.7 b	8.4 b	16.3 b	0.81 a	0.33 b	0.31 b	9.7 a
ANOVA									
N-rate (N)	<.0001	<.0001	0.002	0.0003	<.0001	NS	0.050	0.0266	0.004
CM	0.0002	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
N × CM	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
[§]NS= not significant

Table 4-3. Correlation Coefficients for reflectance vs. N rate, clipping management, quality, color, chlorophyll, N leaching, and shoot growth.

	Wavelength (nm)									
	450	**550**	**660**	**694**	**760**	**810**	**NDVI**	**Stress-1**	**Stress-2**	**IR/R**
N-rates	-0.545 (0.0006)	-0.344 (0.040)	-0.304 (NS)	-0.190 (NS)	0.226 (NS)	0.243 (NS)	0.490 (0.002)	-0.626 (<0.0001)	-0.638 (<0.0001)	0.561 (0.0004)
CM	0.249 (NS)	-0.021 (NS)	0.199 (NS)	0.105 (NS)	-0.253 (NS)	-0.245 (NS)	-0.458 (0.005)	0.418 (0.011)	0.397 (0.017)	-0.383 (0.021)
Quality	-0.702 (<0.0001)	-0.358 (0.032)	-0.417 (0.011)	-0.254 (NS)	0.338 (0.044)	0.364 (0.029)	0.698 (<0.0001)	-0.795 (<0.0001)	-0.804 (<0.0001)	0.771 (<0.0001)
Color	-0.627 (<0.0001)	-0.335 (0.046)	-0.358 (0.032)	-0.207 (NS)	0.342 (0.041)	0.368 (0.027)	0.639 (<0.0001)	-0.750 (<0.0001)	-0.762 (<0.0001)	0.726 (<0.0001)
Chlorophyll	-0.760 (<0.0001)	-0.479 (0.003)	-0.554 (0.0005)	-0.404 (0.015)	0.226 (NS)	0.265 (NS)	0.737 (<0.0001)	-0.830 (<0.0001)	-0.839 (<0.0001)	0.812 (<0.0001)
N-leaching	-0.017 (NS)	0.094 (NS)	0.219 (NS)	0.242 (NS)	0.188 (NS)	0.159 (NS)	-0.105 (NS)	-0.010 (NS)	-0.015 (NS)	-0.042 (NS)
Shoot Yield	-0.529 (0.0009)	-0.222 (NS)	-0.262 (NS)	-0.134 (NS)	0.338 (0.044)	0.350 (0.037)	0.548 (0.0005)	-0.655 (<0.0001)	-0.656 (<0.0001)	0.661 (<0.0001)

(   ): p-value

§NS= not significant

CHAPTER 5
CONCLUSIONS

Six different N rates and two clipping management (return vs. remove) were studied for their effects on NO_3-N leaching, shoot growth, TKN concentration, turf visual quality and color, chlorophyll content, and multispectral reflectance (MSR) in Empire zoysiagrass in 2008.

There were differences in NO_3-N leaching, shoot growth, turf visual quality and color, and chlorophyll content due to N rate. Interestingly, however, there were no significant difference in NO_3-N leaching, shoot growth, TKN concentration, and turf visual color between CRT and CRM treatment. Even CRM had higher score in turf visual quality and chlorophyll content than CRT treatment. However, there was significant interaction for NO_3-N leaching between CM and N rate treatment during all trial periods except Sep. The NO_3-N leachate dramatically increased when the highest N rate (294 kg N ha^{-1}) was combined with more CRT treatment than CRM, resulting in nitrate-N leaching exceeding the USEPA standard. This result implies that N returned from clippings increases in condition of high N rate. Thus, if to maintain N environmentally safe is a goal through avoiding NO_3-N leaching, it is important to abstain from applying high N rate (over 196 kg N ha^{-1}) combined with returning clippings to turf. If turf grass clippings are returned, fertilizer rates should be reduced in high N rate.

These results are well supported through MSR data, in which any reflectance at varying wavelengths had no differences with CM. However, responses of CM to growth and stress indices were significantly different. The CRT showed less turf growth and higher stress than CRM treatment through entire experiment period. Consistent results were also shown that higher N rate plots generally had less stress than lower N rate.

Growth and stress indices such as NDVI, Stress, and IR/R showed the significant and consistent linear correlation with all evaluations used in this study.

In sum, we conclude that CRT treatment caused higher stress and less turf health than CRM treatment for Empire zoysiagrass in 2008. This may result from clipping size, which can cause delay of clipping decomposition, by using rotary mower. Bigger clippings remain on the turf surface longer, covering the surface and reducing photosynthesis activity of turf. This is likely to reduce quality and color as well as chlorophyll level in shoot.

Because of different conclusions from previous research about the effect of CM, and because of physiological or inter-species difference from other turf system, further studies on mower effect of CM and other warm-season grasses are needed.

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