FATE OF APPLIED NITROGEN UNDER FORCED RUNOFF AND LEACHING FROM BERMUDAGRASS FAIRWAYS

By

RYAN STUART ADAMS

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

UNIVERSITY OF FLORIDA

2013

To my parents for their love and support

ACKNOWLEDGMENTS

I wish to express my gratitude to Dr. Bryan Unruh and Dr. Jason Kruse, the co-chair of my supervisory committee. Dr. Unruh and Dr. Kruse gave me the opportunity to follow my dream of attaining a Master of Science degree and also provided mentoring and inspiration along the way. I am also appreciative to the other member of my supervisory committee Dr. Jerry Sartain, for his guidance, encouragement and wisdom.

Special thanks go to Phil Moon, biological scientist at the West Florida Research and Education Center, and Mark Kann, manager of the Plant Science Education and Research Unit, for their assistance and management of my studies. Thanks go to Jayson Ging and Jason Haugh who provided insight and assistance during my graduate studies. Thanks also go to my fellow turf graduate students Brian Glenn, Natasha Restuccia, and Jing Zhang for assistance and encouragement. Finally, thanks go to my parents Todd and Lori Adams and the rest of my family, whose reassurance and support never stopped.

TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

Table page

LIST OF FIGURES

LIST OF ABBREVIATIONS

AS	Ammonium sulfate
BMPS	Best management practices
DGCI	Digital green color index
DIA	Digital image analysis
DAI	Days after initiation
ET	Evapotranspiration
FAWN	Florida automated weather network
FBMPS	Florida best management practices
HAT	Hours after treatment
MG TSN L^{-1}	Milligrams of total soluble nitrogen per liter or parts per million
NDVI	Normalized difference vegetation index
N	Nitrogen
OP	Ortho-Phosphate
PCU	Polymer coated urea (60-day)
RVI	Ratio vegetative index
SCU	Sulfur coated urea
SPL	Subplot location
TKN	Total Kjeldahl nitrogen
TSN	Total soluble nitrogen
UF	Urea formaldehyde
UTC	Untreated control
XCU	Agrium polymer sulfur coated urea

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

FATE OF APPLIED NITROGEN UNDER FORCED RUNOFF AND LEACHING FROM BERMUDAGRASS FAIRWAYS

By

Ryan S. Adams

August 2013

Chair: Name J. Bryan Unruh
Cochair: Jason Kruse
Major: Horticulture Sciences

Numerous regulations and ordinances have recently been enacted to reduce nonpoint source pollution from turfgrass systems as a result of Nitrogen (N) runoff and leaching. A worst case scenario field study was conducted to determine the fate of applied N from bermudagrass fairways. { TC ABSTRACT } Each 48 kg N ha-1 fertilizer treatment was applied to a 7% slope at four separate interval distances (0.0, 0.9, 1.8, and 3.6 m) and was immediately followed by an irrigation event of 46 mm hr-1. The N leaching study was to determine N fate following a 144 kg N ha-1 application coupled with excess natural and simulated rainfall. Forced runoff and leachate samples were collected systematically after treatment and analyzed for Total Soluble Nitrogen (TSN) (Antek 9000N Series analyzer). Runoff TSN loads were significantly affected by fertilizer source with the highest loads occurring from the soluble source ammonium sulfate (4.13 mg TSN L-1) > urea formaldehyde (1.04 mg TSN L-1) > polymer coated urea (0.06 mg TSN L-1) = control (0.02 mg TSN L-1). A 3.6 m unfertilized buffer for ureaformaldehyde reduced TSN loads by a quantity of 0.26 to 0.75 mg TSN L-1 in contrast to 1.8 m buffer. Results from the N leaching found inconsistent results in the

first event, followed by TSN levels in the second and third below the analytical instrument’s method detect limit (MDL) of 1.0 mg TSN L-1.

CHAPTER 1
GENERAL INTRODUCTION

Nonpoint source pollution from plant nutrients has the potential to cause increased levels of algae or phytoplankton. Eutrophication is the process in which a water source becomes polluted with elevated levels of nitrogen (N) or phosphorus (P) (Rice and Horgan, 2010). Eutrophication and low oxygen levels have led to areas of the world being considered dead zones (Dodds, 2006). As algae and phytoplankton levels rise, the carbon dioxide and dissolved oxygen levels fluctuate resulting in rapid pH changes (NCDENR, 2013). Rapid pH changes have the potential to create an environment containing insufficient dissolved oxygen through respiration and/or organism death and decomposition (NCDENR, 2013). A reduction in the amount of dissolved oxygen can produce a habitat unsuitable for certain fish species (Rice and Horgan, 2010). In addition to the environmental concerns surrounding aquatic ecosystems, eutrophication can lead to contaminated drinking water. The current U.S. drinking water standard for nitrate nitrogen (NO_3-N) is 10 mg L^{-1} (USEPA, 1976).

A growing environmental concern in Florida and other states is nutrient leaching and runoff from established turfgrass sites. Previous research concluded that N leaching losses are dependent on the frequency of application and fertilization rate (Erickson et., 2010; Reike and Ellis, 1974; Petrovic, 1990; Barton et al., 2006; Soldat and Petrovic, 2008). In addition to the threat of leaching, Easton et al., (2005) determined nutrient transport in runoff is affected by intensity, duration, and total volume of rainfall/irrigation, soil moisture content, soil texture, slope, and fertilizer application rate and source.

Bermudagrass Fertilization and Maintenance

Some of the world's most important warm-season, sod-forming perennial grasses which are able to produce high quality turf and forage belong to the genus *Cynodon* (Taliaferro, 1995). Bermudagrass (*Cynodon dactylon* [L.] Pers.) was first introduced to the United States from Africa in the mid 1700's (Hanson et al., 1969). In 1954, a hybrid cross of *Cynodon transvaalensis* (2n=2x=18) and *Cynodon dactylon* (2n=4x=36) called 'Tifway' was introduced (Burton, 1960). Tifway was selected due to its texture, rigidity, resiliency, resistance to diseases and weeds, and quick recovery capabilities (Burton, 1960). The generalized mean evapotranspiration (ET) rate for Tifway ranges from 2.5 to 5 cm week^{-1} during the summer months (Cisar and Miller, 1999). Tifway is often labeled as the most extensively used improved cultivar in the warm climatic region (Beard, 1982) and is often used for golf course fairways. Bermudagrass fairways require N fertilization rates between 144 to 288 kg N ha^{-1} yr^{-1} (Sartain et al., 1999).

Turfgrass demands for N are greater than any other nutrient (Beard, 1973). N is relied upon for several different functions which include growth (Beard, 1973), composition of amino acids, protein synthesis (Brady and Weil, 2008), and its role as a component of chlorophyll, which aids in the conversion of light photons to chemical energy (Havlin et al., 2005). With the high frequency of N fertilization, several N-based fertilizer sources have been produced to reduce the number of applications needed by releasing N over time. These products range in source from slow/controlled release sources such as coated, stabilized, and methylated products.

Maintaining sufficient levels of nutrients through fertilization practices can provide enhanced visual quality, recovery, regrowth, and vigor along with increased resistance to pests, diseases and unwanted weed species (Sartain et al., 1999; Bowman et al., 2002). Fertilizer needs and recommendations vary across the state of Florida depending on location, species, and desired maintenance level (Trenholm and Unruh, 2009). Day length has been determined to have a strong influence on turfgrass nutrient uptake, with the largest nutrient quantities occurring during the stage of most active growth (Sartain, 2010). Plant growth rate which is positively correlated to temperature and moisture levels, how much N is available in the soil, N rate and fertilizer source applied, and differences in uptake rate by a specific turfgrass species are all factors that affect N uptake (Petrovic, 1990). Optimizing nutrient levels and N uptake capabilities reduces the consequences and concerns of nonpoint source pollution (Petrovic, 1990).

In addition to the threat of N, P nonpoint source pollution has been of concern for many years and is blamed for accelerated eutrophication (Daniel et al., 1998). Like N, P also plays a significant role in energy transfer (Havlin et al., 2005) and is a structural component of DNA and RNA (Brady and Weil, 2008). P availability for plant use is a function of the root growth, soil P concentration in solution, and the ability of the soil to replenish depleted P (Barber, 1995). With the potential to cause accelerated eutrophication, regulations have been developed to restrict P fertilizer applications across the country. Minnesota (Rosen and Horgan, 2005), Wisconsin (State of Wisconsin, 2009), and Westchester County, New York (County of Westchester, 2009), have implemented P regulations in an effort to minimize environmental threats.

The Florida Department of Environmental Protection (FDEP) in accordance with the United States Environmental Protection Agency (USEPA) have set a numeric nutrient criterion to cover and monitor all significant waterways across the State of Florida (FDEP, 2012; USEPA, 2012a). In addition, the FDEP has taken another approach by designating Lake Okeechobee Basin, Everglades, Green Swamp and Apopka basin as P sensitive regions (FDEP, 2007; 2008; Hodges et al., 2006). P sensitive designation means application of an organic fertilizer source containing P must be determined by crop P requirements and not on N which is typically used for other regions of Florida (Mylavarapu, 2011). The implementation of agricultural BMPs has prevented 2,429,440 kg of P from entering the Florida Everglades (FDEP, 2007). The numeric nutrient criterion, implementation of agricultural BMPs and the designation of P sensitive regions ensures imporved water quality to the 93% of Florida residents who use groundwater for drinking (FDEP, 2008); as well as creating a healthy habitat for wildlife and recreation (Mylavarapu, 2011).

On county and local levels in the State of Florida, new ordinances and legislation have been developed, which only allow P application when deficiencies have been confirmed by a soil or tissue analysis test performed by a State of Florida-certified laboratory (FDEP, 2010; County of Pinellas, 2010). Furthermore, prior to 01 January 2014, all commercial fertilizer applicators must successfully complete training and continuing education requirements in the Florida-friendly Best Management Practices for Protection of Water Resources by the Green Industries, offered by the FDEP through the University of Florida IFAS Florida-friendly Landscapes program (FDEP, 2010). In addition, starting 01 January, 2014 all commercial applicators must carry their Florida Department of Agriculture and Consumer Services commercial fertilizer applicator certificate at all times when applying fertilizer (FDEP, 2010).

Mitigating Nonpoint Source Pollution Unfertilized Buffer Strips

Contamination of a water source that does not meet the definition criteria of "point source" in section 502(14) of the Clean Water Act is known as nonpoint source pollution (USEPA, 2012b). Nonpoint source pollution from golf courses via surface water runoff is a potential environmental threat because of the golf course's close proximity to bodies of water (Linde et. al., 1995). Higher degrees of fairway slope, higher fertilizer use rates, and large fairway acreage present a greater threat to nonpoint source pollution than putting greens and tees drainage systems (Shuman, 2002). Fairway acreage equates to approximately 33% of a typical golf course; which can create an increased risk because of the increased likelihood to border a body of water (Watson et al., 1992). These factors contribute to the negative public perception that golf courses potentially contaminate water bodies via nutrient surface runoff (Shuman, 2002).

Dillaha et al., (1989) categorized buffer strips as riparian buffers, filter strips, grassed waterways, shelterbelts, windbreaks, living snow fences, contour grass strips, cross-wind trap strips, shallow water areas that allow wildlife habitat, field borders, alley cropping, herbaceous wind barriers, and vegetative barriers. Vegetative buffer strips have been well-studied and are a common occurrence to in agricultural settings (Dillaha et al., 1989). Vegetative buffer strips are designed to remove contaminates through filtration, deposition, adsorption, and infiltration (Dillaha et al., 1989). Previous research has shown that one of the best approaches to mitigate nutrient runoff is to use of vegetative buffer strips (Blanco-Canqui et al., 2004; Krutz et al., 2003).

Turfgrass has been used as a vegetative buffer because its dense nature can provide soil stability and reduce large amounts of sediment erosion (Gross et al., 1990). In addition, dense stands of turfgrass create a more tortious pathway and encourage water infiltration (Easton et al., 2005; Moss et al., 2006). Proper management of turfgrass through fertilization, irrigation, mowing and aeration has been shown to promote healthy turfgrass (Walker and Branham, 1992; Balogh and Anderson, 1992; Balogh and Walker, 1992; Turgeon, 2011; Witteveen and Bavier, 1999).

A healthy turfgrass stand reduces nonpoint source pollution in contrast to bare soil or unhealthy turfgrass (Erickson et al., 2001). Turfgrass increased infiltration by more than 65% over a two-year period in comparison to bare soil (Easton et al., 2005). . Soil erosion was reduced when turfgrass was established over bare soils (Wauchope et al., 1990; Gross et al., 1990; 1991). Furthermore, the establishment of turfgrass increased the amount of irrigation/rainfall that was able to be applied before runoff initiated in comparison to bare soils. Krenitsky (1998) found bare soil consistently had higher runoff rates (1.21-1.52 mm min^{-1}) in comparison to an area established with sod (0.21-0.76 mm min^{-1}).

In most research, data supports that N movement through and across the soil profile are positively correlated with rainfall/irrigation amounts and the initial soil moisture. Cole et al., (1997) observed that when the underlying soil of bermudagrass was relatively dry, runoff volumes were 4 to 16% of applied, however, when the same soil was moist, runoff volumes increased to 49 to 80%. Easton et al., (2005) found runoff volumes decreased as infiltration rates and shoot density increased.

The unpredictable nature of rainfall has led to the utilization of rainfall simulators and irrigation when studying N movement. The use of artificial rainfall allows for increased efficiency and control. However, as Meyer & Harmon (1979) identified rainfall simulators often have issues in accurately simulating rainfall’s physical characteristics in wide-spread field use. In a study comparing in-ground irrigation and a rainfall simulator, Bell & Koh (2011) detected that runoff from the irrigated plots averaged 23.6 mm h^{-1}; while runoff from the rainfall simulator plots averaged 22.4 mm h^{-1}. These differences in runoff rates between irrigation and simulation were not statistically significant.

With the focus in Florida on implementation of Best Management Practices (BMPs), there is a need to develop a better understanding of nonpoint source pollution via runoff from turfgrass systems. The N runoff study was created in response to some counties and municipalities developing their own local ordinances to restrict fertilizer application within certain distances from a body of water. However, the optimal unfertilized width that will minimize movement of fertilizer sources and nutrients to nearby bodies of water has not been determined.

N Leaching Following High Application Rates

Potential N losses and nutrient contamination originate from surface runoff, leachate through the soil profile, volatilization, denitrification and clipping removal (Petrovic, 1990). Research suggests that numerous factors such as fertilizer rate, fertilizer source, frequency, application technique, irrigation management, establishment period, and turfgrass species and cultivar are associated with N leaching losses (Barton, et al., 2006; Bowman et al., 2002; Cisar et al., 1991; Erickson et al., 2010; Geron et al., 1993; Reike and Ellis, 1974; Snyder et al., 1976, 1984, 1989; Petrovic, 1990). There are several methods used to study N leaching capabilities. Petrovic (1990) categorized these studies into drainage water, soil sampling, sampling of soil water above the saturated zone, trapping NO_3-N on ion exchange resins, and sampling shallow groundwater.

Overall, research has consistently found that NO_3-N leaching in cool season turfgrass is greater with the use of soluble N products in comparison to slow release products (Nelson et al., 1980; Mosdell and Schmidt, 1985; Sheard et al., 1985; Petrovic et al., 1986; Mancino and Troll, 1990; De Nobili et al., 1992; Geron et al., 1993; Engelsjord and Singh, 1997). Since polymer coated urea (PCU) products were first introduced, there have been several studies to examine their effectiveness at reducing N leaching losses (Guillard and Kopp, 2004; Petrovic, 2004; Wu et al., 2010). Guillard and Kopp (2004) found N leaching varied as much as 30 fold simply based upon fertilizer sources when applied at 147 kg N ha^{-1} yr^{-1}. NO_3-N leaching losses were 16.8%, 1.7% and 0.6% of applied for ammonium nitrate, PCU, and natural organic derived from turkey litter (Sustane™), respectively (Guillard and Kopp, 2004). A study conducted by Petrovic (2004) on a Kentucky bluegrass (*Poa Pratensis* L.) sports field showed N losses were reduced from 29 - 47% to 0-12% of applied when PCU fertilizer were used compared to urea.

Previous slow release N leaching research has shown that the majority of N leached from ureaformaldehyde (UF), sulfur-coated urea (SCU), activated sewage sludge (Milorganite™) or isobutylidenediurea (IBDU) occurs 50-180 days after application (Rieke and Ellis, 1974; Nelson et al., 1980; Brown et al., 1982; Snyder et al., 1984; Morton et al., 1988; Mancino and Troll, 1990). NO_3-N losses in hybrid bermudagrass were greatest when fertilized with ammonium nitrate (AN) in comparison to less soluble sources > 12-12-12 > activated sewage sludge (Milorganite™) > IBDU > UF (Brown et al., 1982). Guertal and Howe (2012) also determined leaching was significantly affected by fertilizer source with the greatest leaching occurring from the soluble source urea (6.8 mg NO_3-N) > PCU (5.6 mg NO_3-N) = stabilized urea (UMaxx™) (5.8 mg NO_3-N) > control (3.0 mg NO_3-N) when applied at a rate 73.0 kg N ha^{-1}. A reduction was observed in NO_3-N leaching from 32% to 23% when fertilized with IBDU rather than urea (Nelson et al., 1980).

Greater nutrient leaching in sandy soils has been heavily correlated with increased irrigation and rainfall (Snyder et al., 1984; Morton et al., 1988; Petrovic, 2004; Erickson et al., 2005). For example, Snyder et al., (1984) found that daily irrigation losses ranged from 22 to 56%, while scheduling irrigation on soil moisture depletion reduced NO_3-N leaching to <1%. Over irrigation and the use of soluble fertilizer sources contributed more to NO_3-N leaching than the underlying soil composition (Brown et al., 1977; Snyder et al., 1984; Morton et al., 1988). Over irrigation and N fertilizer rates were found to be insignificant on total NO_3-N leached (McGroary et al., 2011). However, McGroary et al., (2011) observed the highest totals of NO_3-N leaching occurred under the highest N rate and most heavily irrigated plots.

The nutrient leaching study was created to assess and evaluate nine N sources applied at an excess rate coupled with intense irrigation/rainfall events. Research has previously determined N leaching is of minimal risk when applied at recommended rates (Erickson et al., 2008; Reike and Ellis, 1974; Sheard et al., 1985; Starr and DeRoo, 1981; Mancino and Troll, 1990; Miltner et al., 1996); however, the majority of these studies did not look at N fate when fertilizer recommendations and irrigation rates were exceeded.

CHAPTER 2
WIDTH OF TURFGRASS UNFERTILIZED BUFFER STRIPS AND THEIR IMMEDIATE INFLUENCE ON NITROGEN FERTILIZER MOVEMENT FOLLOWING EXCESS IRRIGATION

Introduction

Dillaha et al., (1989) categorized buffer strips as riparian buffers, filter strips, grassed waterways, shelterbelts, windbreaks, living snow fences, contour grass strips, cross-wind trap strips, shallow water areas that allow wildlife habitat, field borders, alley cropping, herbaceous wind barriers, and vegetative barriers. Furthermore, vegetative buffer strips are recognized as one of the most widely accepted methods to mitigate runoff and prevent nutrient contamination (Blanco-Canqui et al., 2004; Krutz et al., 2003). Vegetative buffer strips are designed to remove contaminates through filtration, deposition, adsorption, and infiltration (Dillaha et al., 1989). With proper maintenance, turfgrass has the ability to minimize environmental risks by performing as a vegetative buffer (Erikson et al., 2001). Dense turfgrass creates a more tortious pathway that encourages water infiltration and reduces nutrient runoff (Easton et al., 2005; Moss et al., 2006).

Turf sites need fertilization and water, which has led to the public's perception that turf contributes to nonpoint source pollution (King et al., 2007). However, the public's perception of turf contributing to nonpoint source pollution exists and adequate steps need to be taken to minimize risk (Pratt, 1985; Peacock et al., 1996; Smith and Bridges, 1996; Shuman, 2002; Kohler et al., 2004; Balogh and Walker, 1992). Nitrogen (N) applied to turfgrass can escape the turf/soil system via volatilization, denitrification, leaching, runoff, and clipping removal (Petrovic, 1990).

With the focus in Florida on implementation of Best Management Practices (BMPs), there is a need to develop a better understanding of nonpoint source pollution via runoff from turfgrass systems. One attempt to reduce fertilizer loss from turfgrass systems is the Model Ordinance for Florida-Friendly Fertilizer Use on Urban Landscapes (Florida Department of Environmental Protection, 2009b). The Model was designed to assess fertilizer application, landscape design, site preparedness, and irrigation. Within the ordinance, FDEP recommends a low maintenance zone within 3.0 m of any potential water source. This ordinance has been subjected to more stringent local and county ordinances and, as a result, some counties and municipalities have developed their own local ordinances to minimize urban fertilizer applications (Hartman et al., 2008; Hochmuth et al., 2011). Collier County, FL restricts fertilizer application within 3.0 m of water bodies or within 0.9 m when using a deflector shield or drop spreader (Collier County, 2011). Manatee County, FL recommends a 1.8 m low maintenance zone, with no fertilizer applied within 3.0 m of a body of water (Manatee County, 2011). However, the optimal unfertilized width that will minimize movement of fertilizers and nutrients to nearby bodies of water has not been determined. Therefore, the objective of this study was to quantify total soluble nitrogen (N) transport and to evaluate the effective size of an untreated buffer strip or “ring of responsibility” located adjacent to a water body.

Materials and Methods

Field trials were conducted at the University of Florida Plant Science Research and Education Unit (PSREU) in Citra, FL (29°41´ N, 82°17´ W). Thirty-year average temperature and rainfall data have been compiled for Citra, FL (Figure 2-1). On 12 July 2005 ‘Tifway’ hybrid bermudagrass (*Cynodon dactylon x C. transvaalensis* Burtt-Davey) was sprigged onto a research site constructed to simulate a golf course fairway. The study area is comprised of 85.0% Tavares sand (NRCS, 2009), mixed with soil from nearby lake to create a 7.0% laser-graded sloped fairway. To better determine the soil composition, textural analysis samples were taken to a depth of 15.2 cm in November 2011 (Table 2-1). The soils were 78-91% sand, 1.7-6.6% clay, and 3.6-20% silt. The pH ranged from 5.7 and 6.0 according to the University of Florida PSREU soil map (Figure 2-2).

The fairway was segmented into fifty-two individual plots running parallel to the slope (12.2 m by 1.4 m). Each plot was separated by an L-shaped aluminum flashing material that ran the length of the plot. Flashing was buried to a depth of approximately 5.1 cm, leaving 2.5 cm above the turf to discourage runoff water from moving into adjacent plots. A V-shaped aluminum collection weir was situated at the downhill end of each runoff plot. Runoff water that accumulated at the collection weir was directed through approximately 61.0 cm of 5.1 cm PVC drain pipe into a 114.0 L plastic barrel (Figure 2-3).

Between 01 Dec 2009 and 31 Jan 2010 collection containers were installed by boring and removing soil with a 90.0 cm diameter auger. A 20.3 cm layer of gravel was placed in the bottom of each bored hole followed by a 61.0 cm long piece of 10.2 cm perforated pipe leading to a 10.2 cm header pipe. 114 L plastic barrels were placed over the underlying gravel and piping followed by backfilling with native soil. Three downslope drainage lines were later added to the headers to prevent collection containers from floating. A French drain was installed along the uphill end of study site and perpendicular to the plots to reduce upslope runoff from entering the plots. During simulated runoff events holes were dug to help infiltration in areas near irrigation heads where excess water was known to aggregate.

Each plot was mowed biweekly at a height of 12.7 mm using a Toro Greensmaster 1000 walking mower (The Toro Co., Bloomington, MN). Due to the inability to mow closely to the flashing and weir, each triangular weir was mowed with a Redmax® Reciprocator (Redmax Zenoah America Inc., Lawrenceville, GA) to approximately 12.7 mm before each experimental run. Following mowing, a backpack blower was used to remove any grass clippings. The height-of-cut along the flashing edge was slightly higher to provide a more tortious pathway that would minimize water movement down the flashing. The turfgrass near the flashing edges was maintained at a height of approximately 19.0 mm using a string trimmer. This higher height-of-cut was preserved 7.6 cm inward from the aluminum flashing that ran the length of each plot.

Twelve Toro 835 (The Toro Co., Bloomington, MN) irrigation heads supplied the irrigation for each simulated rainfall event and to produce supplemental irrigation. A row of six heads ran parallel across the top of the sloped fairway and six heads ran parallel across the bottom of the sloped fairway below the collection containers. All irrigation heads were leveled and set to 180° for pre-wetting and runoff events. Each irrigation head was installed with nozzle set #34, which supplied 35 gpm. In between runoff events and during fallow periods, irrigation heads were returned to 360° and watered to meet evapotranspiration (ET) rates.

Three N-containing fertilizers were evaluated: 1.) ammonium sulfate (AS); 2.) polymer coated urea (PCU); and 3.) ureaformaldehyde (UF). Each N source was applied at a rate of 48.0 kg N ha^{-1} to plots situated upslope from the collection weirs.

Four different upslope distances were tested; 0, 0.9, 1.8, and 3.6 m and each fertilized plot measured 1.4 m by 2.7 m. Four replications of each combination of N source and distance were conducted along with four untreated plots for comparison purposes. Experimental treatments were arranged as a 3 X 4 factorial in a randomized complete block design with the factors being N source, upslope distance, and an untreated control.

To manage the area above the fertilized swath a 91.0 cm drop spreader was used to apply 24.0 kg N ha^{-1} of AS six times during the summer of 2012. The fertilization started on 27 May 2012 and was subsequently applied on 10 June, 4 July, 23 July, 7 August and 24 August 2012. The area outside of the drop spreader width (each 22.9 cm plot edge separately) was fertilized on the same dates by predetermined weighing and hand fertilization. The plots were lightly watered to prevent fertilization volatilization loss, turfgrass burn and downslope movement. The area downslope from each 2.7 m fertilized swath was left unfertilized throughout the duration of the study period. On 23 February 2012, Oxadiazon (Ronstar™ Bayer Crop Science Corp., Shawnee Mission, KS) impregnated on a 5-0-15 carrier was applied at a rate of 48.0 kg N ha^{-1} to the entire study area. Three (Celsius™ Bayer Crop Science Corp., Shawnee Mission, KS) applications were applied on 13 March 2012, 13 June 2012, and 12 July 2012 to help manage doveweed (*Murdannia nudiflora* Brenan).

Prior to each simulated rainfall event and fertilizer application, the entire site was pre-wet to the point of saturation. Two irrigation events of approximately 76.2 mm were applied 48h prior to fertilizer application followed by a third application of 95.3 mm 24h prior. The day prior to each runoff event, flashing integrity was confirmed and collection barrels were emptied and cleaned using a submersible pump and wet/dry vacuum.

Following fertilizer application, but prior to rainfall simulation, % soil moisture readings were taken using a Field Scout TDR 300 (Spectrum Technologies Inc., Plainfield, IL). Three 7.6 cm depth soil moisture readings were taken 0.0, 1.5, 4.6, 7.6, and 10.7 m from the collection weir. Soil moisture readings at the same location were also taken immediately following rainfall simulation.

During each runoff event, four catch-cans were placed in each plot at 1.5, 4.6, 7.6, and 10.7 m upslope from the runoff weir to catch irrigation water and to allow the determination of irrigation system uniformity. After the simulated rainfall event concluded, each catch-can was emptied into a graduated cylinder and volumes were recorded. Catch-can totals were extrapolated across the runoff gradient as a determination of total irrigation applied to each plot. Irrigation uniformity based upon Christiansen's Coefficient of Uniformity (CU) (Christiansen, 1942) and Distribution Uniformity (DU) (Merriam and Keller, 1978) were determined to be 83.2/72.5; 87.3/79.2; 85.6/79.5 for the first, second and third runs, respectively.

Three simulated runoff events using the in-ground irrigation system were generated during 2012: 11 May, 29 June, and 15 August. Runoff was encouraged by irrigation events providing 44.7, 46.2, and 47.2 mm h^{-1} for the first, second and third runs, respectively. Once runoff ceased approximately 10-15 min after initiation, runoff samples were collected. Contents of each collection barrel were stirred and a 20 ml water sample was collected and placed into a 20 ml scintillation vial. Duplicates were taken every eight samples to check for accuracy.

Water samples were analyzed for total soluble nitrogen (TSN) using an Antek 9000NS Series analyzer (Antek Instruments, Inc., Houston, TX). Samples were also analyzed for Ortho-Phosphate (OP) using a Seal AQ2 method discrete auto analyzer (Seal Analytical Inc., Mequon, WI). The Antek 9000N instrument allows for TSN calibration standards to be analyzed, which produce internal calibration curves. The standard curve before each test required an R^2 value of 0.995 and each four-injection calibrant was examined for outliers using a 5.0% relative standard deviation (RSD).

Once the calibration curves of the known standards were determined to be sufficient, raw unknown N contents were analyzed and compared to the known calibration curve concentrations. Each sample was initially tested on a 1-10 mg TSN L^{-1} calibration curve with four injections per sample. Samples with less than 1 mg TSN L^{-1} concentration were under the method detection limit (MDL) and considered to have undetectable levels. Samples greater than 10 mg TSN L^{-1} were reanalyzed on a 10-100 mg TSN L^{-1} calibration curve with the same set requirements. Samples with a RSD >5.0% were reanalyzed until an accepted standard deviation was achieved. All samples were analyzed within 72h after runoff initiation.

The AQ2 OP method uses internal calibration curves based upon absorbance measured photometrically at 880 nm with a MDL of 0.002 mg P L^{-1}. Quality control solutions such as duplicates and spikes were used every 15 samples. If duplicates were not within a 5.0% RSD, all samples processed since the last spike/duplicate combination were reanalyzed automatically to ensure accuracy. OP samples were analyzed within 48h of collection during the second and third runoff events. Samples from the first event were frozen and analyzed within 3 months of sampling.

Weight flow analysis was conducted after concentration samples were taken by pumping collection tanks into a 208.2 L water barrel suspended from a model DI-100-U RAS1 Restrictive Load Cell (Loadstar Sensors, Inc., Fremont, CA) mounted to a tripod. Runoff water from each plot was weighed individually. Runoff water was inspected for fertilizer prills when samples were collected.

Photos of each unfertilized buffer strip were collected weekly using a Sony Cybershot camera, model DSC-H10 (Sony Corp., New York, NY). Camera settings were; ISO100, 1/40 second shutter speed, and F3 aperture. All images were collected with the use of a portable 53 x 61 x 51 cm light box fitted with four ten-watt compact florescent, 6500 kelvin daylight bulbs. Digital images were taken at 56.0 cm increments down the entire unfertilized buffer strip to detect downslope fertilizer movement following rainfall simulation (Figure 2-4). The number of distances was dependent on the unfertilized buffer strip size; with the possibility of 1, 2, 4, or 8 distances for 0.0, 0.9, 1.8, and 3.6 m, respectively. Each distance refered to the distance downslope from the fertilized swath with 1 = the 56.0 cm increment adjacent to the fertilized swath and 2 = the 56 to 112 cm area downslope of fertilized swath. For example a 1.8 m buffer treatment would have four distances, with distance 1 being adjacent to the fertilized swath, while distance 4 would be the unfertilized buffer strip section next to collection weir. Distance 0 refers to the fertilized swath and distance -1 is the UTC.

Unfertilized buffer strip images were analyzed for dark green color index (DGCI) with the use of digital image analysis software (SigmaScan, v. 5.0, SPSS, Inc., Chicago, IL) and the “Turf Analysis” macro (Karcher and Richardson, 2005). A single image was taken of the fertilized swath.

Normalized Difference Vegetation Index (NDVI) and Ratio Vegetative Index (RVI) were taken using a Crop Circle Model ACS 210 (Holland Scientific Inc., Lincoln, NE). A Geo Scout GIS-400 (Holland Scientific., Lincoln, NE) was used to log the NDVI/RVI data. While taking data, the instrument was held approximately 91.4 cm above the turf surface and each subplot was recorded separately. The subplots were defined as the area above the fertilized swath, the fertilized swath, and unfertilized buffer strip.

Clippings were collected weekly for one month following runoff events. Clippings were only collected from a single mower pass through the fertilized strip. Clipping samples were immediately placed into a drying oven set at 70°C for a minimum of 72 hours. Once weighed, clipping were proportioned (25% of each sample) and combined (5 collections) based upon plot designation, during a given run. Clippings were ground to 1 mm using a Cyclone Sample Mill (UDY Corp., Fort Collins, CO) in preparation for total-Kjeldahl nitrogen (TKN) tissue analysis at UF/IFAS Analytical Services Laboratories in Gainesville, FL.

Color, Quality and Density visual ratings were taken based upon the NTEP rating scale which ranges from 1-9 with a quality rating of 9 being optimal and 1 being dead turf, color rating of 9 being a dark green turf and 1 light pale green color, and density rating of 9 being maximum density (Shearman and Morris, 200x). Ratings in this study $\geq$ 6 were considered acceptable. All ratings were reported in whole numbers.

Results

The main objectives of the statistical analysis were to identify the most effective combination between unfertilized buffer strip size and fertilizer source to minimize TSN runoff loads from turfgrass systems and to maximize turfgrass quality surrounding environmentally sensitive areas. To carry out such an analysis, data were pooled over all three runs and analyzed with SAS/GLIMMIX using a linear mixed model (SAS, 2008). A heterogeneous fitted model was used because variability was not constant across TSN loads by sources. The variability of the response was heterogeneous across two groups; Group 1 (Soluble N source) contained AS, while Group 2 was composed of UF, PCU (Insoluble N source) and the UTC. When separated by grouping, variability became more constant and the resulting heterogeneous parameter estimates are listed in Table 2-2.

A fitted linear mixed effects model using SAS/GLIMMIX determined an event by treatment (fertilizer source by upslope placement) interaction (Table 2-3). Treatments fertilized with AS had the highest TSN loads across all runoff events (Figure 2-5). PCU was able to reduce TSN loads in runoff waters to 0.02 g or 0.41% of the applied N. UF fell in between the two other fertilizer sources at 1.048 g (Table 2-4). Tukey-Kramer's estimates using a 0.05 nominal level showed no differences between PCU and the UTC and upslope placement across AS and PCU. Tukey-Kramer's mean estimates also indicated 95% confidence that the average TSN runoff under UF treatments was 0.86 to 1.11 mg L^{-1} greater than PCU (Table 2-5). TSN significance occurred when UF was applied from a 3.6 m buffer strip (Figure 2-6), which reduced N losses to 3.9% of applied N, while all other distances were comparable and ranged from 6.9% - 7.7% of applied N. A 3.6 m buffer provided 45% less N in comparison to downslope placement closer to the water body. Using Tukey-Kramer's mean estimates, there was 95% confidence that average AS treatments was 1.90 to 4.27 mg TSN L^{-1} greater than UF and 2.89 to 5.26 mg TSN L^{-1} greater than PCU (Table 2-6).

Total Kjeldahl Nitrogen and Biomass for Turfgrass Clippings

A linear mixed effects model for Total Kjeldahl Nitrogen (TKN) concluded significant interaction between treatment and runoff event (Table 2-7). PCU in the August event had the highest TKN levels across all fertilizer sources (Table 2-8). The UTC in the August and June events had the lowest TKN levels in comparison to all other August and June treatments; however UTC TKN levels in August and June runoff events were still higher than any treatment in the May event. Results of statistical tests determined the May event had the lowest TKN and no differences between treatments (Table 2-9).

A linear mixed effects model for clipping biomass weights concluded significant interaction between treatment and Days After Initiation (DAI) (Table 2-10). With the exception of the PCU applied at 0.0, 1.8, and 3.6 m at 1 DAI (Table 2-11), all DAI treatments were not significantly different than the UTC. A difference in clippings at 7 and 14 DAI suggests AS and PCU had higher biomass weights than the UTC. There is no evidence to suggest UF treatments yielded more biomass than the UTC at 1, 7, 14, and 28 DAI. At 21 DAI, all treatments had higher biomass weights than the UTC.

Soil Moisture

A linear mixed effects model for soil moisture concluded a significant interaction between treatment and runoff event by time (Table 2-12). Soil Moisture Before (SMB) application was highly correlated with Soil Moisture After (SMA) runoff events. For all three runoff events soil moisture following runoff events was highest, while the SMB was lower. The soil moisture before and after simulations was highest during the August event. SMA application from the May and June events were in the lowest statistical grouping; while June’s SMB was statistically higher than May (Figure 2-7).

Soil moisture analysis found no evidence AS treatments were significantly different at 0.05 nominal levels (Table 2-13). Tests of statistical analysis determined UF with a 1.8 unfertilized buffer had higher VWC% than the 3.6 m buffer treatment. The offset zero and 0.9 m treatments were not statistically different than the 1.8 or 3.6 m UF treatments. Tukey Kramer's mean separation also suggests the 1.8 m unfertilized buffer was the wettest treatment among the fertilizer source PCU. The 3.6 m PCU treatment was in the second statistical grouping and was greater than the offset zero at a 0.05 nominal level. No evidence suggested that soil moisture was different across PCU 0.0, 0.9, and 3.6 m treatments.

Total Ortho-Phosphate Loading in Runoff

The main objectives of the Ortho-Phosphate (OP) statistical analysis were to identify the potential OP losses following N fertilization. Total OP loads were determined to be of environmental significance ($\geq$ 10 µg OP L^{-1}). Data were pooled over all three runoff events and analyzed using SAS/GLIMMIX across N fertilizer sources using a linear mixed model. Analysis of OP was similar to TSN, but the variability of the response was homogenous across all fertilizer sources and no grouping was used.

Across all three runoff events of the study, the driving factor to reduce OP loads was based upon runoff event by N treatment (Table 2-3). AS treatments had the highest OP loads in runoff occurring in June (Figure 2-8). The May and August events had less OP loads in runoff water following AS fertilization. The lowest statistical OP loads for UF and PCU were observed in the May event. These were the only two fertilizer sources by runoff event interactions that reduced loads under the 10 µg OP L^{-1} threshold. Higher loads were recorded in June and August for both UF and PCU.

The June event produced the highest OP loads and significantly higher than the May event (Figure 2-9). August fell between the other runoff events and differences in Total OP loads were observed from both runoff events. Using Tukey-Kramer's means estimates, the average OP loads under AS treatments were greater than UF, PCU and the UTC at the nominal 0.05 level (Table 2-14). Least square means estimates also indicated there was a 95% confidence level that the average OP loads under UF fertilization from 0.9 m was 0.76 to 13.12 µg OP L^{-1} greater than UF applied 3.6 m above the collection weir.

RVI and NDVI Reflectance

Turfgrass reflectance measurements were taken to compare the relative strengths and uses between RVI and NDVI reflectance as a plant stress indicator. Results of statistical tests for RVI indicated a significant interaction between runoff event and subplot location (SPL) and SPL and DAI (Table 2-15). The fitted linear mixed effects model provided no evidence to suggest differences in SPL at 1 DAI (Table 2-16). RVI values for fertilized AS subplots were greater than unfertilized PCU and UF subplots at 7 and 14 DAI. PCU subplots were in a higher statistical grouping than all unfertilized subplots at 28 DAI and UTC subplots exhibited the least RVI reflectance at 7, 14, 21, and 28 DAI.

Statistical tests concluded a SPL by runoff event interaction for RVI and NDVI. In May, NDVI measured from AS fertilized subplots was in a higher statistical grouping than the UTC. According to RVI (Table 2-17) and NDVI (Table 2-18), AS subplots fertilized in June had greater values than the unfertilized PCU, UF, and UTC subplots. Statistical tests from the August runoff event also determined UF's NDVI was statistically greater than the UTC. The fitted linear mixed effects model for NDVI provided no evidence for a SPL by DAI interaction and was analyzed by DAI. Tukey-Kramer's grouping at the 0.05 nominal levels found 7, 14, and 21 DAI had the highest NDVI values (Figure 2-10). The second categorical grouping contained 28 DAI, followed by the lowest NDVI reflectance being the first day following runoff events (1DAI).

Visual Assessments

Changes in visual parameters as a result of fertilization application and runoff events were fitted into a linear mixed effects model which determined runoff event by SPL interactions for color, quality, and density (Table 2-15). Visual color of AS fertilized turf in May was statistically greater than unfertilized subplots, UTC, and the area managed above the fertilized swath (Table 2-19). Visual color in June and August had higher ratings for fertilized swaths than all unfertilized buffer strips and UTC plots, as well as, PCU fertilized swaths had better color of green than the area above the fertilized swath. During June and August turf color of all fertilized subplots was above the minimum acceptable color rating.

Visual quality of fertilized subplots locations was better than the UTC in June and August (Table 2-20). The August runoff event provided no evidence to suggest differences between the management above and fertilized subplots existed. Throughout the August runoff event, fertilized subplot quality and density were above the minimum acceptable rating.

Ratings of visual density indicated AS and PCU fertilized subplots were more dense than the UTC in June (Table 2-21). During the August runoff event, subplots fertilized with AS had increased density in comparison to the UF unfertilized buffer strip. AS and PCU consistently produced higher density ratings than the UTC throughout all three runoff events.

Visual color ratings were different between SPL by DAI (Table 2-22). Subplots fertilized with PCU and AS had a higher visual color rating then unfertilized subplots 7 and 21 DAI. At 14 DAI, AS treatments had higher visual quality ratings than the unfertilized buffer strips. Color ratings at 1 and 28 DAI showed fertilized PCU subplots performed better than unfertilized buffer subplots regardless of fertilizer source.

Visual quality and density ratings were analyzed using a fitted linear mixed model, which indicated differences between DAI. Analysis of visual quality ratings showed that 1, 14, and 21 DAI had the best overall visual quality (Figure 2-11). Visual quality ratings taken at 7 and 28 DAI were lower. Analysis of visual density ratings suggested that turf at 7 and 14 DAI had the greatest density. Density at 21 DAI was in the second statistical grouping, while 1 and 28 DAI had the lowest turf density ratings.

Dark Green Color Index Imagery

Dark Green Color Index (DGCI) imagery data were pooled over all three runoff events and analyzed using SAS/GLIMMIX with a linear mixed model. Statistical tests using a fitted linear mixed model determined an event by distance and a distance by treatment interaction (Table 2-23). Analysis of DGCI distance by treatment using the fitted linear mixed model found no differences at distances 0,2,3,5,6,7,8 when separated by distance (Table 2-24). At distance 1, AS and UF treatments applied with no buffer had a higher DGCI than PCU applied at 1.8 and 3.6 m. Distance 4 determined AS's DGCI applied at 1.8 m was statistically greater DGCI than UF and PCU 3.6 m as well as PCU applied at 1.8m. When the linear mixed model was separated by treatment, all fertilized DGCI distances had a significantly higher DGCI than unfertilized buffer strips, with the exception of the 0.0 m AS treatment (Table 2-25). AS applied from a 1.8 m unfertilized buffer strip was the only treatment that saw unfertilized buffer strip distance differences at 0.05 nominal levels. Distance 4 had a statistically greater DGCI in comparison to all other distances. The untreated had the lightest green color throughout the study.

The fitted linear model for DGCI also found an interaction between runoff events by distance. The fertilized swath and the distance furthest away from the fertilzed swath had the highest DGCI in May (Table 2-26). Distances 1, 5, 6 were found to have greater DGCI values than other distances. In June the fertilized swath had the highest DGCI. There was no evidence to suggest differences between other distances in June. Distances -1, 0, 4, 7, and 8 were in the highest grouping in August; however distances -1, 7, 4 were not statistically different than the rest of the DGCI distances.

Discussion

In this worst case scenario, PCU minimized TSN runoff levels in comparison to AS and UF. PCU also had the highest TKN values in August across all events by treatments. Although not statically different, TKN from the May runoff event showed that PCU was higher than any other fertilizer source. Petrovic (1990) determined that optimizing nutrient levels and N uptake capabilities reduces nonpoint source pollution, which was shown here by PCU’s increased TKN levels and lower levels of TSN in the runoff water.

An increase in TKN levels was seen across all fertilizer sources as day length and the period most conducive to growth increased over the summer months. The only exception to this was the PCU treatment in June which had a higher TKN value then the other treatments in the June runoff event. This was potentially skewed by the possibility that a fertilizer prill ended up in the TKN analysis. Numerous prills were observed in the clippings biomass from collections 1 and 7 DAI, but were separated out as best as possible prior to tissue grinding and TKN analysis.

PCU produced high visual ratings, consistently above the minimum level of acceptability from June on (with a few exceptions of values just below the minimal acceptable threshold). PCU color ratings also increased 7 DAI. The lower color ratings prior to 7 DAI may have been caused by excess irrigation applied for the runoff event or because of PCU's slow release nature.

All turfgrass plots began the season at or below minimal acceptable, however as the season progressed there was a steady increase in color, quality, density, NDVI, and RVI values, with the highest values occurring following the August runoff event. This may have been due to the minimal fertilization the plots had received in the years leading up to the study. Also the possibility of the excess irrigation above evapotranspiration rates applied between 12 May 2012 and 3 June 2012 and the increased growth rates during the summer months could have influenced the turf.

Differences among subplots were supported by NDVI/RVI data taken across all three runoff events. NDVI/RVI is a measurement value of reflectance sensory that has been show in bermudagrass to be closely correlated with turf quality, N fertilization, and irrigation (Xiong et al., 2007). NDVI/RVI values seemed with relate with differences in fertility (fertilized vs. unfertilized subplots), however differences were not observed across N sources.

There was only one significant difference among TSN loads based upon upslope placement in this study. A reduction in TSN and OP loads was observed when UF was applied from a 3.6m buffer in contrast to shorter buffer strips (1.8, 0.9, 0.0 m). The rest of the fertilizer sources produced no significant differences in upslope placement, which indicates that buffer strip sizes were too narrow in range to reduce AS TSN loads, and regardless of placement minimal to no TSN came from PCU treatments.

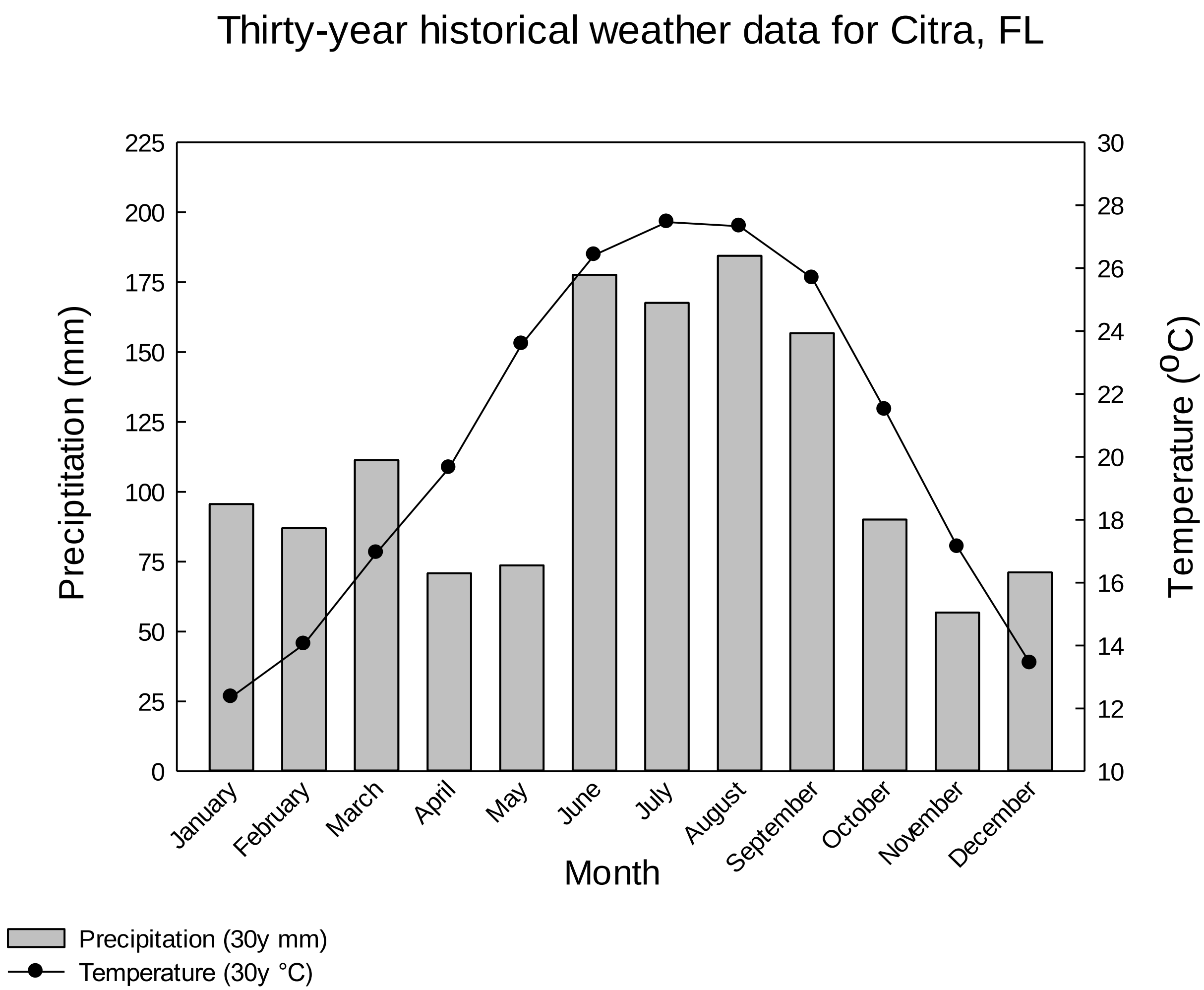

Figure 2-1. Compiled Thirty-Year Weather Data for the Citra, FL region: NOAA National Climatic Data Center

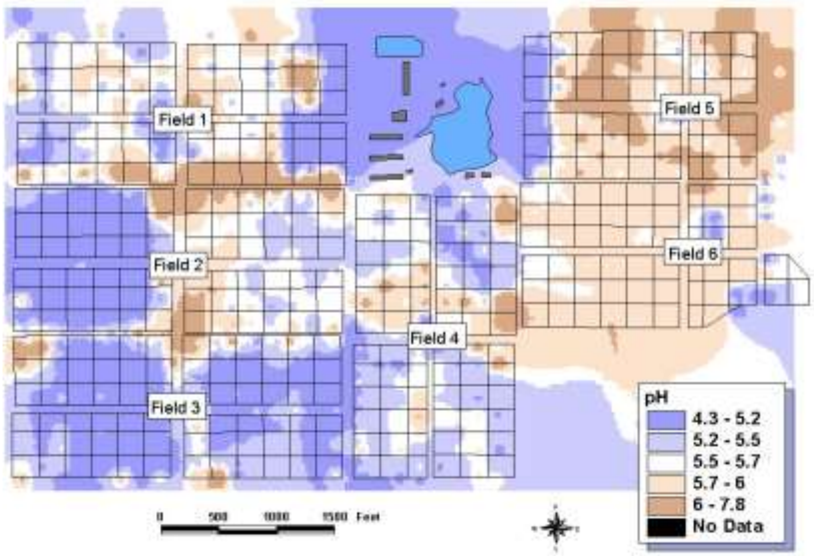

Figure 2-2. Plant Science Research and Education Unit (PSREU) Soil pH Map. Photo courtesy of the Inst. of Food and Agric. Sci., Univ. of Florida, Gainesville. Area of interest is located in the northern part of field six.

Figure 2-3. A V-shaped aluminum collection weir was situated at the downslope end of each runoff plot. Runoff water that accumulated at the collection weir was directed through approximately 61.0 cm of 5.1 cm PVC drain pipe into a 114.0 L plastic barrel. Sleeves and buckets were removed during runoff events. Photo courtesy of Ryan Adams.

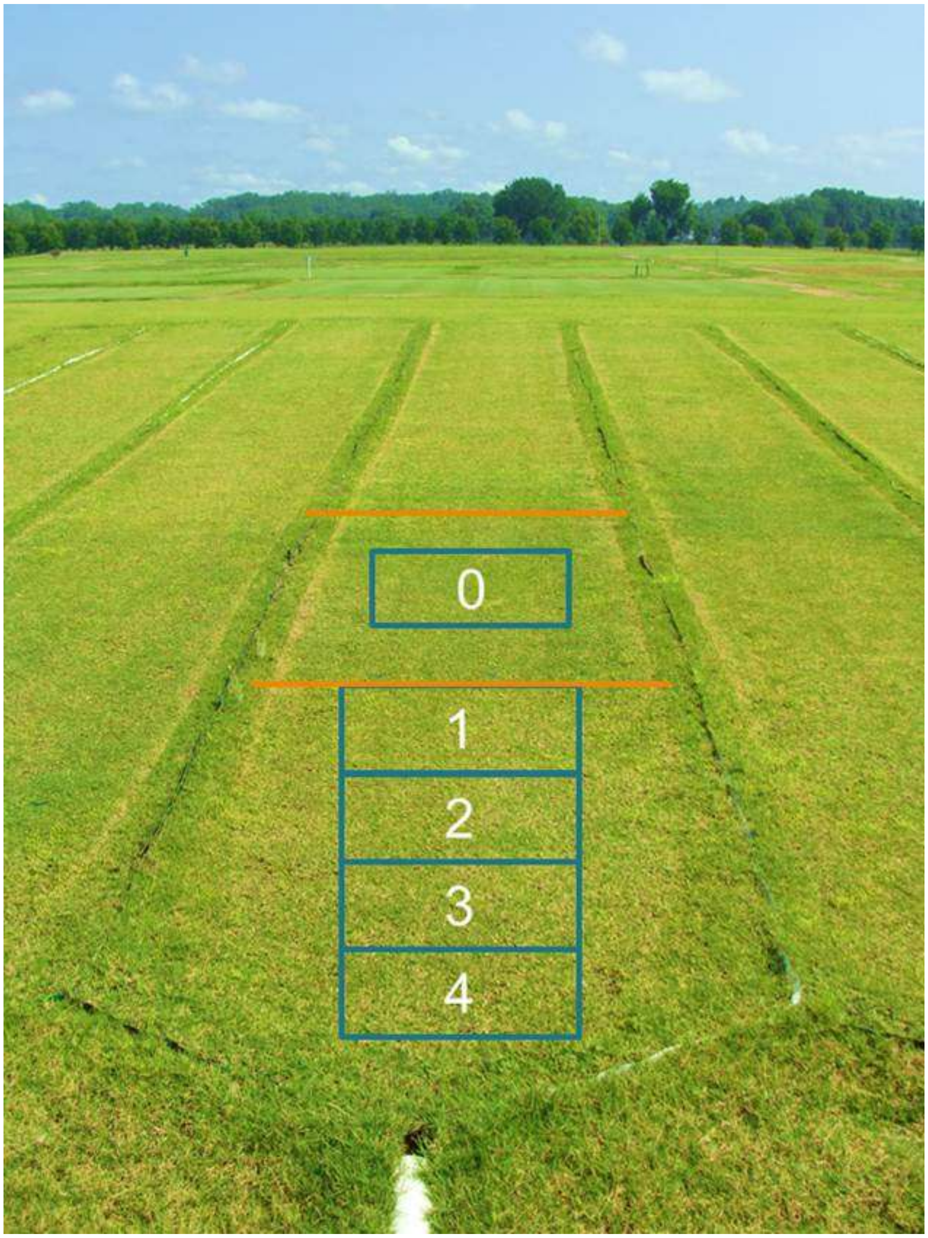

Figure 2-4. The number of images for dark green color index values was dependent on the unfertilized buffer strip size; with a possibility of 1, 3, 5, or 9 distances for 0.0, 0.9, 1.8, and 3.6 m, respectively. Each distance refers to the distance away from the fertilized swath with 1 = the 56 cm increment adjacent to the fertilized swath, 2 = the 56 to 112 cm area downslope of fertilized swath. For example in this image, a 1.8 m buffer treatment would have five distances, with distance 1 being adjacent to the fertilized swath, while distance 4 would be the unfertilized buffer strip section next to collection weir. Distance 0 refers to the fertilized swath. Photo courtesy of Ryan Adams.

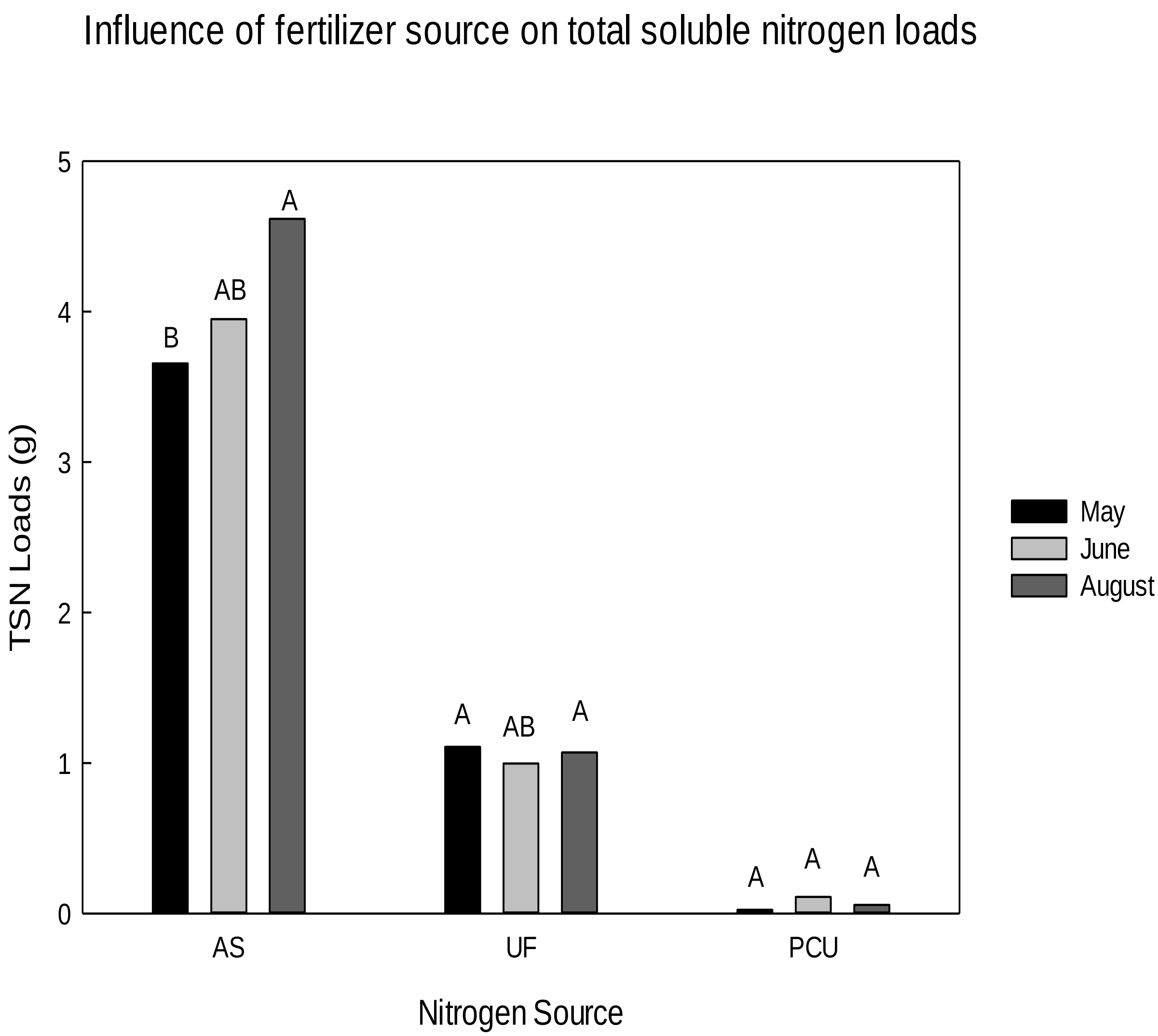

Figure 2-5. Total soluble nitrogen (TSN) loads determined with nitrogen source application of ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) by runoff event: May, June and August. Means with the same letter in a given source were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

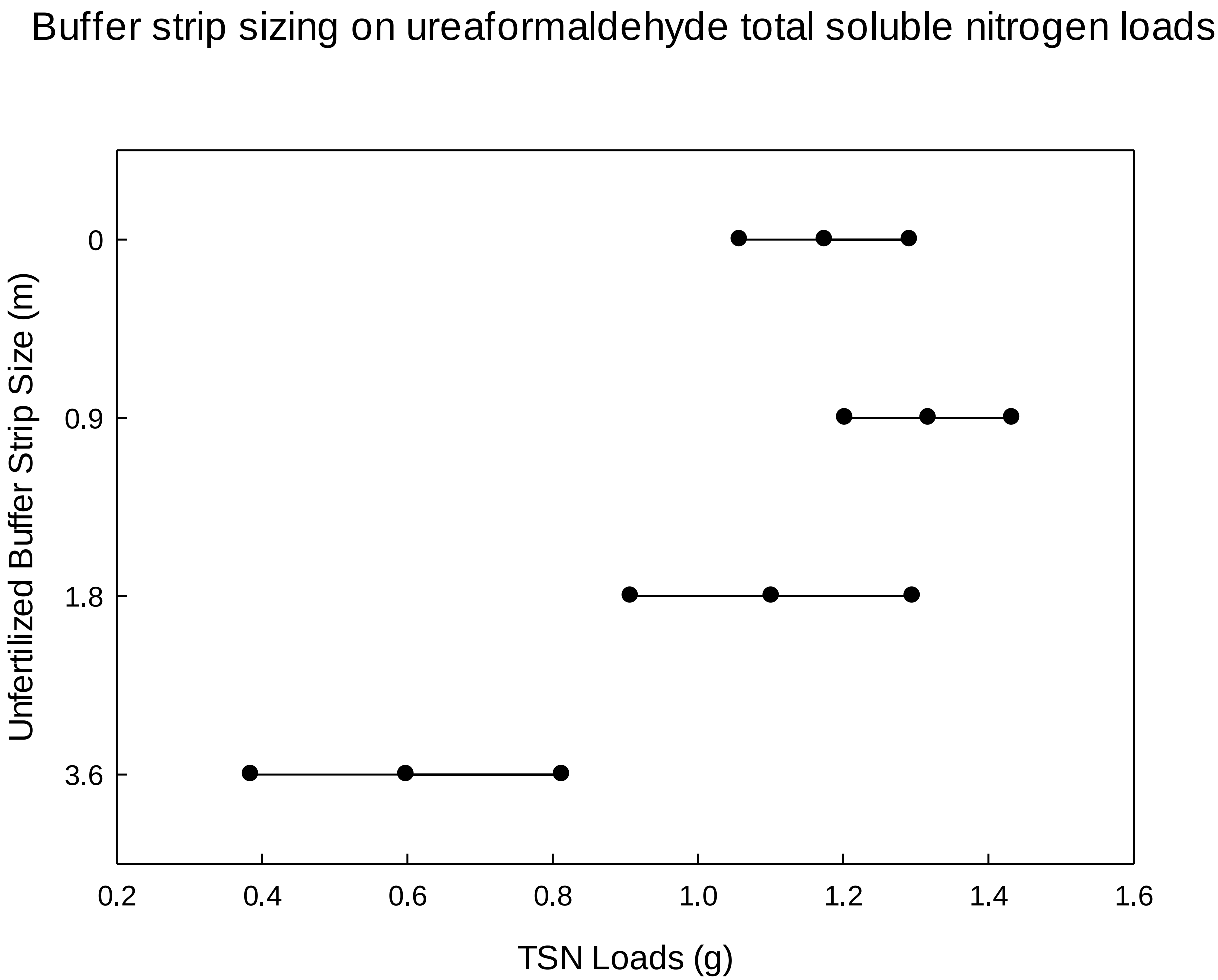

Figure 2-6. Influence of unfertilized buffer strip size on total soluble nitrogen (TSN) loads below an ureaformaldehyde fertilized swath. Lines represent 95% confidence limits and overall means using Proc Glimmix for each unfertilized buffer strip size.

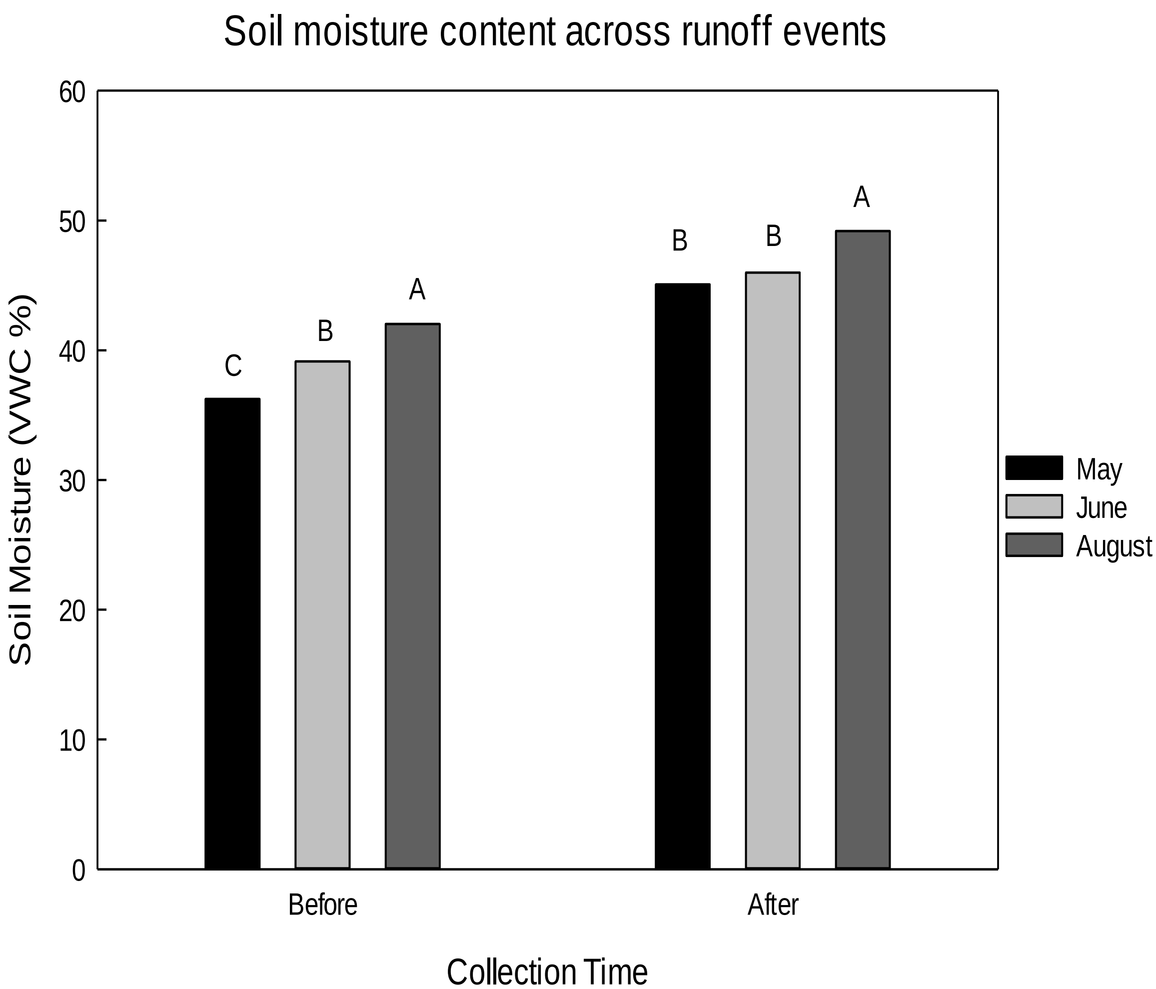

Figure 2-7. Soil moisture content percentage (SMC%) across runoff events sorted by time of collection. In each runoff event, soil moisture was taken before and after runoff initiation. Means with the same letter in a given collection time were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

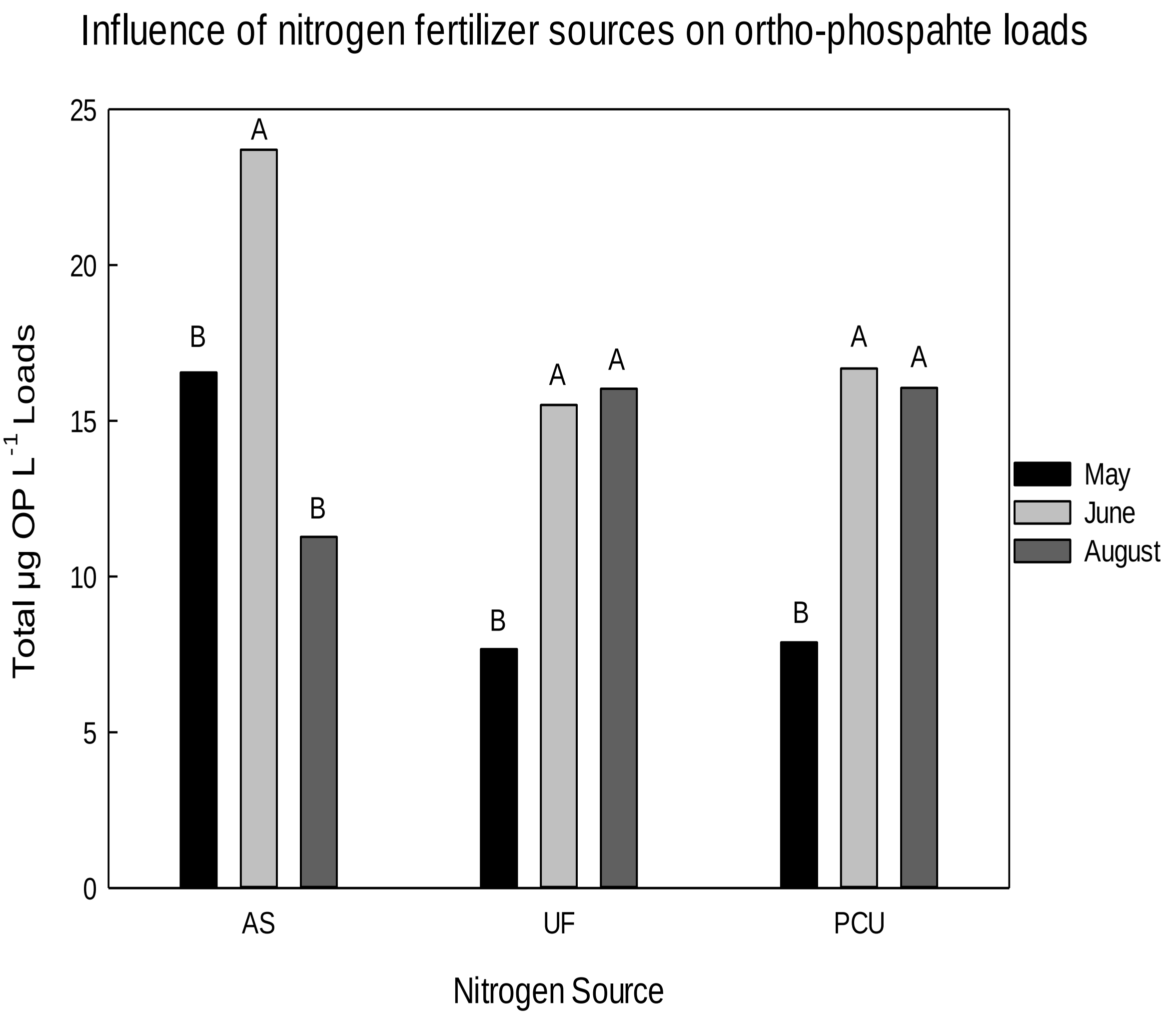

Figure 2-8. Total ortho-phosphate (OP) runoff loads as influenced by application of ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) separated by runoff event: May, June, August. Means with the same letter in a given source were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

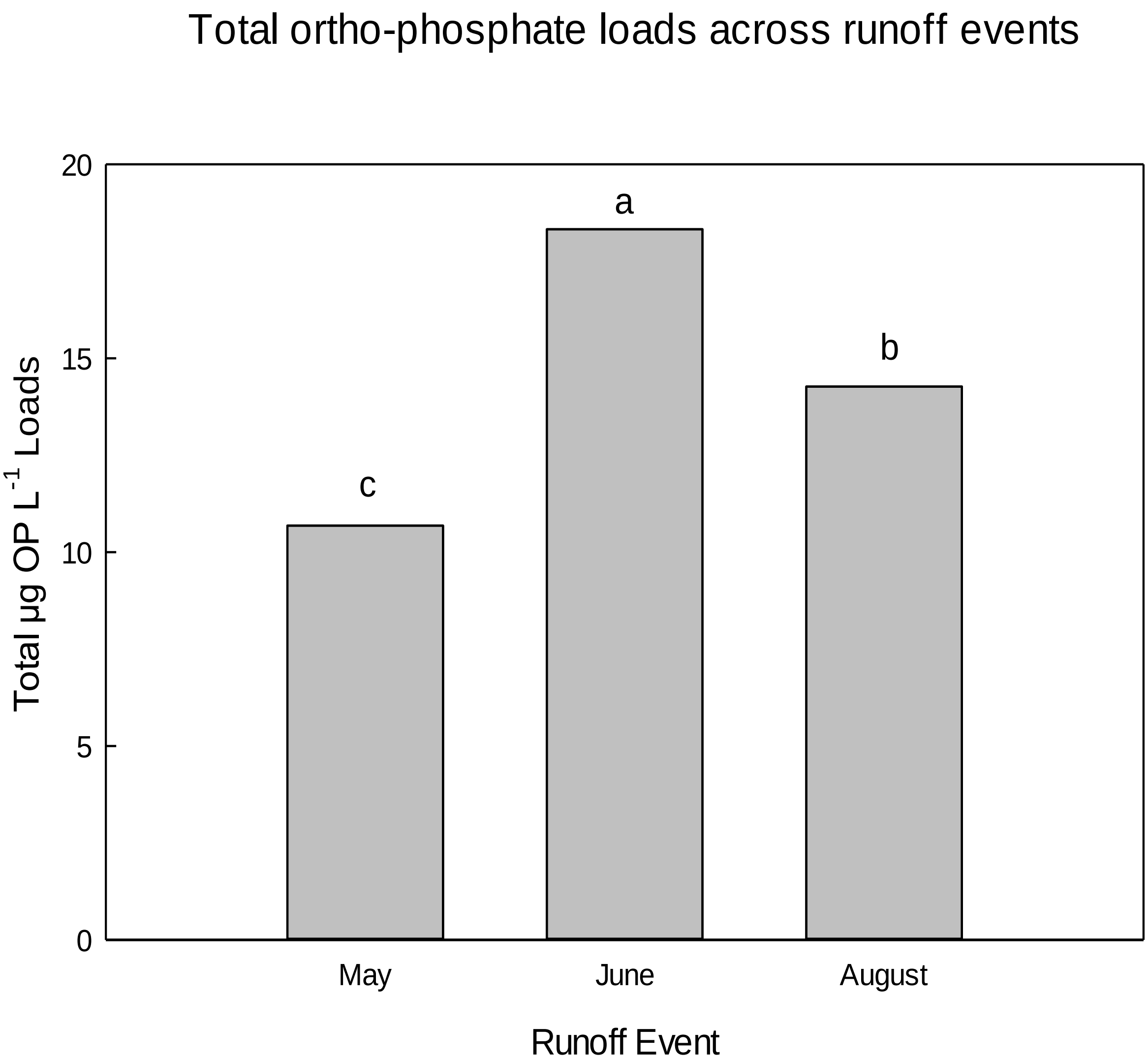

Figure 2-9. Total ortho-phosphate (OP) loads by runoff event: May, June, August. Means with the same letter were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

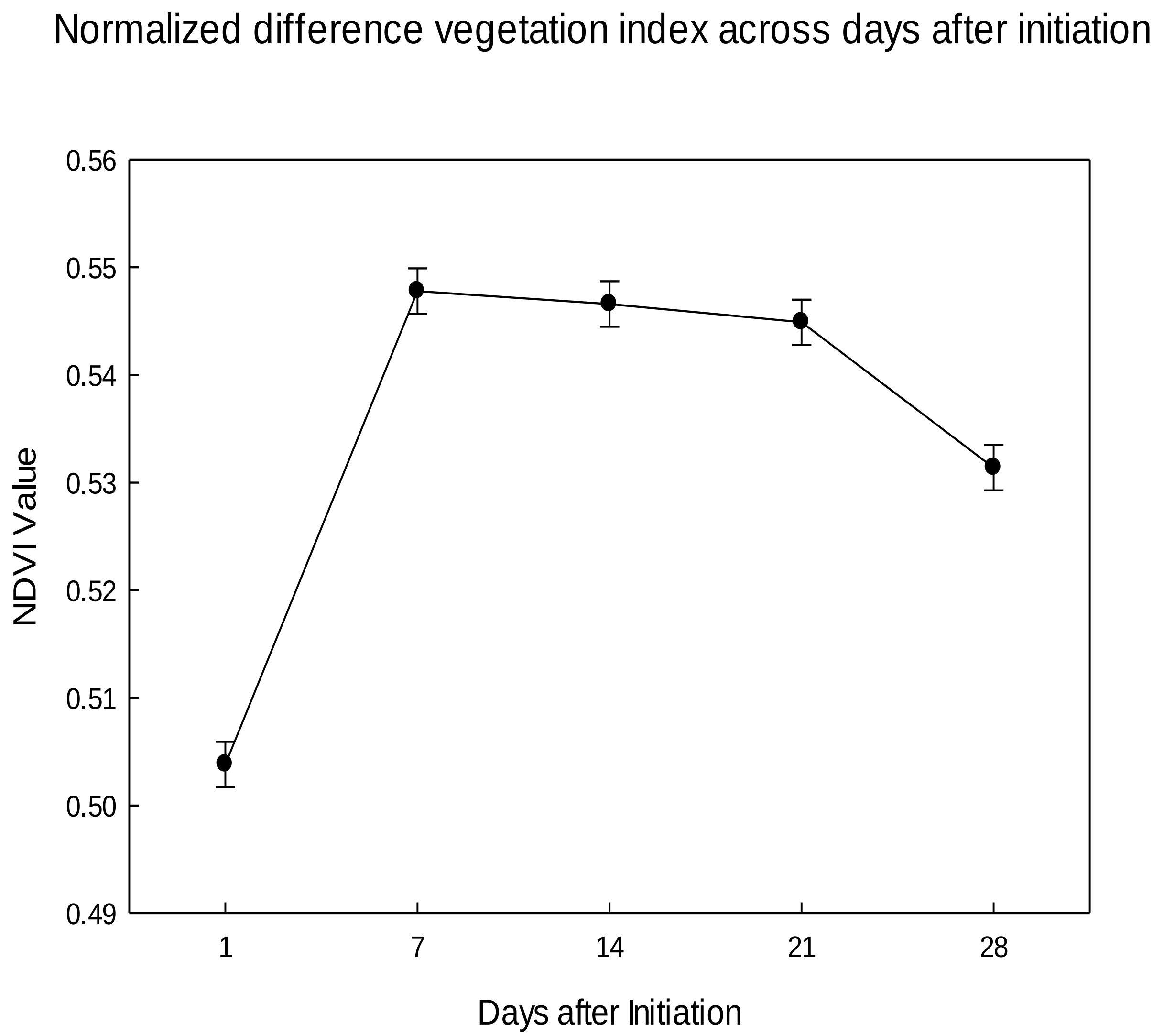

Figure 2-10. Three event average normalized difference vegetation index (NDVI) values across days after initiation (DAI) using Tukey Kramer's LS means separation. Bars at each DAI represent 95% confidence intervals. Normalized difference vegetation index (NDVI) value was calculated using: NDVI = $(R_{NIR} - R_{red})/(R_{NIR} + R_{red})$.

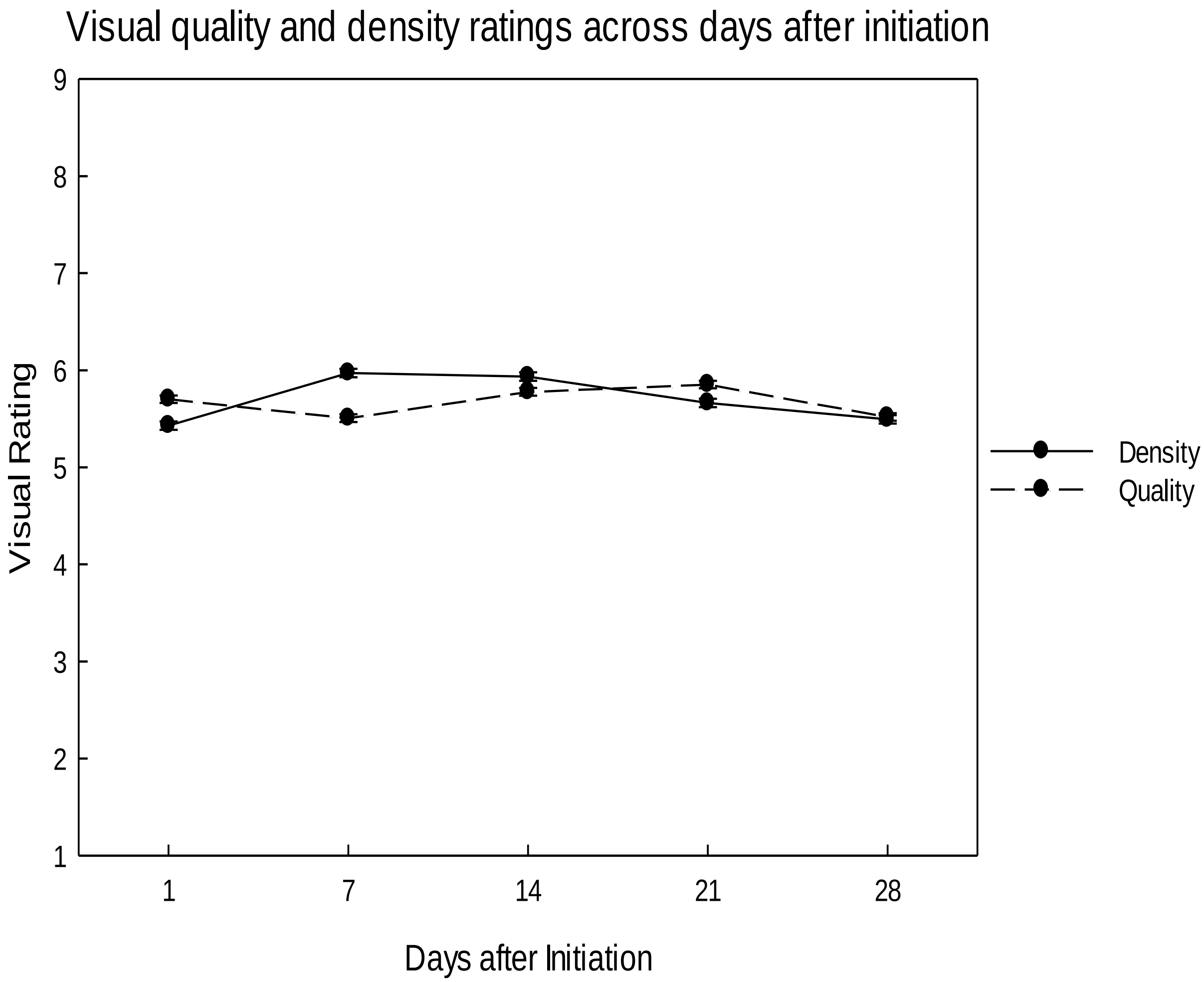

Figure 2-11. Three event average of visual quality and density ratings by days after initiation (DAI) using Tukey Kramer's LS means separation (P = 0.05). Bars at each DAI represent 95% confidence intervals. Scale is from 1 to 9, 9=optimal turf quality/density, 6=acceptable turf quality/density.

Table 2-1. Runoff study area textural analysis data from Nov. 2011 to depth of 15.2 mm

	Textural Analysis†‡			
Sample #§	%Sand	% Clay	%Silt	Class
1	90.81	5.60	3.60	Sand
2	86.54	2.96	10.50	Loamy Sand
3	81.05	6.60	12.34	Loamy Sand
4	87.60	1.68	10.72	Loamy Sand
4	85.94	3.12	10.94	Loamy Sand
5	83.89	3.68	12.43	Loamy Sand
6	85.46	2.88	11.66	Loamy Sand
7	84.00	3.52	12.48	Loamy Sand
8	87.25	2.32	10.44	Sand
9	77.87	2.16	19.98	Loamy Sand
10	84.72	2.96	12.32	Loamy Sand
11	87.49	2.72	9.79	Sand
12	89.08	2.32	8.60	Sand
13	87.60	2.48	9.92	Sand
14	87.80	2.88	9.32	Sand
15	88.53	2.64	8.83	Sand
16	87.55	2.64	9.81	Sand
17	86.50	2.64	10.86	Loamy Sand

† Samples were analyzed at the Soil and Water Science Pedology and Mineralogy Lab.
‡ Processed at 22^{0}C for 183 min with a pipette depth of 100 mm.
§ Samples were taken from random plots moving west to east across study site.

Table 2-2. Grouping co-variance estimates for total soluble nitrogen analysis

		Covariance Parameters		
Group†	Subject	Parameter	Estimate	Standard Error
Soluble	Treatment*Rep	Variance	0.819	0.215
Soluble	Treatment*Rep	CS‡	0.459	0.323
Insoluble	Treatment*Rep	Variance	0.015	0.003
Insoluble	Treatment*Rep	CS	0.017	0.006

† Grouping consists of soluble; ammonium sulfate (AS) and Insoluble; polymer coated urea (PCU), ureaformaldehyde (UF), and the untreated control (UTC).
‡ Compound symmetry (CS)

Table 2-3. Analysis of variance for total soluble nitrogen and ortho-phosphate

Runoff ANOVA			
		TSN	OP
Effect	Df	pr > F	pr > F
Treatment†	12	<0.001	0.045
Event‡	2	0.005	0.001
Event*Treatment	24	0.011	0.019

† Treatments refer to fertilizer sources; ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) by unfertilized buffer strip sizes (0.0, 0.9, 1.8, and 3.6m) and an untreated control.

‡ Event consists of the May, June, and August runoff events.

Table 2-4. Total soluble nitrogen loads by fertilizer source averaged across three runs

Total Soluble Nitrogen Loads	
Source	TSN Loads†
	-g-
Ammonium Sulfate	4.069 a
Urea Formaldehyde	1.048 b
Polymer Coated Urea	0.064 c
Untreated Control	0.020 c

† Means with the same letters were not significantly different (P = 0.05) according to Tukey Kramer’s means separation averaged across three runoff events.

Table 2-5. Tukey-Kramer's means estimates for ureaformaldehyde total soluble nitrogen for buffer strip sizes

Effect	Buffer -m-	Estimate	Standard Error	DF	t Value	Pr > |t|‡	alpha	Lower	Upper
UF†	0.0 vs 0.9	-0.01	0.12	27	-1.19	0.243	0.05	-0.39	0.10
	0.0 vs 1.8	0.07	0.12	27	0.61	0.545	0.05	-0.17	0.32
	0.0 vs 3.6	0.58	0.12	27	4.82	<0.001	0.05	0.33	0.82
	0.9 vs 1.8	0.22	0.12	27	1.81	0.082	0.05	-0.03	0.46
	0.9 vs 3.6	0.72	0.12	27	6.01	<0.001	0.05	0.47	0.96
	1.8 vs 3.6	0.50	0.12	27	4.21	0.003	0.05	0.26	0.75

† Ureaformaldehyde (UF) TSN Loads by unfertilized buffer strip sizes (0.0, 0.9, 1.8, and 3.6 m).
‡ Adjusted Pr > |t|, lower, and upper limits were equal to normalized and removed.

Table 2-6. Tukey-Kramer's means estimates for fertilizer sources

Effect	Source	Estimate	Standard Error	DF	t Value	Pr > |t|‡	alpha	Lower	Upper
F†	AS vs UF	3.09	0.55	27	5.66	0.001	0.05	1.90	4.27
	AS vs PCU	4.07	0.55	27	7.47	<0.001	0.05	2.89	5.26
	UF vs PCU	0.98	0.06	27	16.48	<0.001	0.05	0.86	1.11
	AS vs UTC	4.12	0.55	27	7.48	<0.001	0.05	2.92	5.31
	UF vs UTC	1.03	0.09	27	10.89	<0.001	0.05	0.83	1.22
	PCU vs UTC	0.04	0.09	27	0.47	0.644	0.05	-0.15	0.24

† Fertilizer sources (F) were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) according Tukey Kramer's means separation averaged across three runoff events.
‡ Adjusted Pr > |t|, lower, and upper limits were equal to normalized and removed.

Table 2-7. Analysis of variance for total Kjeldahl nitrogen clippings

Total Kjeldahl Nitrogen ANOVA		
Effect	Df	pr > F
Treatment†	12	<0.001
Event‡	2	<0.001
Treatment*Event	24	<0.001

† Treatment refers to sources; ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) by unfertilized buffer strip sizes (0.0, 0.9, 1.8, and 3.6m).
‡ Event consists of the May, June, and August runoff events.

Table 2-8. Total Kjeldahl nitrogen clippings tissue analysis for fertilizer treatment by buffer strip size averaged across runoff events

F†	Buffer	Total Kjeldahl Nitrogen		
	-m-		-% N -	
		May	June	August
AS	0.0	1.7	2.7 a‡	2.7 ab
AS	0.9	1.7	2.6 ab	2.8 ab
AS	1.8	1.7	2.6 ab	2.9 a
AS	3.6	1.8	2.6 ab	2.7 ab
UF	0.0	1.5	2.4 ab	2.8 ab
UF	0.9	1.6	2.6 ab	2.8 ab
UF	1.8	1.6	2.4 ab	2.8 ab
UF	3.6	1.5	2.5 ab	2.8 ab
PCU	0.0	1.5	2.7 ab	3.2 a
PCU	0.9	1.6	2.8 a	3.1 a
PCU	1.8	1.5	2.7 ab	3.1 a
PCU	3.6	1.3	2.5 ab	3.1 a
UTC	-	1.5	2.2 b	2.2 b

† Nitrogen sources (F) used were ammonium sulfate (AS), ureaformaldehyde (UF), polymer coated urea (PCU), and an untreated control (UTC).
‡ Means with the same letter in a given event were not significantly different (P = 0.05) according to Tukey Kramer’s means separation.

Table 2-9. Total Kjeldahl nitrogen tissue clippings analysis by runoff event

Total Kjeldahl Nitrogen Loads	
Event	TKN†
	- % N -
May	1.6 a
June	2.6 b
August	2.9 c

† Means with the same letters were not significantly different (P = 0.05) according to Tukey Kramer's means separation for three runoff events.

Table 2-10. Analysis of variance for clipping biomass

Clipping Biomass ANOVA†		
Effect	df	pr > F
Treatment†	12	0.154
DAI‡	4	<0.001
DAI*Treatment	48	<0.001

† Treatment refers to sources; ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) by unfertilized buffer strip sizes (0.0, 0.9, 1.8, and 3.6m).

‡ Days after initiation (DAI) refer to collection days 1, 7, 14, 21, and 28 following three runoff events.

Table 2-11. Differences in clipping biomass collection for days after initiation across fertilizer source by buffer strip size

F‡	Buffer -m-	Days After Initiation† -g- of clippings				
		1	7	14	21	28
AS	0.0	2.10 j-o	3.98 abc	4.31 a	3.93 a-d	3.50 a-g
AS	0.9	2.07 k-o	3.57 a-g	3.86 a-f	3.79 a-g	3.51 a-g
AS	1.8	1.96 mno	3.53 a-g	3.58 a-g	3.75 a-g	3.25 a-l
AS	3.6	1.98 mno	3.58 a-g	3.58 a-g	3.59 a-g	3.15 a-m
UF	0.0	2.15 i-o	3.51 a-g	3.80 a-g	3.74 a-g	3.20 a-m
UF	0.9	2.07 k-o	2.68 d-o	2.72 c-n	3.17 a-m	3.03 b-n
UF	1.8	2.19 h-o	3.19 a-m	2.65 e-o	3.37 a-j	3.27 a-l
UF	3.6	2.02 l-o	2.76 b-n	2.62 f-o	3.20 a-m	2.85 b-n
PCU	0.0	2.72 b-n	3.41 a-i	3.67 a-g	3.96 abc	3.68 a-g
PCU	0.9	2.55 g-o	3.26 a-l	3.38 a-j	3.90 a-e	3.53 a-g
PCU	1.8	2.88 b-n	3.46 a-h	3.30 a-k	3.94 a-d	3.77 a-g
PCU	3.6	3.04 b-n	3.51 a-g	3.62 a-g	3.99 ab	3.77 a-g
UTC	-	1.29 o	1.80 mno	1.73 no	1.66 no	1.72 no

† Means with the same letter were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

‡ Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

Table 2-12. Analysis of variance for soil moisture

Soil Moisture ANOVA†		
Effect	Df	pr > F
Time‡	1	<0.001
Event§	2	<0.001
Sourceβ	3	<0.001
Event*Time	2	0.001
Treatment?	9	<0.001

† Full ANOVA table is not shown; all interactions not displayed here had Pr >F values above 0.05.

‡ Time refers to the volumetric water content percentage taken before and after runoff initiation

§ Event consists of the May, June, August runoff events.

β Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

? Treatment refers to sources; ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) by unfertilized buffer strip sizes (0.0, 0.9, 1.8, and 3.6m)

Table 2-13. Soil moisture differences across fertilizer treatment (source by buffer strip size)

Source	Buffer	Soil Moisture
	-m-	-SWC%†-
Ammonium Sulfate	0.0	44.667 ab
Ammonium Sulfate	0.9	44.968 a
Ammonium Sulfate	1.8	44.998 a
Ammonium Sulfate	3.6	44.059 abc
Urea Formaldehyde	0.0	42.442 a-d
Urea Formaldehyde	0.9	42.763 a-d
Urea Formaldehyde	1.8	43.588 abc
Urea Formaldehyde	3.6	42.175 bcd
Polymer Coated Urea	0.0	40.253 e
Polymer Coated Urea	0.9	41.117 e
Polymer Coated Urea	1.8	42.907 a-d
Polymer Coated Urea	3.6	41.591 cde
Untreated Control	-	42.911 a-d

† Soil water content percentage was taken before and after runoff initiation and averaged across source by buffer strip size. Means with the same letters were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 2-14. Tukey-Kramer's means estimates for ortho-phosphate loads influence by differing ureaformaldehyde buffer strip sizes†

Effect	Label -m-	Estimate	Standard Error	DF	t Value	Pr > |t|‡	alpha	Lower	Upper
UF	0.0 vs 0.9	-0.003	0.003	117	-0.84	0.403	0.05	-0.009	0.004
	0.0 vs 1.8	0.003	0.003	117	0.87	0.384	0.05	-0.003	0.009
	0.0 vs 3.6	0.004	0.003	117	1.38	0.169	0.05	-0.002	0.011
	0.9 vs 1.8	0.005	0.003	117	1.71	0.089	0.05	-0.001	0.012
	0.9 vs 3.6	0.007	0.003	117	2.22	0.028	0.05	0.001	0.013
	1.8 vs 3.6	0.002	0.003	117	0.51	0.611	0.05	-0.005	0.008

† Ureaformaldehyde (UF) ortho-phosphate loads by unfertilized buffer strip sizes (0.0, 0.9, 1.8, and 3.6m).
‡ Adjusted Pr > |t|, lower, and upper limits were equal to normalized and removed.

Table 2-15. Analysis of variance for normalized difference vegetation index, ratio vegetative index, visual color, visual quality, and visual density

		Visual Assessment ANOVA†				
		NDVI	RVI	Color	Quality	Density
Effect	Df	pr > F	pr > F	pr > F	pr > F	pr > F
Event‡	2	<0.001	<0.001	<0.001	<0.001	<0.001
SPL	33	<0.001	<0.001	<0.001	<0.001	<0.001
DAI	4	<0.001	<0.001	<0.001	<0.001	<0.001
Event*SPL	66	<0.001	<0.001	<0.001	<0.001	<0.001
DAI*SPL§	132	0.091	0.009	<0.001	0.052	0.147

† Full ANOVA table is not shown; all interactions not displayed here had Pr >F values above 0.05.
‡ Event consists of the May, June, and August runoff events.
§ Subplot location (SPL) refers to fertilized swath, unfertilized buffer strip and the management of the area above by days after initiation (DAI) across all treatment combinations.

Table 2-16. Ratio vegetative index values for subplot location by days after initiation†

		Ratio Vegetation Index‡								
F§	Buffer		Day 1			Day 7			Day 14	
	-m-	Fert	Unfert	Above	Fert	Unfert	Above	Fert	Unfert	Above
AS	0.0	3.208	-	3.114	3.942 a-dβ	-	3.480 b-e	3.942 ab	-	3.514 a-e
AS	0.9	3.177	3.230	3.001	4.049 abc	3.587 b-e	3.534 b-e	3.961 ab	3.787 abc	3.537 a-e
AS	1.8	3.067	2.912	2.903	4.212 a	3.431 de	3.504 b-e	4.067 a	3.536 a-e	3.499 a-e
AS	3.6	3.252	3.122	2.990	4.081 ab	3.374 de	3.483 b-e	3.930 ab	3.380 b-e	3.472 a-e
UF	0.0	2.998	-	3.104	3.405 de	-	3.498 b-e	3.458 b-e	-	3.476 a-e
UF	0.9	3.227	2.955	3.172	3.558 b-e	3.253 e	3.387 de	3.511 a-e	3.289 cde	3.364 b-e
UF	1.8	3.024	2.831	2.983	3.567 b-e	3.260 e	3.454 cde	3.450 b-e	3.249 cde	3.411 b-e
UF	3.6	3.093	2.967	3.062	3.578 b-e	3.219 e	3.493 b-e	3.504 a-e	3.237 cde	3.456 b-e
PCU	0.0	3.042	-	3.058	3.452 cde	-	3.405 de	3.376 b-e	-	3.390 b-e
PCU	0.9	3.119	2.857	3.041	3.585 b-e	3.318 e	3.478 b-e	3.595 a-e	3.302 cde	3.526 a-e
PCU	1.8	3.318	2.903	3.060	3.627 a-e	3.196 e	3.342 de	3.669 a-d	3.130 de	3.296 b-e
PCU	3.6	3.252	2.939	2.988	3.653 a-e	3.143 e	3.403 de	3.715 a-d	3.050 e	3.372 cde
UTC	-	-	2.930	-	-	3.115 e	-	-	2.995 e	-

† Subplot location (SPL) refers to fertilized swath, unfertilized buffer strip and the management of the area above the fertilized swath by days after initiation (DAI) across all treatment combinations.

‡ Ratio vegetation index (RVI) value was calculated using: RVI = R_{NIR}/R_{VIS}. RVI was taken weekly for a month following runoff events.

§ Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

β Means with the same letter in a given day after initiation (DAI) were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 2-16. Continued†

F§	Buffer -m-	Ratio Vegetation Index‡ Day 21 Fert	Day 21 Unfert	Day 21 Above	Day 28 Fert	Day 28 Unfert	Day 28 Above
AS	0.0	3.706 abcβ	-	3.345 abc	3.404 a-f	-	3.248 b-f
AS	0.9	3.780 ab	3.935 a	3.235 bc	3.508 a-f	3.575 a-e	3.299 a-f
AS	1.8	3.797 ab	3.463 abc	3.313 bc	3.658 a-d	3.234 b-f	3.248 b-f
AS	3.6	3.706 abc	3.498 abc	3.202 bc	3.503 a-f	3.147 c-f	3.195 b-f
UF	0.0	3.492 abc	-	3.466 abc	3.509 a-f	-	3.286 a-f
UF	0.9	3.560 abc	3.469 abc	3.406 abc	3.513 a-f	3.170 b-f	3.163 c-f
UF	1.8	3.531 abc	3.329 bc	3.378 abc	3.523 a-f	3.049 ef	3.174 b-f
UF	3.6	3.557 abc	3.371 abc	3.311 bc	3.559 a-f	3.119 c-f	3.205 b-f
PCU	0.0	3.438 abc	-	3.248 bc	3.498 a-f	-	3.139 c-f
PCU	0.9	3.489 abc	3.236 bc	3.296 bc	3.768 ab	2.967 f	3.263 b-f
PCU	1.8	3.716 abc	3.173 c	3.266 bc	3.672 abc	3.033 ef	3.090 def
PCU	3.6	3.747 abc	3.266 bc	3.266 bc	3.876 a	3.060 def	3.144 c-f
UTC	-	-	3.144 c	-	-	2.997 ef	-

† Subplot location (SPL) refers to fertilized swath, unfertilized buffer strip and the management of the area above the fertilized swath by days after initiation (DAI) across all treatment combinations.

‡ Ratio vegetation index (RVI) value was calculated using: RVI = R_{NIR}/R_{VIS}. RVI was taken weekly for a month following runoff events.

§ Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

β Means with the same letter in a given day after initiation (DAI) were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 2-17. Ratio vegetative index values for subplot location by runoff events†

		Ratio Vegetation Index‡								
F§	Buffer		May			June			August	
	-m-	Fert	Unfert	Above	Fert	Unfert	Above	Fert	Unfert	Above
AS	0.0	3.387 abβ	-	2.980 b-e	3.874 a-d	-	3.556 a-f	3.660 a-f	-	3.484 a-f
AS	0.9	3.378 abc	3.353 a-d	2.928 b-e	3.897 abc	3.554 a-f	3.517 a-g	3.811 a-d	3.961 a	3.519 a-f
AS	1.8	3.347 a-d	2.928 b-e	2.821 e	4.018 a	3.404 c-g	3.516 a-g	3.915 ab	3.619 a-f	3.543 a-f
AS	3.6	3.522 a	3.007 b-e	2.910 b-e	3.858 a-d	3.386 d-g	3.444 b-g	3.703 a-e	3.521 a-f	3.451 a-f
UF	0.0	3.005 b-e	-	2.967 b-e	3.421 c-g	-	3.598 a-e	3.691 a-f	-	3.532 a-f
UF	0.9	3.085 a-e	2.972 b-e	2.918 b-e	3.611 a-e	3.242 efg	3.527 a-g	3.726 a-e	3.467 a-f	3.451 a-f
UF	1.8	2.985 b-e	2.848 de	2.809 e	3.565 a-f	3.194 efg	3.544 a-g	3.707 a-e	3.389 c-f	3.487 a-f
UF	3.6	3.064 a-e	2.946 b-e	2.876 cde	3.527 a-g	3.190 efg	3.522 a-g	3.783 a-e	3.412 b-f	3.518 a-f
PCU	0.0	2.936 b-e	-	2.866 de	3.564 a-f	-	3.464 b-g	3.583 a-f	-	3.414 b-f
PCU	0.9	3.078 a-e	2.954 b-e	2.950 b-e	3.769 a-d	3.120 efg	3.511 a-g	3.687 a-f	3.334 c-f	3.501 a-f
PCU	1.8	3.086 a-e	2.871 cde	2.888 b-e	3.950 ab	3.108 efg	3.375 c-g	3.765 a-e	3.281 ef	3.369 c-f
PCU	3.6	3.121 a-e	2.918 b-e	2.848 de	3.990 a	3.061 fg	3.432 d-g	3.835 abc	3.304 def	3.406 b-f
UTC	-	-	2.882 b-e	-	-	3.039 g	-	-	3.188 f	-

† Subplot location (SPL) refers to fertilized swath, unfertilized buffer strip and the management of the area above by days after initiation (DAI) across all treatment combinations.

‡ Ratio vegetation index (RVI) value was calculated using: RVI = R_{NIR}/R_{VIS}. RVI was taken weekly for a month following runoff events.

§ Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

β Means with the same letter in a given monthly event were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 2-18. Normalized difference vegetation index values for subplot location by runoff events†

F§	Buffer	Normalized Difference Vegetation Index‡								
		May			June			August		
	-m-	Fert	Unfert	Above	Fert	Unfert	Above	Fert	Unfert	Above
AS	0.0	0.536 abcβ	-	0.493 cde	0.583 abc	-	0.557 a-e	0.566 a-f	-	0.551 a-f
AS	0.9	0.535 abc	0.529 a-d	0.487 de	0.585 abc	0.555 a-f	0.552 a-g	0.578 a-e	0.591 a	0.553 a-f
AS	1.8	0.545 ab	0.497 b-e	0.485 de	0.596 a	0.541 c-h	0.553 a-f	0.589 ab	0.564 a-f	0.555 a-f
AS	3.6	0.550 a	0.496 b-e	0.485 de	0.581 abc	0.537 c-h	0.545 b-h	0.569 a-e	0.554 a-f	0.546 a-f
UF	0.0	0.495 cde	-	0.492 cde	0.543 b-h	-	0.560 a-d	0.571 a-e	-	0.555 a-f
UF	0.9	0.505 a-e	0.492 cde	0.486 de	0.563 a-d	0.523 d-h	0.554 a-f	0.575 a-e	0.548 a-f	0.547 a-f
UF	1.8	0.506 a-e	0.488 cde	0.484 de	0.559 a-e	0.518 d-h	0.556 a-f	0.573 a-e	0.540 b-f	0.550 a-f
UF	3.6	0.503 a-e	0.489 cde	0.481 de	0.555 a-f	0.518 d-h	0.554 a-f	0.579 a-d	0.544 a-f	0.553 a-f
PCU	0.0	0.486 de	-	0.479 e	0.558 a-e	-	0.548 a-h	0.560 a-f	-	0.543 a-f
PCU	0.9	0.503 a-e	0.487 cde	0.490 cde	0.577 abc	0.507 fgh	0.552 a-g	0.569 a-e	0.533 d-f	0.551 a-f
PCU	1.8	0.504 a-e	0.480 de	0.483 de	0.592 ab	0.510 e-h	0.537 c-h	0.578 a-e	0.530 ef	0.537 c-f
PCU	3.6	0.508 a-e	0.485 de	0.479 e	0.595 a	0.503 gh	0.545 b-h	0.582 abc	0.532 def	0.542 a-f
UTC	-	-	0.482 de	-	-	0.502 h	-	-	0.519 f	-

† Subplot location (SPL) refers to fertilized swath, unfertilized buffer strip and the management of the area above by days after initiation (DAI) across all treatment combinations.

‡ Normalized difference vegetation index (NDVI) value was calculated using: NDVI = $(R_{NIR} - R_{red})/(R_{NIR} + R_{red})$. Average of NDVI values taken weekly for a month following runoff events.

§ Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

β Means with the same letter in a given monthly event were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 2-19. Visual color ratings for subplot location by runoff events†

		Visual Color Ratings‡								
F§	Buffer	May			June			August		
	-m-	Fert	Unfert	Above	Fert	Unfert	Above	Fert	Unfert	Above
AS	0.0	6.2 aβ	-	5.0 c-j	7.0 ab	-	5.9 efg	6.5 b-e	-	6.2 d-i
AS	0.9	6.1 ab	5.1 c-j	4.8 f-j	6.7 a-d	5.0 hij	5.7 fgh	6.3 c-h	5.5 i-n	6.0 e-j
AS	1.8	6.2 a‡	5.0 d-j	4.7 ij	6.9 abc	4.9 ij	5.9 efg	6.5 b-e	5.1 k-o	6.0 e-j
AS	3.6	6.1 ab	4.9 e-j	4.8 g-j	6.7 a-d	4.8 j	6.1 d-g	6.5 b-g	5.1 l-p	6.0 e-j
UF	0.0	5.4 b-i	-	4.8 f-j	6.2 c-g	-	5.9 efg	6.6 a-e	-	6.0 d-i
UF	0.9	5.5 a-f	5.3 c-j	4.8 f-j	6.3 b-f	4.8 j	5.8 efg	6.5 b-g	5.3 j-o	5.9 e-j
UF	1.8	5.6 a-e	5.0 c-j	4.7 ij	6.2 c-g	4.7 j	5.8 efg	6.7 a-d	5.0 m-p	5.8 g-l
UF	3.6	5.4 b-i	5.0 c-j	4.7 hij	6.4 a-e	4.8 j	5.8 efg	6.5 b-g	5.0 nop	5.7 h-m
PCU	0.0	5.5 a-g	-	4.6 j	6.8 abc	-	5.9 efg	7.0 abc	-	5.9 e-j
PCU	0.9	5.4 b-h	5.0 c-j	4.7 hij	7.0 ab	4.7 j	5.8 efg	7.0 abc	5.3 j-o	5.8 f-k
PCU	1.8	5.7 abc	4.9 f-j	4.7 hij	7.1 a	4.7 j	5.8 efg	7.3 a	4.7 op	5.9 e-j
PCU	3.6	5.7 a-d	5.0 c-j	4.9 e-j	7.1 a	4.7 j	5.6 ghi	7.1 ab	5.1 k-o	6.0 d-i
UTC	-	-	4.8 g-j	-	-	4.5 j	-	-	4.4 p	-

† Subplot location (SPL) refers to fertilized swath, unfertilized buffer strip and the management of the area above by days after initiation (DAI) across all treatment combinations.

‡ Average of visual color rating taken weekly for a month following runoff events. Scale is from 1 to 9, 9=optimal turf color, 6=acceptable turf color.

§ Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

β Means with the same letter in a given monthly run were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 2-20. Visual quality ratings for subplot location by runoff events†

		Visual Quality Ratings‡								
F§	Buffer	May			June			August		
	-m-	Fert	Unfert	Above	Fert	Unfert	Above	Fert	Unfert	Above
AS	0.0	5.9 abβ	-	5.2 abc	6.8 a	-	6.1 a-e	6.6 ab	-	6.5 abc
AS	0.9	5.7 abc	5.6 abc	5.0 bc	6.1 a-e	5.2 fgh	5.5 b-h	6.3 a-d	5.6 d-h	6.0 b-f
AS	1.8	5.7 abc	5.2 abc	5.1 abc	6.2 a-d	5.1 fgh	5.6 b-h	6.9 a	5.4 e-h	6.1 a-f
AS	3.6	5.5 abc	5.4 abc	5.4 abc	6.2 a-d	5.3 e-h	6.1 a-e	6.6 ab	5.3 fgh	6.3 a-d
UF	0.0	5.9 a	-	5.3 abc	6.3 ab	-	6.2 abc	6.1 a-f	-	6.2 a-f
UF	0.9	5.3 abc	5.5 abc	5.3 abc	5.8 b-g	5.3 e-h	6.1 a-e	6.0 b-f	5.1 gh	6.3 a-d
UF	1.8	5.2 abc	5.6 abc	5.0 bc	5.7 b-g	5.3 e-h	5.6 b-h	6.2 a-e	5.5 d-h	6.0 b-f
UF	3.6	4.9 c	5.4 abc	5.2 abc	5.6 b-h	5.5 b-h	5.7 b-g	6.1 a-f	5.3 fgh	5.9 b-g
PCU	0.0	5.5 abc	-	4.9 c	6.2 abc	-	6.0 a-f	6.2 a-e	-	6.3 a-d
PCU	0.9	5.3 abc	5.5 abc	5.0 bc	6.2 abc	5.3 d-h	5.7 b-g	6.6 ab	5.8 b-g	6.0 b-f
PCU	1.8	5.4 abc	5.4 abc	5.1 abc	6.3 ab	5.1 gh	5.8 b-g	6.5 ab	5.4 e-h	6.0 b-f
PCU	3.6	5.0 bc	5.6 abc	5.2 abc	5.8 b-g	5.4 c-h	5.9 b-g	6.1 a-f	5.6 c-h	6.3 a-d
UTC	-	-	5.1 abc	-	-	4.8 h	-	-	4.8 h	-

† Subplot location (SPL) refers to fertilized swath, unfertilized buffer strip and the management of the area above by days after initiation (DAI) across all treatment combinations.

‡ Average of visual quality rating taken weekly for a month following runoff events. Scale is from 1 to 9, 9=optimal turf quality, 6=acceptable turf quality.

§ Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

β Means with the same letter in a given monthly run were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 2-21. Visual density ratings for subplot location by runoff events†

F§	Buffer	Visual Density Ratings‡								
		May			June			August		
	-m-	Fert	Unfert	Above	Fert	Unfert	Above	Fert	Unfert	Above
AS	0.0	6.1 abcβ	-	5.3 bc	6.7 a	-	5.9 a-g	6.5 abc	-	6.4 abc
AS	0.9	5.8 abc	6.1 ab	5.1 c	6.0 a-f	5.2 e-i	5.5 b-i	6.4 abc	5.6 b-g	5.7 b-g
AS	1.8	6.1 abc	5.7 abc	5.4 bc	6.2 a-d	5.1 f-i	5.5 b-i	6.9 a	5.1 fg	5.9 b-g
AS	3.6	5.7 abc	5.6 abc	5.7 abc	6.2 abc	5.0 ghi	5.8 a-h	6.6 ab	5.4 d-g	6.2 a-e
UF	0.0	6.6 a	-	5.2 bc	6.1 a-e	-	5.9 a-g	6.1 a-f	-	6.0 a-g
UF	0.9	5.5 bc	6.0 abc	5.3 bc	5.8 a-h	5.2 d-i	5.9 a-h	5.8 b-g	5.0 g	6.2 a-e
UF	1.8	5.4 bc	5.8 abc	5.2 bc	5.7 b-i	5.1 f-i	5.7 b-i	6.2 a-e	5.3 efg	5.8 b-g
UF	3.6	5.4 bc	5.8 abc	5.4 bc	5.3 c-i	5.2 d-i	5.6 b-i	6.1 a-f	5.4 d-g	5.9 b-g
PCU	0.0	5.8 abc	-	5.3 bc	6.1 a-e	-	5.8 a-h	6.4 abc	-	6.2 a-e
PCU	0.9	5.6 abc	6.0 abc	5.5 bc	6.1 a-e	5.3 c-i	5.7 b-i	6.4 abc	5.5 c-g	5.9 a-g
PCU	1.8	5.4 bc	5.6 bc	5.2 bc	6.3 ab	4.9 hi	5.8 a-h	6.4 abc	5.0 g	5.9 b-g
PCU	3.6	5.3 bc	5.8 abc	5.6 bc	5.9 a-h	5.3 d-i	5.8 a-h	6.1 a-e	5.5 c-g	6.2 a-e
UTC	-	-	5.2 bc	-	-	4.8 i	-	-	5.0 g	-

† Subplot location (SPL) refers to fertilized swath, unfertilized buffer strip and the management of the area above by days after initiation (DAI) across all treatment combinations.

‡ Average of visual density rating taken weekly for a month following runoff events. Scale is from 1 to 9, 9=optimal turf density, 6=acceptable turf density.

§ Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

β Means with the same letter in a given monthly run were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 2-22. Visual color ratings for subplot location by days after initiation†

		Visual Color Ratings‡								
F§	Buffer		Day 1			Day 7			Day 14	
	-m-	Fert	Unfert	Above	Fert	Unfert	Above	Fert	Unfert	Above
AS	0.0	5.9 abcβ	-	5.7 a-e	7.0 a	-	5.8 d-g	6.7 a	-	5.9 a-e
AS	0.9	5.7 a-e	5.0 d-g	5.2 c-g	6.5 a-d	4.9 ghi	5.5 e-h	6.7 a	5.7 cde	6.1 a-e
AS	1.8	6.0 abc	4.9 d-g	5.3 c-g	6.8 ab	4.8 hi	5.7 d-h	6.6 ab	5.7 cde	6.1 a-e
AS	3.6	5.7 a-e	4.8 efg	5.4 b-f	6.7 abc	4.9 ghi	5.5 e-h	6.6 ab	5.7 cde	6.0 a-e
UF	0.0	5.9 abc	-	5.5 b-f	5.8 d-g	-	5.3 fgh	6.3 a-e	-	5.8 a-e
UF	0.9	5.5 b-f	4.8 fg	5.3 c-g	5.9 c-f	5.0 ghi	5.5 e-h	6.3 a-e	5.7 cde	5.8 a-e
UF	1.8	5.8 a-d	4.8 efg	5.2 c-g	6.0 b-f	5.0 ghi	5.6 e-h	6.2 a-e	5.7 cde	6.0 a-e
UF	3.6	5.8 a-d	4.8 fg	5.2 c-g	5.8 d-g	4.8 hi	5.3 fgh	6.5 abc	5.7 cde	6.0 a-e
PCU	0.0	6.2 ab	-	5.3 c-g	6.0 b-f	-	5.4 e-h	6.3 a-e	-	6.0 a-e
PCU	0.9	6.2 ab	4.9 d-g	5.2 c-g	5.9 c-f	5.0 ghi	5.5 e-h	6.4 a-d	5.7 cde	6.0 a-e
PCU	1.8	6.5 a	4.5 g	5.3 c-g	6.1 b-f	4.9 ghi	5.4 e-h	6.5 abc	5.5 e	5.8 a-e
PCU	3.6	5.9 abc	4.8 efg	5.2 c-g	6.2 a-e	4.8 hi	5.6 e-h	6.4 a-d	5.7 cde	5.8 b-e
UTC	-	-	4.4 g	-	-	4.3 i	-	-	5.6 de	-

† Subplot location (SPL) refers to fertilized swath, unfertilized buffer strip and the management of the area above by days after initiation (DAI) across all treatment combinations.

‡ Average of visual color rating taken weekly for a month following runoff events. Scale is from 1 to 9, 9=optimal turf color, 6=acceptable turf color.

§ Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

β Means with the same letter in a given monthly run were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 2-22. Continued†

		Visual Color Ratings‡					
F§	Buffer	Day 21			Day 28		
	-m-	Fert	Unfert	Above	Fert	Unfert	Above
AS	0.0	6.9 abβ	-	5.6 f-k	6.3 bcd	-	5.4 d-g
AS	0.9	6.6 a-d	5.3 f-k	5.5 f-k	6.3 bcd	5.0 g-l	5.1 g-k
AS	1.8	6.7 abc	4.9 i-m	5.3 f-k	6.4 abc	4.5 h-l	5.1 g-k
AS	3.6	6.8 ab	4.8 klm	5.7 e-j	6.3 bcd	4.4 i-l	5.3 e-h
UF	0.0	6.1 b-g	-	5.8 c-h	6.0 c-f	-	5.3 e-h
UF	0.9	6.5 a-e	5.2 h-l	5.7 e-j	6.2 cde	4.9 g-l	5.3 f-i
UF	1.8	6.5 a-e	4.8 klm	5.3 g-l	6.4 abc	4.3 kl	4.9 g-l
UF	3.6	6.2 b-f	4.9 i-m	5.5 f-k	6.2 cde	4.4 i-l	5.0 g-l
PCU	0.0	6.8 ab	-	5.3 f-k	6.7 abc	-	5.2 f-j
PCU	0.9	6.6 a-d	4.8 klm	5.5 f-k	7.1 ab	4.5 h-l	5.0 g-l
PCU	1.8	7.2 a	4.4 lm	5.6 f-k	7.2 a	4.3 jkl	5.1 g-k
PCU	3.6	7.3 a	4.8 j-m	5.8 d-i	7.2 a	4.5 h-l	5.2 f-j
UTC	-	-	4.2 m	-	-	4.2 l	-

† Subplot location (SPL) refers to fertilized swath, unfertilized buffer strip and the management of the area above by days after initiation (DAI) across all treatment combinations.

‡ Average of visual color rating taken weekly for a month following runoff events. Scale is from 1 to 9, 9=optimal turf color, 6=acceptable turf color.

§ Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

β Means with the same letter in a given monthly run were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 2-23. Analysis of variance for dark green color index

Dark Green Color Index ANOVA		
Effect	df	Pr > F
Treatment†*Event‡	22	0.353
Event*Distance§	16	<0.001
Distance*Treatment	37	<0.001

† Treatment refers to sources; ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) by unfertilized buffer strip sizes (0.0, 0.9, 1.8, and 3.6m).

‡ Event consists of the May, June and August runoff events

§ Each distance refers to the distance away from the fertilized swath with 1 = the 56.0 cm increment adjacent to the fertilized swath, 2 = the 56.0 to 112.0 cm area downslope of fertilized swath.

Table 2-24. Dark green color index separated by distance adjacent to fertilized swath

F†	Buffer	Dark Green Color Index‡								
	-m-	D0	D1	D2	D3	D4	D5	D6	D7	D8
AS	0.0	0.510	0.509 a§							
AS	0.9	0.516	0.483 bcd	0.488						
AS	1.8	0.516	0.488 bcd	0.486	0.490	0.502 a				
AS	3.6	0.510	0.489 bcd	0.490	0.492	0.489 ab	0.489	0.486	0.492	0.495
UF	0.0	0.506	0.498 ab							
UF	0.9	0.506	0.483 bcd	0.486						
UF	1.8	0.507	0.487 bcd	0.485	0.483	0.489 ab				
UF	3.6	0.508	0.486 bcd	0.484	0.487	0.485 b	0.483	0.486	0.491	0.494
PCU	0.0	0.509	0.497 abc							
PCU	0.9	0.514	0.480 d	0.486						
PCU	1.8	0.511	0.483 cd	0.481	0.480	0.485 b				
PCU	3.6	0.512	0.482 d	0.483	0.485	0.483 b	0.483	0.483	0.485	0.488

† Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

‡ Each distance refers to the distance away from the fertilized swath with 1 = the 56.0 cm increment adjacent to the fertilized swath, 2 = the 56.0 to 112.0 cm area downslope of fertilized swath.

§ Means with the same letter in a given distance were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 2-25. Dark green color index separated by fertilizer source by buffer strip size

F†	Buffer	Dark Green Color Index‡								
	-m-	D0	D1	D2	D3	D4	D5	D6	D7	D8
AS	0.0	0.510	0.509							
AS	0.9	0.516 a§	0.483 b	0.488 b						
AS	1.8	0.516 a	0.488 c	0.486 c	0.490 c	0.502 b				
AS	3.6	0.510 a	0.489 b	0.490 b	0.492 b	0.489 b	0.489 b	0.486 b	0.492 b	0.495 b
UF	0.0	0.506 a	0.498 b							
UF	0.9	0.506 a	0.483 b	0.486 b						
UF	1.8	0.507 a	0.487 b	0.485 b	0.483 b	0.489 b				
UF	3.6	0.508 a	0.486 b	0.484 b	0.487 b	0.485 b	0.483 b	0.486 b	0.491 b	0.494 b
PCU	0.0	0.509 a	0.497 b							
PCU	0.9	0.514 a	0.480 b	0.486 b						
PCU	1.8	0.511 a	0.483 b	0.481 b	0.480 b	0.483 b				
PCU	3.6	0.512 a	0.482 b	0.483 b	0.485 b	0.485 b	0.483 b	0.483 b	0.485 b	0.488 b

† Nitrogen sources used were ammonium sulfate (AS), ureaformaldehyde (UF), and polymer coated urea (PCU) and an untreated control (UTC).

‡ Each distance refers to the distance away from the fertilized swath with 1 = the 56.0 cm increment adjacent to the fertilized swath, 2 = the 56.0 to 112.0 cm area downslope of fertilized swath.

§ Means with the same letter in a given fertilizer source by buffer strip size were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 2-26. Dark green color index for distance away from fertilized swath by events

	Dark Green Color Index		
Distance†	May	June	August
-1	0.4952 ab‡	0.4946 b	0.5076 ab
0	0.5089 a	0.5108 a	0.5131 a
1	0.4783 bc	0.4873 b	0.4992 b
2	0.4744 c	0.4834 b	0.4966 b
3	0.4765 c	0.4857 b	0.4944 b
4	0.4765 c	0.4873 b	0.5026 ab
5	0.4780 bc	0.4832 b	0.4908 b
6	0.4777 bc	0.4842 b	0.4905 b
7	0.4736 c	0.4881 b	0.5055 ab
8	0.4766 c	0.4884 b	0.5137 a

† Each distance refers to the distance away from the fertilized swath with 1 = the 56.0 cm increment adjacent to the fertilized swath, 2 = the 56.0 to 112.0 cm area downslope of fertilized swath. Distance 0 refers to the fertilized swath and distance -1 is the UTC.
‡ Means with the same letter in a given event were not significantly different (P = 0.05) according to Tukey Kramer’s means separation.

CHAPTER 3
TOTAL SOLUBLE NITROGEN LEACHED FROM NINE FERTILIZER SOURCES IN A BERMUDAGRASS FAIRWAY RECEIVING EXCESSIVE IRRIGATION

Introduction

Contamination of the world's groundwater supply from nitrogenous fertilizers has the potential to cause eutrophication, red tides, and algal blooms (Spalding and Exner, 1993). Overall, most previous turfgrass research has generally found that nitrogen (N) leaching is a small risk in properly managed turfgrass (Erickson et al., 2008; Reike and Ellis, 1974; Sheard et al., 1985; Starr and DeRoo, 1981; Mancino and Troll, 1990; Miltner et al., 1996). However, research has suggested that numerous factors such as fertilizer rate, source, frequency, application technique, irrigation management, establishment period, and turf species and cultivar are associated with N leaching losses (Barton, et al., 2006; Bowman et al., 2002; Cisar et al., 1991; Erickson et al., 2010; Geron et al., 1993; Reike and Ellis, 1974; Snyder et al., 1984; Snyder et al., 1989; Petrovic, 1990).

Several methods have been used in studying N leaching factors. Petrovic (1990), categorized them as soil testing, measuring saturated zone nutrients levels, monitoring drainage, trapping NO_3-N on ion exchange sites and testing groundwater supplies for nutrient concentration. Morton et al. (1988) reported that when N fertilizers where applied at recommended rates, NO_3-N leachate was low and below the maximum contaminant limit (MCL) of 10mg L^{-1} for drinking water set by the United States Environmental Protection Agency (USEPA) under the Safe Drinking Water Act of 1974 (USEPA, 1976). The objectives of this study were to determine total soluble N leaching following an excess rate of applied N coupled with high natural rainfall or simulated irrigation practices.

Materials and Methods

Trials were conducted at the University of Florida's West Florida Research and Education Center (WFREC) in Jay, FL (30°46´3 N, 87°08´ W). Thirty-year average temperature and rainfall data has been compiled for Jay, FL (Figure 3-1). Plots were established on a native soil comprised of 85.3% Dothan fine sandy loam and 14.7% Fuquay loamy sand (NRCS, 2009), with an approximate pH of 5.7 and CEC value of 3.7 (Waters Agricultural Laboratory, Inc., Camilla, GA).

Forty high-density polyethylene (HDPE) drainage lysimeters were installed in the center of each 3.1 m x 6.1 m plot. Lysimeters measured 56 cm in diameter and 88 cm in height with a volume of 200 L. Lysimeters were assembled by placing HDPE cylinders into a one piece galvanized steel base unit measuring 25.4 cm in height. The leachate was accessed directly with the 9.5 mm LDPE tubing through one of two 9.5 mm holes bored through the side wall 10.16 cm down from the top rim of the lysimeter and routed to the inside apex of the conical bottom, the second hole placed directly above allowed for a ventilation line to prevent pressure differentials. The tubing was run underground from the lysimeter to a central aboveground collection portal.

Lysimeters were installed by boring and removing soil in 15.2 cm sections to an approximate depth of 107 cm. Lysimeters were placed in holes and 38 L of washed egg rock (1.9 – 6.4 cm) were placed in the bottom of each lysimeter. The rock 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 rock. Soil was replaced into the lysimeters as it had been removed from the soil profile. Soil was gently tamped with a tamping tool (17.0 kg and 858.0 cm^2) to approximate original soil bulk density. The top of each lysimeter was 10 cm below the soil surface.

'Tifway' hybrid bermudagrass (*Cynodon dactylon x C. transvaalensis* Burtt-Davey) was established from sod on 31 May 2011. Plots were mowed three times weekly at 12.7 mm in height using a 3500 Toro Sidewinder reel mower (The Toro Co., Bloomington, MN). Turf stands were allowed to mature until mid-September, 2011. The turf received three 24.0 kg N ha^{-1} foliar applications between 31 May 2011 and 30 Aug 2011 to increase turf quality.

Four quadrants of four Rain Bird 7005 (Rain Bird Corp., Azusa, CA) rotary irrigation heads supplied irrigation during turf establishment. Irrigation heads were arranged in a square layout with four 90° arcs creating a precipitation rate of 0.5 mm min^{-1}. Throughout the establishment period plots were irrigated at a rate equal to reference evapotranspiration (ET) according to FAWN (Florida Automated Weather Network, University of Florida, Gainesville, FL) weather station at the Jay research facility. The Christiansen's coefficient of uniformity (CU) (Christiansen, 1942) for the irrigation system averaged >80% throughout several summer 2011 audits. However, uniformity was greatly dependent on wind strength and direction.

The fertilizer treatments were arranged in a complete block design with four replications. Nine organic and inorganic N sources were applied at a 144 kg N ha^{-1} rate using hand spreader on 20 September 2011, 22 May 2012 and 27 August 2012. The 27 August 2012 event was planned to run concurrently to Hurricane Isaac's landfall. Fertilizers sources used are given in (Table 3-1). The 20 September 2011 (event 1) and 22 May 2012 (event 2) were an identical irrigation regime, while a new protocol was developed for the 27 August 2012 (event 3) event. Forty-eight hours prior to treatment in the first two runs, plots were pre-irrigated to soil saturation to ensure uniform water distribution. Pre-wet irrigation totaled 57.2 mm and was stopped 24h prior to fertilizer application to allow soil moisture to return to field capacity. During the 27 August 2012 leaching event there was no pre-wetting of the soil.

Leachate samples were collected at 0, 4, 8, 12, 24, 48, 72, 96, 120, 144, and 168 hours after treatment (HAT), followed by weekly sampling through 5 February 2012 (event 1), and 24 July 2012 (event 2). In the third event leachate samples were taken at 24, 48, 72, 96,168 HAT, followed by weekly sampling for 31 weeks until 1 April 2013 (event 3).

Four separate irrigation events conducted at 7:00, 10:00, 13:00 and 17:00 supplied the 25.4 mm d^{-1} total in the first two events, while weekly irrigation audits were taken to monitor irrigation uniformity (Appendix B). Irrigation audits were performed every two weeks during the third event. Additional precipitation from rainfall events and subsequent increases in leachate were quantified and reported as comparators to non-rain event data. The third event's protocol was changed to reduce irrigation to a rainfall minus evapotranspiration (R-ET) based irrigation scheme.

Infiltration rates were determined by a single ring infiltrometer utilizing the falling head method vs. static head (Wu, 1998). Infiltration rates were taken weekly throughout the first two runs until 01 December 2012 when it was moved to every other week in the third event. Rainfall and ET totals were recorded using FAWN.

Visual data were taken using the National Turfgrass Evaluation Program rating system (Shearman and Morris, 200x). Color, quality, density ratings were taken weekly from 20 May 2012 through 1 Dec 2012. Starting 1 Dec 2012 visual ratings were collected twice monthly. The NTEP scale ranges from 1-9 with a quality rating of 9 being optimal and 1 being dead turf; color rating of 9 being a dark green turf and 1 light pale green color; and density rating of 9 being maximum density. Ratings in this study $\geq$ 6 were considered to be acceptable. Ratings were reported in whole numbers.

Leachate samples were collected with the use of a leachate sampling vacuum apparatus. Once each leachate sample was collected, the entire vacuum trap was sanitized by distilled water pumped into the triple rinse device (FDEP, 2004). Scintillation vial samples were immediately preserved using 1:1 sulfuric acid solution (pH <2) and chilled on wet ice (<4°C) after extraction (FDEP, 2004). Following scintillation vial collection, leachate catchment vessels were emptied into an 18.9 L bucket and weighed for leachate volume with the use of a hanging scale. Field duplicates and field blanks were taken every tenth sample (FDEP, 2004). Equipment blanks were taken at the end of each sampling period to ensure sufficient distilled water rinsing and the prevention of contamination. Irrigation water samples were taken regularly to provide NO_3-N concentration added via irrigation.

Samples were either frozen or refrigerated based upon next sample transport from Jay, FL to Gainesville, FL. All samples were transported on wet ice in insulated coolers (FDEP, 2004). Once the samples arrived in Gainesville, those that were not immediately analyzed were kept frozen. All samples were analyzed for total soluble nitrogen (TSN) using an Antek 9000NS Series analyzer (Antek Instruments, Inc., Houston, TX).

The Antek 9000N instrument allows for TSN calibration standards to be analyzed, which produce internal calibration curves. The standard curve before each test required an R^2 value of 0.995 and each four-injection calibrant was examined for outliers using a 5.0% relative standard deviation (RSD).

Once the calibration curves of the known standards were determined to be sufficient, raw unknown N contents were analyzed and compared to the known calibration curve concentrations. Each sample was initially tested on a 1-10 mg TSN L^{-1} calibration curve with four injections per sample. Samples with less than 1 mg TSN L^{-1} concentration were under the method detection limit (MDL) and considered to have undetectable levels. Samples greater than 10 mg TSN L^{-1} were reanalyzed on a 10-100 mg TSN L^{-1} calibration curve with the same set requirements. Samples with a RSD >5.0% were reanalyzed until an acceptable standard deviation was achieved.

Results

The main objective of the study was to identify the most effective fertilizer source to reduce TSN leaching. To determine if one or more sources performed greater than all others, data were analyzed using SAS/GLIMMIX across N fertilizer sources using a fitted linear mixed model. All samples analyzed for TSN from the second and third events were under the method detect limit (<1 mg TSN L^{-1}) and sample analysis was stopped. At no time were differences between N sources observed.

The fitted linear mixed effects model for leachate determined sampling time significance (Table 3-2). At 1008 HAT, the highest average leaching loads were observed followed by 840 HAT. Leaching occurring 12 HAT had the least TSN collected (Table 3-4).

Change in visual evaluations as a result of fertilization application was fitted into a linear mixed effects model which showed time significant for visual color, quality, and density (Table 3-3). The best visual color ratings occurred at 14 and 21 DAT (Table 3-

5). Visual quality ratings at 14, 21, 35, 126, and 140 DAT had the best overall quality. Visual quality at 7, 49, 77, 91 and 105 DAT resulted in lower quality ratings. Visual density was greatest at 14 and 35 DAT. At all collection dates visual color, quality, and density were above the minimum acceptable rating.

Analysis of visual color showed an event by fertilizer source significance. During the third leaching event, ammonium sulfate, polymer coated urea (Polyon), sulfur coated urea, polymer sulfur coated urea (Agrium XCU), methylene urea (Nutralene), and activated sewage sludge (Milorganite™) provided the highest visual color ratings (Table 3-6). The untreated control provided the lowest visual color. All fertilizer sources, with the exception of the untreated control, were above the minimum acceptable rating in the third event. There were no differences between fertilizer sources during the second event.

Discussion

In this study there was no fertilizer source that performed better throughout the evaluation period. Time seemed to be the biggest factor according to nitrogen leaching, visual ratings, and percolation ratings. Only a small fraction of the fertilizer applied was recovered via N leaching across all three events. Unaccounted N was presumably lost through volatilization, runoff and the collection process. With the excessively high amounts of irrigation in the first two events, runoff, and ponding water that was collected and analyzed contained high levels of TSN (10-100 mg TSN L^{-1}). High runoff TSN was also confirmed with a visual N response to the hillside adjacent to the study.

Another possible explanation to the unaccounted N was a situation that would have promoted anaerobic conditions with high levels of biochemical oxygen demand (BOD). BOD is the total amount of oxygen from water used by bacteria during the process of oxidizing organic matter (Hach et al., 1997). Converting the organic matter from a soluble fraction to a biological solid encourages removal of the organic matter through the process biological cells settling (Grady et al., 1980). Excessive BOD and low oxygen levels can encourage growth of anaerobic bacteria such as a mucilaginous coating which can clog groundwater leaching (County of Barnstable, 2011). Denitrifying bacterial relies on BOD as a primary food source in systems where bacterially-mediated nitrogen removal occurs (County of Barnstable, 2011). After dry downs during the second and third runs, a majority of the plots began to grow algae on the turf surface. The anaerobic environment also had the potential to slow or prevent nitrification altogether.

Chen et al., (2007) found that in waterlogged conditions; both the amount of ammonia volatilization and the percentage of lost fertilizer N were higher than under non-waterlogged conditions. Chen (2007) also found that the ammonium volatilization rate increased with increasing N rates. With our waterlogged conditions and excessively high (144 kg N ha^{-1}) rate of N application, there was the potential for excessively high volatilization rates. Gioacchini (2002) reported volatilization losses range between 1 to 60% of applied N. Many factors effect nitrogen volatilization losses; with the most important being pH, nitrate concentration, and wind speed (De Datta, 1981). The depletion on carbon dioxide in floodwater during the day and restored levels during night respiration cause diurnal variations in O2 content and pH. During a given day, the pH may reach 10 and shift 2-3 units at night (Mikkelsen et al., 1978), while the O2 levels potentially could be oversaturated by 200% (Roger et al., 1983).

In addition to the possibility of runoff and volatilization, the collection of each leachate sample occurred at the end of lysimeters sampling collection. If stratification occurred in the lysimeters, the gravity-fed vacuum extraction of water grab samples has the potential to have missed the N contained in each lysimeter.

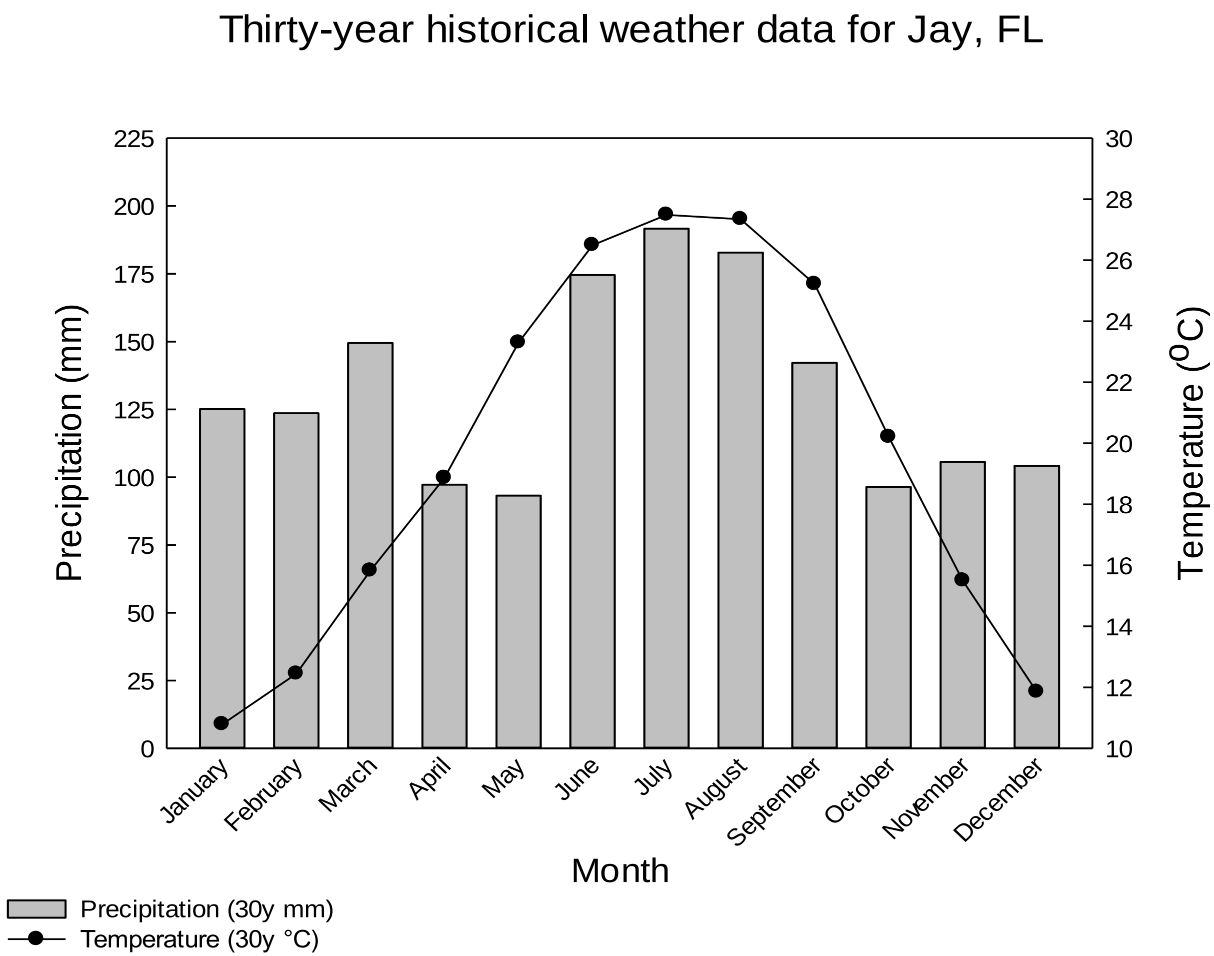

Figure 3-1. Compiled Thirty-Year Weather Data for the Jay, FL region from 1982-2012: NOAA National Climatic Data Center

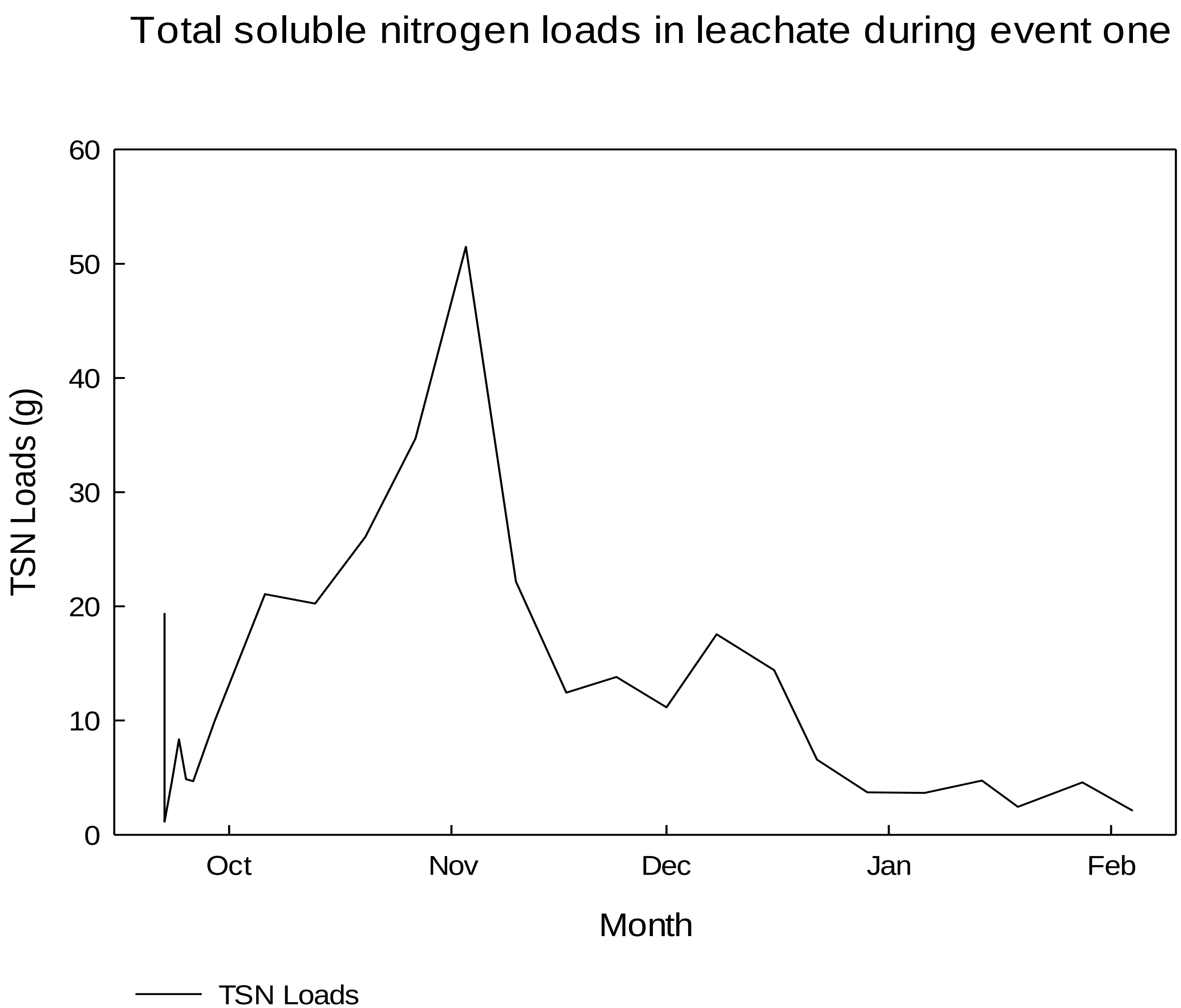

Figure 3-2. Total soluble nitrogen (TSN) Loads in leachate from September 20th, 2011 to February 5th, 2012.

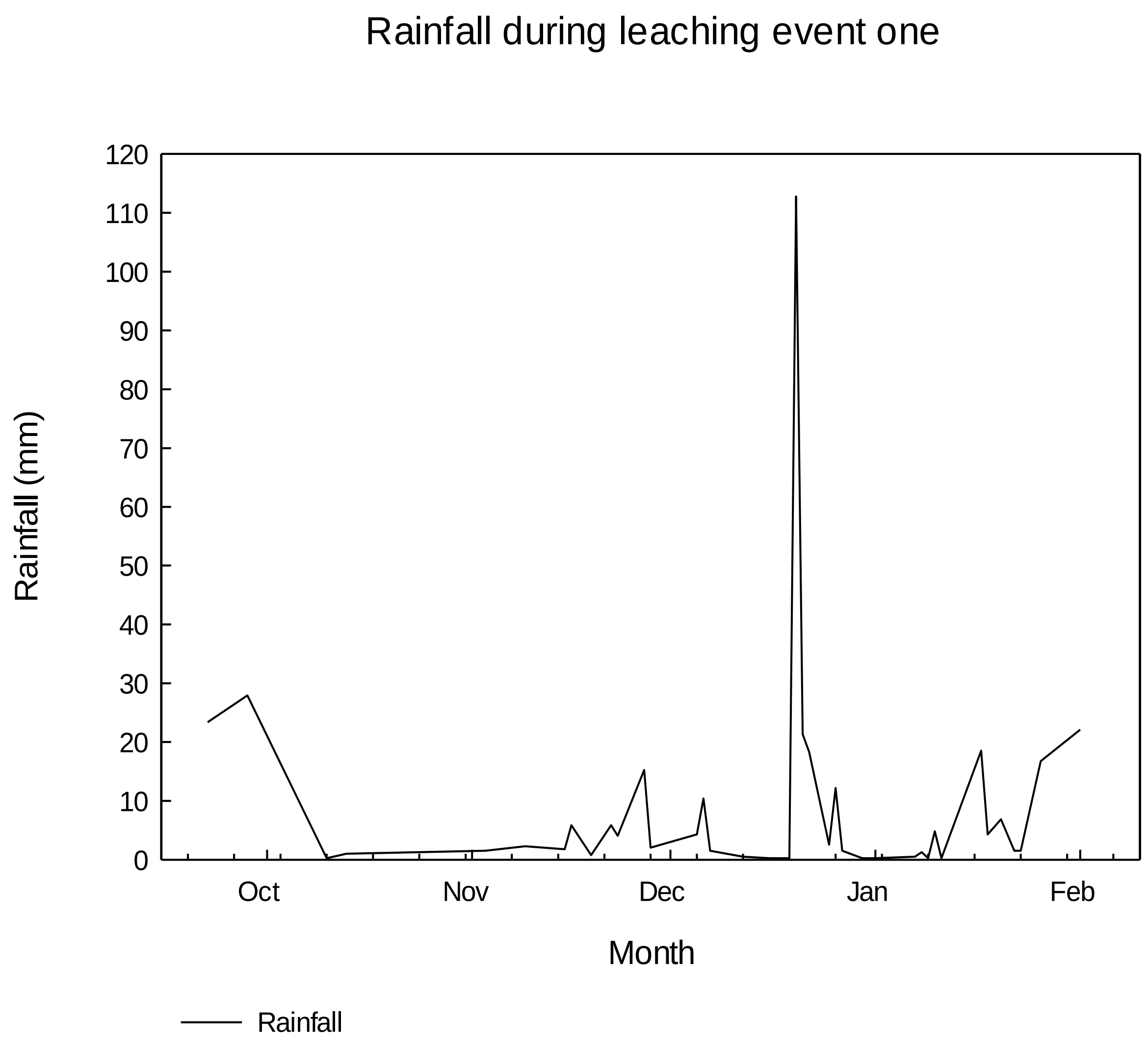

Figure 3-3. Rainfall in Jay, FL from September 20th, 2011 to February 5th, 2012.

Table 3-1. Leaching study nitrogen fertilizer sources

Product	Class†	Analysis	Release Mechanism	Additional Information‡
Ammonium Sulfate	soluble	21-0-0	Immediately available for plant uptake	24% Sulfur and high burn potential
Urea	soluble	46-0-0	Immediately available for plant uptake	Non-Ionic compound
Stabilized Urea (UFLEXX)	soluble	46-0-0	Immediately available for plant uptake	Composition inhibits volatilization and nitrification
UreaForm(Nitroform)	slow release	38-0-0	Biological activity	10-15% Unreacted urea - 4-5 methyl groups or more
Methylene Urea (Nutralene)	slow release	40-0-0	Biological activity	15-30% Unreacted urea - 3-4 methyl groups or more
Activated Sewage Sludge (Milorganite)	slow release	6-2-0	Biological activity	Natural organic contains water insoluble nitrogen
Polymer Coated Urea (Poly-on)	controlled release	41-0-0	Osmotic diffusion	Reactive layer technology
Polymer/Sulfur Coated Urea (XCU, Agrium Technologies)	controlled release	43-0-0	Diffusion and capillary action	Polymer/sulfur coated hybrid
Sulfur Coated Urea (SCU)	controlled release	39-0-0	Water penetration through micropores and imperfections	Coating thickness, quality, biological activity, soil pH and temperature influence release. Burn potential

†The Fertilizer Institute. 2012. Enhanced Efficiency Fertilizers. 24 October 2012 < http://www.tfi.org/>.
‡Sartain, J.B., and J.K. Kruse. 2001. Selected Fertilizers Used in Turfgrass Fertilization. Inst. of Food and Agric. Sci. (IFAS), CIR. 1262. Univ. of Florida, Gainesville.

Table 3-2. Analysis of variance for total soluble nitrogen leachate

Effect	Df	TSN pr > F
Leaching ANOVA		
Event One		
Treatment†	9	0.157
DAT§	26	<0.001
Treatment*DAT	234	0.844
Event Two		
Treatment†	9	1.000
DAT§	16	1.000
Treatment*DAT	144	1.000
Event Three		
Treatment†	9	1.000
DAT§	34	1.000
Treatment*DAT	306	1.000

Table 3-3. Analysis of variance for visual color, visual quality, and visual density

Visual Assessment ANOVA†				
Effect	Df	Color pr > F	Quality pr > F	Density pr > F
Event†	1	0.053	0.758	0.967
Treatment§	9	0.056	0.162	0.165
DATβ	16	<0.001	<0.001	<0.001
Event*Treatment	9	0.027	0.529	0.301
Treatment*DAT	144	0.084	0.999	0.989

† Visual color, quality and density was rated using the NTEP scale which is from 1 to 9, 9=optimal turf quality/density, 6=acceptable turf quality/density.
‡ Event consisted of event two and three.
§ Treatments refer to nitrogen sources used; ammonium sulfate, urea, stabilized urea, ureaformaldehyde, methylated urea, biosolid, polymer coated urea, sulfur coated urea and polymer/sulfur coated urea.
β Days after Treatment (DAT) consists of the weekly visual ratings assessment during the second and third leaching events.

Table 3-4. Total soluble nitrogen leachate loads by days after treatment during the first event

Total Soluble Nitrogen Loads DAT†					
DAT	TSN -g-	DAT	TSN -g-	DAT	TSN -g-
0h	19.42 b-e‡	14d	21.06 b-e	77d	17.55 b-e
4h	2.52 de	21d	20.24 b-e	84d	14.41 b-e
8h	1.83 de	28d	26.10 bc	91d	6.57 cde
12h	1.14 e	35d	34.71 b	98d	3.71 de
1d	4.61 de	42d	51.48 a	105d	3.66 de
2d	8.35 cde	49d	22.16 bcd	112d	4.73 de
3d	4.86 de	56d	12.44 cde	119d	2.45 de
4d	4.68 de	63d	13.80 cde	126d	4.58 de
7d	9.96 cde	70d	11.16 cde	133d	2.10 de

† Days after treatment (DAT) consist of the lysimeter sampling times; (0, 4, 8, 12 hours and 1, 2, 3, 4, 7 days followed by weekly sampling for 22 weeks).

‡ Total soluble nitrogen (TSN) mg L^{-1} means with the same letter were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 3-5. Visual color, visual quality, and visual density ratings by days after treatment

	Visual Ratings†		
DAT‡	Color	Quality	Density
1	6.4 def§	6.6 c-f	6.3 cd
7	6.4 ef	6.2 fg	6.1 d
14	7.3 ab	7.5 a	7.6 a
21	7.5 a	7.1 abc	6.8 bc
28	6.6 c-f	6.6 b-f	6.7 bc
35	6.9 bcd	7.2 ab	7.0 ab
42	7.0 bc	6.5 def	6.6 bcd
49	6.5 def	6.0 g	6.3 cd
56	6.8 b-e	6.7 b-e	6.7 bc
63	6.8 b-e	6.6 c-f	6.6 bc
77	6.6 cde	6.2 gf	6.4 cd
91	6.7 b-e	6.3 d-g	6.5 bcd
105	6.8 b-e	6.2 efg	6.4 cd
126	6.5 c-e	6.9 a-e	6.8 bc
140	6.0 f	7.0 a-d	6.8 bc
154	6.8 b-e	6.7 b-f	6.5 bcd
168	6.4 def	6.6 b-f	6.4 cd

† Visual color, quality and density was rated using the NTEP scale which is from 1 to 9, 9=optimal turf quality/density, 6=acceptable turf quality/density.
‡ Days after Treatment (DAT) consist of percolation test dates which were weekly until 01 December 2012 when it was moved to a biweekly basis in the third leaching event.
§ Means with the same letter were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

Table 3-6. Visual color ratings for leaching event by fertilizer source

	Color Ratings†	
Fertilizer Source	Event Two	Event Three
Ammonium Sulfate	6.9	7.1 a‡
Polymer Coated Urea	6.7	7.1 a
Sulfur Coated Urea	6.8	7.2 a
Agrium XCU	6.7	6.9 a
Nutralene	6.5	7.0 a
Nitroform	6.5	6.6 ab
Milorganite	7.1	7.1 a
Urea	6.8	6.7 ab
UFLEXX	6.6	6.6 ab
Untreated Control	6.0	5.5 b

† Visual color was rated using the NTEP scale which is from 1 to 9, 9=optimal turf color, 6=acceptable turf color.
‡ Means with the same letter were not significantly different (P = 0.05) according to Tukey Kramer's means separation.

CHAPTER 4
CONCLUSIONS

Nitrogen source should be chosen with consideration of the potential fate and contribution to nonpoint source pollution. In this study N runoff seemed to be a greater threat to eutrophication than N leaching. With greater loads observed from the runoff study than the leaching study greater emphasis needs to be on research and development of best management practices near environmentally sensitive areas.

The solubility of the given N source applied in the forced runoff events proved to be the most influential determination of total soluble nitrogen recovery rate. In this worst case scenario, PCU outperformed AS and UF by minimizing TSN levels in runoff waters. Since AS and UF (10-15%) contain a soluble fraction, it may be beneficial to use polymer coated N products when fertilization is required when excess rainfall/irrigation is known to be imminent and in low maintenance zones surrounding a body of water.

Although inconsistent results were found in the first N leaching event, it substantiated previous research claims that immature turf is often more susceptible to N leaching. In addition to a relatively immature turf stand, it was quite evident that a 144 kg N ha^{-1} fertilization rate coupled with extreme irrigation practices of 25 mm day^{-1} was not conducive to proper turf management. Even with the intense irrigation and fertilization regime, TSN leachate in the second event was below the MDL of 1 mg TSN L^{-1}.

Future research needs to be conducted with a wider range of fertilizer sources and unfertilized buffer strip sizes as well as differing soil moisture values and soil textures. This study was conducted at field capacity with forced runoff without watering in the product. Results may vary significantly if BMP's were followed and runoff was not forced immediately following fertilizer application. The significance of this research can be surmised by the understanding that N source and solubility should be chosen under consideration that a potential misapplication could result in nonpoint source pollution via runoff.

APPENDIX A
IRRIGATION UNIFORMITY FOR JAY LEACHING STUDY

Date	Time	Distribution	Christiansen	Wind Speed
5/22/2012	9:45:00 AM	0.8684	0.8015	15-20mph
5/29/2012	11:00:00 AM	0.7571	0.5692	25-30mph
6/14/2012	10:30:00 AM	0.7357	0.5912	10-15mph
6/21/2012	1:00:00 PM	0.7070	0.5342	20mph
6/27/2012	10:00:00 AM	0.7669	0.6234	5mph
7/3/2012	9:00:00 AM	0.7595	0.5855	10-15mph
7/10/2012	NR†	0.7941	0.6491	NR
7/17/2012	8:00:00 AM	0.8969	0.8331	0-5 mph
9/4/2012	NR	0.6870	0.5550	NR
9/10/2012	2:05:00 PM	0.7455	0.5910	10mph
9/17/2012	12:00:00 PM	0.6732	0.5010	10-20mph
9/24/2012	NR	0.7318	0.5561	NR
10/1/2012	NR	0.8323	0.7281	NR
10/8/2012	10:00:00 AM	0.6473	0.4164	20-25mph
10/16/2012	8:10:00 AM	0.7896	0.6749	10mph
11/14/2012	10:00:00 AM	0.8637	0.8163	0-5mph
12/4/2012	NR	0.5823	0.4867	NR
12/19/2012	12:45:00 PM	0.6671	0.5301	15-25mph
1/14/2013	11:00:00 AM	0.6813	0.5391	10-20mph
1/28/2013	2:30:00 PM	0.7300	0.6245	15-20mph
2/11/2013	11:00:00 AM	0.8322	0.7517	NR
2/25/2013	10:00:00 AM	0.8532	0.7553	0-5mph
3/11/2013	2:00:00 PM	0.8586	0.8065	5-10mph

† Not recorded (NR)

APPENDIX B
PERCOLATION RATES FOR LEACHING EVENT BY DAYS AFTER TREATMENT

Event Two		Event Three	
DAT†	Percolation cm h^{-1}	DAT	Percolation cm h^{-1}
1	0.3571 a‡	1	0.3769 a
2	0.2375 ab	7	0.0292 b
3	0.0340 c	14	0.1217 b
4	0.0965 bc	28	0.0541 b
5	0.2289 ab	35	0.0686 b
7	0.1935 abc	42	0.2012 b
21	0.0780 bc	49	0.1059 b
28	0.1293 bc	56	0.0805 b
35	0.1537 bc	79	0.0523 b
42	0.1166 bc	93	0.1069 b
49	0.1153 bc	107	0.0660 b
56	0.0846 bc	128	0.1354 b
65	0.0366 c	142	0.1118 b
		156	0.0828 b
		170	0.1095 b
		184	0.1082 b
		198	0.1179 b

† DAT (Days after Treatment) consists of the lysimeter sampling dates
‡ Means with the same letter were not significantly different (P = 0.05) according to Tukey Kramer’s means separation.

LIST OF REFERENCES

Balogh, J.C., and J.L. Anderson. 1992. Environmental impacts of turfgrass pesticides. p. 221-353. *In* J.C. Balogh and W.J. Walker (ed.) Golf course management and construction: environmental issues. Lewis Publishing, Chelsea, MI.

Balogh, J.C., and W.J. Walker. 1992. Role and conservation of water resources. p. 39-104. *In* J.C. Balogh and W.J. Walker (ed.) Golf course management and construction: environmental issues. Lewis Publishing, Chelsea, MI.

Barber, S.A. 1995. Soil nutrient bioavailability: a mechanistic approach. 2nd ed. John Wiley & Sons, New York.

Barton, L., G.G.Y. Wan, and T.D. Colmer. 2006. Turfgrass (*Cynodon dactylon L.)* sod production on sandy soils: II. Effects of irrigation and fertilizer regimes on N leaching. Plant Soil. 284:147-164.

Beard, J.B. 1973. Turfgrass science and culture. Prentice Hall Publishing, New York.

Beard, J.B. 1982. Turf management for golf courses. Macmillan Publishing, New York.

Bell, G.E., and K. Koh. 2011. Nutrient and pesticide losses caused by simulated rainfall and sprinkler irrigation. USGA turfgrass and environmental research online. 10(2):1-10.

Blanco-Canqui, H., C.J. Gantzer, S.H. Anderson, E.E. Alberts, and A.L. Thompson. 2004. Grass barrier and vegetative filter strip effectiveness in reducing runoff, sediment, nitrogen, and phosphorus loss. Soil Sci. Soc: Am. J. 68:1670-1678.

Bowman, D.C., C.T. Cherney, and T.W. Rufty Jr. 2002. Fate and transport of nitrogen applied to six warm-season turfgrasses. Crop Sci. 42:833-841.

Brady, N.C., and R.R. Weil. 2008. The nature and properties of soils, 14th ed. Prentice Hall Publishing, New York.

Brown, K. W., R.L. Duble, and J.C. Thomas. 1977. Influence of management and season on fate of N applied to golf courses. Agron. J. 69(4):667-671.

Brown, K. W., J. C. Thomas, and R.L. Duble. 1982. Nitrogen source effect on nitrate and ammonium leaching and runoff losses from greens. Agron. J. 74:947-950.

Burton, G.W. 1960. Tifway (Tifton 419) bermudagrass (Reg. No. 7). Crop Sci. 6:93-94.

Chen, Z.H., L.J. Chen, Z.J. Wu, Y.L. Zhang, and Y.H. Juan. 2007. Ammonia volatilization from rice field under different water conditions in low Liaohe river plain. J. Appl. Ecol.. 12:2771-2776

Christiansen, J.E. 1942. Irrigation by sprinkling. Bull. 670. California Agric. Exp. Stn., Oakland, GA.

Cisar, J.L., and G.L. Miller. 1999. Irrigation water quantity. p. 25-35. *In* J.B. Unruh and M.L. Elliot (2 ed.) Best management practices for Florida golf courses. Inst. of Food and Agric. Sci., Univ. of Florida, Gainesville.

Cisar, J.L., G.H. Snyder, and P. Nkedi-Kizza. 1991. maintaining quality turfgrass with minimal nitrogen leaching. Bull. 273. Inst. of Food and Agric. Sci., Univ. of Florida, Gainesville.

Cole, J.T., J.H. Baird, N.T. Basta, R.L. Huhnke, D.E. Storm, G.V. Johnson, M.E. Payton, M.D. Smolen, D.L. Martin, and J.C. Cole. 1997. Influence of buffers on pesticide and nutrient runoff from bermudagrass turf. J. Environ. Qual. 26:1589-1598.

County of Barnstable. 2011. Basic constituents of wastewater: Biochemical oxygen demand. Dept. of Health and Environment. Available at http://www.barnstablecountyhealth.org/ia-systems/information-center/compendium-of-information-on-alternative-onsite-septic-system-technology/basics-of-wastewater-treatment/ (Verified 22 July 2013).

County of Collier, 2009. Collier County Florida-friendly use of fertilizer on urban landscapes. Ord. No. 11-24. Sec. 6., Sec. 7.

County of Manatee, 2011. Regulating landscape maintenance practices and use of fertilizers. Ord. No. 11-21. Sec. 2-35-8., Sec. 2-35-13.

County of Pinellas. 2010. Fertilizer and landscape maintenance ordinance. Article XIII. Sec. 58:471-485.

County of Westchester. 2009. Restrictions on the application and sale of lawn fertilizer within the County of Westchester. Sec. 1-36-863., Laws of Westchester County, New York.

Daniel, T.C., A.N. Sharpley, and J.L. Lemunyon. 1998. Agricultural phosphorus and eutrophication: A symposium overview. J. Environ. Qual. 27:251-257.

De Datta, S.K. (1981). Princes and practices of rice production. John Wiley & Sons, New York

De Nobili, M., S. Santi, and C. Mondini. 1992. Fate of nitrogen (^{15}N) from oxamide and urea applied to turf grass: A lysimeter study. Fert. Res. 33:71-79.

Dillaha, T.A., R.B. Reneau, S. Mostaghimi, and D. Lee. 1989. Vegetative filter strips for agricultural nonpoint source pollution-control. Trans. ASAE 32:513-519.

Dodds, W.K. 2006. Nutrients and the “dead zone”: The link between nutrient ratios and dissolved oxygen in the Northern Gulf of Mexico. Frontiers in Ecology and the Environment 4:211–217.

Easton, Z.M., A.M. Petrovic, D.J. Lisk, and I.M. Larsson-Kovach. 2005. Hillslope position effect on nutrient and pesticide runoff from turfgrass. Int. Turfgrass Soc. Res. J. 10:121-129.

Engelsjord, M.E., and B.R. Singh. 1997. Effects of slow-release fertilizers on growth and on uptake and leaching of nutrients in Kentucky bluegrass turfs established on sand-based root zones. Can. J. Plant Sci. 77:433-444.

Enloe, J. 2013a. Florida Climate Division 1 Time Series. NOAA National Climatic Data Center. Available at http://ncdc.noaa.gov/temp-and-precip/time-series/ (Verified 10 Mar 2013)

Enloe, J. 2013b. Florida Climate Division 2 Time Series. NOAA National Climatic Data Center. Available at http://ncdc.noaa.gov/temp-and-precip/time-series/ (Verified 10 Mar 2013)

Erickson, J.E., J.L. Cisar, G.H. Snyder, D.M. Park, and K.E. Williams. 2008. Does a mixed-species landscape reduce inorganic-N leaching following establishment compared to a conventional st. augustinegrass lawn? Crop Sci. 48:1586-1594.

Erickson, J. E., J.L. Cisar, G.H. Snyder, J.C. Volin, and D.M. Park. 2005. Phosphorus and potassium leaching under contrasting residential landscape models established on a sandy soil. Crop Sci. 45(2):546-552.

Erickson, J.E., J.L. Cisar, J.C. Volin, and G.H. Snyder. 2001. Comparing nitrogen runoff and leaching between newly established st. augustinegrass turf and an alternative residential landscape. Crop Sci. 41:1889-1895.

Erickson, J.E., D.M. Park, J.L. Cisar, G.H. Snyder, and A.L. Wright. 2010. Effects on sod type, irrigation, and fertilization on nitrate-nitrogen and orthophosphate-phosphorus leaching from newly established st. augustinegrass sod. Crop Sci. 50:1030-1036.

The Fertilizer Institute. 2012. Enhanced Efficiency Fertilizers. Available at http://www.tfi.org/ (Verified 24 Oct. 2012)

FDEP. 2004. FDEP SOP sampling training for groundwater, surface water, and wastewater. SOP-001/01. Sec. 2. FD 5000, Sec. 3. FQ 1214 and 1220, Sec. 5. FC 1190, Sec. 6. FS 1000, Sec. 8. FS 2100.

FDEP. 2007. Everglades restoration. Available at http://www.dep.state.fl.us/secretary/everglades/ (Verified 10 Aug 2012).

FDEP. 2008. Water resources management program. Available at http://www.dep.state.fl.us/water/groundwater/whatis.htm/ (Verified 10 Aug. 2012).

FDEP. 2009. Florida-friendly landscape guidance models for ordinances, covenants, and restrictions. FDEP and the Univ. of Florida, Gainesville.

FDEP. 2010. Model ordinance for Florida-friendly fertilizer use on urban landscapes. FDEP and the Univ. of Florida.

FDEP. 2012. Development of numeric nutrient criteria for Florida's waters. Available at http://www.dep.state.fl.us/water/wqssp/nutrients/ (Verified 5 Jan. 2013).

Geron, C.A., T.K. Danneberger, S.J. Traina, T.J. Logan, and J.R. Street. 1993. The effects of establishment methods and fertilization practices on nitrate leaching from turfgrass. J. Enivron. Qual. 22:119-125.

Gioacchini P., A. Nastri, and C. Marzadori. 2002. Influence of urease and nitrification inhibitors on N losses from soils fertilized with urea. Biol. Fert. Soils, 36:129-135

Grady, C.P., and L.C. Lim. 1980. Biological wastewater treatment: Theory and applications. Marcel Decker, New York.

Gross, C.M., J.S. Angle, and M.S. Welterlen.1990. Nutrient and sediment losses from turfgrass. J. Environ. Qual. 19:663-668.3

Gross, C.M., J.S. Angle, R.L. Hill, and M.S. Welterlen. 1991. Runoff and sediment losses from tall fescue under simulated rainfall. J. Environ. Qual. 20:604-607.

Guertal, E. A., and J.A. Howe. 2012. Nitrate, ammonium, and urea leaching in hybrid bermudagrass as affected by nitrogen source. Agron. J. 104(2):344-352.

Guillard, K., and K.L. Kopp. 2004. Nitrogen fertilizer form and associated nitrate leaching from cool-season lawn turf. J. Environ. Qual. 33:1822-1827.

Hach, C. C., R.L. Klein Jr., and C.R. Gibbs. 1997. Biochemical oxygen demand. Tech. Monogr, (7).

Hanson, A.A., F. V. Juska, and G.W. Burton. 1969. Species and varieties. *In* A. A. Hanson and F.V. Juska (ed.), Turfgrass sci., Agron. 14:370-409, Madison, WI.

Hartman, R., F. Alcock, and C. Pettit. 2008. The spread of fertilizer ordinances in Florida. Sea Grant Law and Policy J. 1:98–114.

Havlin, J.L., J.D. Beaton, S.L. Tisdal, and W.L. Nelson. 2005. Soil fertility and nutrient management. 7th ed. Prentice Hall Publishing, New York.

Hochmuth, G., T. Neil, J.B Unruh, L. Trenholm, and J. Sartain. 2012. Potential unintended consequences with urban fertilizer bans in Florida – A scientific review. Hort. Tech. 22(5):600-616

Hodges, A.W., M. Rahmani, and D.W. Mulkey. 2006. Economic contributions of agricultural, food manufacturing, and natural resource industries in Florida in 2006. FE702, Food and Resource Economics Department, IFAS Cooperative Extension Service, Gainesville, FL. Available at http://edis.ifas.ufl.edu/pdffiles/FE/FE70200.pdf/ (Verified 5 Feb. 2013)

Inst. of Food and Agric. Sci., Univ. of Florida. Analytical Services Laboratories. Wallace bldg. 631, Gainesville.

Inst. of Food and Agric. Sci., Univ. of Florida. Florida Automated Weather Network, Gainesville.

Inst. of Food and Agric. Sci., Univ. of Florida. 2010a. PSREU soil map, Gainesville.

Inst. of Food and Agric. Sci., Univ. of Florida. 2010b. Soil and water science department core laboratories pedology and mineralogy laboratory. 2181 McCarty Hall, Gainesville.

Karcher, D.E., and M.D. Richardson. 2005. Batch analysis of digital images to evaluate turfgrass characteristics. Crop Sci. 45:1536-1539.

King, K.W., J.C. Balogh, K.L. Hughes, and R.D. Harmel. 2007. Nutrient load generated by storm event runoff from a golf course watershed. J. Environ. Qual 36:1021-1030.

Kohler, E.A., V.L. Poole, Z.J. Reicher, and R.F. Turco. 2004. Nutrient, metal, and pesticide removal during storm and nonstorm events by a constructed wetland on an urban golf course. Ecol. Eng. 23:285-298.

Krenitsky, E.C., M.J. Carroll, R.L. Hill, and J.M. Krouse. 1998. Runoff and sediment losses from natural and man-made erosion control materials. Crop Sci. 38:1042-1046.

Krutz, L. J.; S.A. Senseman, M.C. Dozier; D.W. Hoffman, and D.P. Tierney. 2003. Infiltration and adsorption of dissolved atrazine and atrazine metabolites in buffalograss filter strips. J. Environ. Qual. 32:2319-2324.

Linde, D.T., T.L. Watschke, A.R. Jarrett, and J.A. Borger. 1995. Surface runoff assessment from creeping bentgrass and perennial ryegrass turf. Agron. J. 87:176-182.

Mancino, C.F., and J. Troll. 1990. Nitrate and ammonium leaching losses from N fertilizers applied to 'Penncross' creeping bentgrass. Hort Sci. 25:194-196.

McGroary, P. C., J.L. Cisar, G.H. Snyder, J.E. Erickson, J.E. Daroub, and J.B. Sartain. 2011. Water use of st. augustinegrass and bahiagrass under varying nitrogen rates. Agron. J. 103:100-106.

Merriam J.L., and J. Keller. 1978. Farm irrigation system evaluation: A guide for management. Department of Agric. and Irri. Eng., Utah St. Univ., Logan.

Meyer, L.D., and W.C. Harmon. 1979. Multiple-intensity rainfall simulator for erosion research on row sideslopes. ASAE. 77-2025.

Mikkelsen, D.S., S.K. De Datta, and W. Obcemea. 1978. Ammonia volatilization losses from flooded rie soils. Soil Sci. Soc. Am. J. 42:725-730.

Miltner, E.D., B.E. Branham, E.A. Paul, and P.E. Reike. 1996. Leaching and mass balance of ^{15}N-labeled urea applied to a Kentucky bluegrass turf. Crop Sci. 36:1427-1433.

Morton, T.G., A.J. Gold, and W.M. Sullivan. 1988. Influence of over-water and fertilization on nitrogen losses from home lawns. J. Environ. Qual. 17:124-130.

Mosdell, D. K., and R.E. Schmidt. 1985. Proc. of the Int. Turfgrass Res. Conf., 5th, p. 487-494.

Moss, J.Q., G.E. Bell, M.A. Kizer, M.E. Payton, H. Zhang, and D.L. Martin. 2006. Reducing nutrient runoff from golf course fairways using grass buffers of multiple heights. Crop Sci. 46:72-80.

Mylavarapu, R. 2011. Impact of phosphorus on water quality. Inst. of Food and Agric. Sci., EDIS SL 275. Univ. of Florida, Gainesville.

NCDENR. 2013. Algal Blooms. Raleigh, NC. Available at http://portal.ncdenr.org/web/wq/ess/eco/blooms/ (Verified 15 July 2012).

Nelson, K.E., A.J. Turgeon, and J.R. Street. 1980. Thatch influence on mobility and transformation of nitrogen carriers applied to turf. Agron. J. 72:487-492.

NRCS. 2009. United States Dept. of Agric., web soil survey. Available online at http://websoilsurvey.nrcs.usda.gov/ (Verified 19 May 2011).

Peacock, C.H., M.M. Smart, and W. Warren-Hicks. 1996. Best management practices and integrated pest management strategies for protection of natural resources on golf course watersheds. p. 335-338. Watershed Proc., 96th. Baltimore, MD. 8-12 June 1996.

Petrovic, A.M. 1990. The fate of nitrogenous fertilizers applied to turfgrass. J. Environ. Qual. 19:1-14.

Petrovic, A. M. 2004. Nitrogen source and timing impact on nitrate leaching from turf. Acta Horticulturae 661:427-432.

Petrovic, A.M., N.W. Hummel, and M.J. Carrol. 1986. Nitrogen source effects on nitrate leaching from late fall nitrogen applied to turfgrass. p.137. *In* 1986 Agronomy abstracts. ASA, Madison, WI.

Pratt, P.F. 1985. Agricultural and groundwater quality. p. 62. Council for Agric. Sci. and Tech., Cast Rep. No. 103. Ames, IA.

Rice, P., and B.P. Horgan. 2010. Nutrient loss in runoff from turf: effect on surface water quality. USGA turfgrass and environmental research online 9(1):1-10.

Rieke, P.E., and B.G. Eliis. 1974. Effects of nitrogen fertilization on nitrate movement under turfgrass. p. 120-130. *In* E.C. Roberts (ed.) Proc. 2nd Int. Turfgrass Res. Conf. ASA, Madison, WI. 19-21 June 1972. Blacksburg, VA.

Roger, P.A., W.J. Zimmerman, and T.A. Lumpkin. 1993. Microbiological management of wetland rice fields. *In* B. Metting (ed.) Soil microbial technologies, p 417-455. Marcel Decker, New York.

Rosen, C.J., and B.P. Horgan. 2005. Regulation of phosphorus fertilizer application in Minnesota: Historical perspective and opportunities for research and education. Int. Turf Res. J. 10:130-135.

Sartain, J.B. 2010. Comparative influences of N source on leaching of N and st. augstinegrass quality, growth and N uptake. Soil Crop Sci. Soc., Florida Proc. 69.

Sartain, J.B., and J.K. Kruse. 2001. Selected fertilizers used in turfgrass fertilization. Inst. of Food and Agric. Sci. CIR. 1262. Univ. of Florida, Gainesville.

Sartain, J.B., G.L. Miller, G.H. Snyder, J.L. Cisar, and J.B. Unruh. 1999. Fertilizer programs. p. 65-94. *In* J.B. Unruh and M.L. Elliot (2 ed.) Best management practices for Florida golf courses. Inst. of Food and Agric. Sci., Univ. of Florida, Gainesville.

SAS Institute. 2008. The SAS System for Windows: Release 9.2.1. SAS Inst., Cary, NC.

Sheard, R.W., M.A. Haw, G.B. Johnson, and J.A. Ferguson. 1985. Mineral Nutrition of bentgrass on sand rooting systems. p. 469-485. *In* F.L. Lemaire Proc. 5th Int. Turfgrass Research Conf., Avignon, France. 1-5 July 1985. INRA Paris, France.

Shearman, R.C. and K.N. Morris. [200x]. NTEP turfgrass evaluation guidelines. Available at http://www.ntep.org/pdf/ratings.pdf (Verified 8 June 2010). Beltsville,MD: National Turfgrass Evaluation Program.

Shuman, L.M. 2002. Phosphorus and nitrate nitrogen in runoff following fertilizer application. J. Environ. Qual. 31:1710-1715.

Smith, A.E., and D.C. Bridges. 1996. Movement of certain herbicides following application to simulated golf course greens and fairways. Crop Sci. 36:1439-1445.

Snyder, G. H., B.J. Augustin, and J.L. Cisar. 1989. Fertigation for stabilizing turfgrass nitrogen nutrition. p. 217-219 *In* H. Takatoh (ed.) Proc. 6th Int. Turfgrass Res. Conf., Tokyo, Japan, Japanese Soc. Turfgrass Sci., Tokyo.

Snyder, G.H., B.J. Augustin, and J.M. Davidson. 1984. Moisture sensor-controlled irrigation for reducing leaching in bermudagrass turf. Agron. J. 76:664-669.

Snyder, G. H., E.O. Burt, and B.L. James. 1976. Proc. of the annual meeting of the Florida State Hort. Soc. 89:326-330.

Soldat, D.J., and A.M. Petrovic. 2008. The fate and transport of phosphorus in turfgrass ecosystems. Crop Sci. 48:2051–2065.

Spalding, R.F., and M.E. Exner. 1993. Occurrence of nitrate in ground-water – A review. J. Environ. Qual. 22:392-402.

Starr, J.L., and H.C. DeRoo. 1981. The fate of nitrogen applied to turfgrass. Crop Sci. 21:531-536.

State of Wisconsin. 2009, Restrictions on the use and sale of fertilizer containing phosphorus. 2009 Assembly Bill 3, Wisconsin Act 9, Section 1, 94.643. Wisconsin Statutes 2009. Wisconsin State Legislature, Legislative Reference Bureau. Madison, Wisconsin.

Taliaferro, C.M. 1995. Diversity and vulnerability of bermuda turfgrass species. Crop Sci. 35:327-332.

Trenholm, L.E., and J.B. Unruh. 2009. Figuring out fertilizer for the home lawn. Inst. of Food and Agric. Sci., EDIS ENH 962. Univ. of Florida, Gainesville.

Turgeon, A.J. 2011. Turfgrass Management. 9th ed. Regents/Prentice Hall, Englewood Cliffs, NJ.

USEPA. 1976. Quality criteria for water. Rep. 440/9-76-023. U.S. Gov. Print. Office, Washington D.C.

USEPA. 2012a. Development of numeric nutrient criteria for Florida's waters. 40 C.F.R. Part 131 and the Clean Water Act. Phase 1. U.S. Gov. Print Office, Washington D.C.

USEPA. 2012b. What is nonpoint source pollution. U.S. Gov. Print Office, Washington D.C. Available at http://water.epa.gov/polwaste/nps/whatis.cfm/ (Verified 10 Jan. 2013).

Unruh, J.B., and M.L. Elliot. 1999. Best management practices for Florida golf courses. Inst. of Food and Agric. Sci., Univ. of Florida, Gainesville.

Wauchope, R.D., R.G. Williams, and L.R. Marti. 1990. Runoff of sulfometuron-methyl and cyanazine from small plots: Effects of formulation and ground cover. J. Environ. Qual. 19:119-125.

Walker, W.J., and B. Branham. 1992. Environmental impacts of turfgrass fertilization. p. 105-220. *In* J.C. Balogh and W.J. Walker (ed.) Golf course management and construction: environmental issues. Lewis Publishing, Chelsea, MI.

Watson, J.R., H.E. Kaerwer, and D.P. Martin. 1992. The turfgrass industry. p. 29-88. *In* D.V. Waddington, R.N. Carrow, and R.C. Shearman, (ed.) Turfgrass Agron. Monogr. 32. ASA, Madison, WI.

Witteveen, G., and M. Bavier. 1999. Practical golf course maintenance. p. 256. Ann Arbor Press, Chelsea, MI.

Wu, L. 1998. New method developed to measure the vertical infiltration capacity of Soils using single ring infiltrometers. Soil water and irrigation management, Univ. of California, Oakland.

Wu, L., R. Green, G. Klein, J.S. Hartin, and D.W. Burger. 2010. Nitrogen source and rate influence on tall fescue quality and nitrate leaching in southern California lawn. Agron. J. 102:31-38.

Xiong, X., G.E. Bell, J.B. Solie, M.W. Smith, and B. Marter. 2007. Bermudagrass season responses to nitrogen fertilization and irrigation detected using optical sensing. Crop Sci. 47:1603-1610.

BIOGRAPHICAL SKETCH

Ryan Adams received his M.S. degree under the direction of Dr. J. Bryan Unruh and Dr. Jason Kruse in August 2013. His work focused on nutrient management of bermudagrass fairways surrounding environmentally sensitive areas. Mr. Adams received his B.S degree in 2010 from Iowa State University, Ames, IA. During his tenure at Iowa State University, Ryan interned at Pinehurst Resort in Pinehurst, NC, Shoal Creek Country Club in Shoal Creek, Alabama and with the United States Golf Association Green Section. He has also worked at the Iowa State University Research Farm, Ames, IA and at Charlotte Country Club in Charlotte, NC.