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THE FATE OF NITROGEN AND PHOSPHORUS FROM A SIMULATED HIGHWAY CROSS-SECTION

by

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B.S.Env.E., University of Central Florida, 2012

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ABSTRACT

Nutrient pollution as a result of excessive fertilizer application is of major concern for Florida’s water resources. Excess fertilizer can be lost either via surface runoff or by leaching through the soil mass eventually reaching water bodies and leading to eutrophication. The focus of this study is to analyze the effect of low rainfall intensities and overland flow from an adjacent roadway surface on the loss of nutrients from two different fertilizers. This study focuses on the fate of the nitrogen and phosphorus present in fertilizers utilized by the Florida Department of Transportation for the stabilization of highway embankments. This research was performed on a field-scale test bed and rainfall simulator located at the Stormwater Management Academy at the University of Central Florida.

The loss of nutrients was measured from two soil and sod combinations typically found in Florida and used for highway stabilization –Pensacola Bahia on AASHTO A-2-4 soil and Argentine Bahia on AASHTO A-3 soil. Two different fertilizers were analyzed, an all-purpose, quick-release 10-10-10 (N-P-K) fertilizer previously used by FDOT, and the new slow-release 16-0-8 (N-P-K) fertilizer, both applied at a rate of 0.5 lb/1000 ft^2 consistent with FDOT’s practice. Each combination was analyzed under two rainfall intensities: 0.1 in/hr and 0.25 in/hr at a slope consistent with typical highway cross-sections found in Florida. Nutrient losses were measured by collection of runoff and/or baseflow that escaped the test bed. Additionally, from the soil samples collected throughout the testing period, the mass of the nutrients was compared to the mass balances values based on literature from a previous study on fertilizers performed at the Stormwater Management Academy.

The experimental findings of this study showed that there was a reduction in total nitrogen and total phosphorus on both A-2-4 soil and A-3 soil at the 0.25 in/hr intensity as a result of switching to the slow-release 16-0-8 (N-P-K) fertilizer. Results from the 0.1 in/hr rainfall intensity, which were available only for the A-2-4 soil, showed that at this intensity there was no apparent benefit to the switch in fertilizers. Furthermore, it was found that less total nitrogen and total phosphorus was lost from A-3 soil than A-2-4 soil at 0.25 in/hr when using 10-10-10 (N-P-K). At 0.1 in/hr, there was no apparent difference in total nitrogen lost. However, less total phosphorus was lost at this intensity.

The results of this study showed that there is an environmental benefit to applying slow-release fertilizers. This was more significant for the 0.25 in/hr intensity than the 0.1 in/hr intensity at which no apparent benefit was found. In addition, it was found that runoff was a greater source of nutrient loss than baseflow, although baseflow losses were substantial. Furthermore, it was found that total nitrogen tends to be lost via both pathways of runoff and baseflow while phosphorus has a lower tendency to leach through the soil but readily runs off the soil surface. It was also observed that because fresh sod tends to be heavily fertilized, applications of fertilizer could be reduced or avoided entirely after sod placement and applied as needed.

This thesis is dedicated to my daughter, Julianna, and my fiancé Clay.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BMAP	Basin Management Action Plan
CEC	Cation Exchange Capacity
FDEP	Florida Department of Environmental Protection
FDOT	Florida Department of Transportation
HABs	Harmful Algal Blooms
LEACHM	Leaching Estimation and Chemistry Model
LEACHN	Nitrogen module of the LEACHM model
SMARTL	Stormwater Management Academy Research and Testing Laboratory
SR	Slow Release
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus

CHAPTER 1: INTRODUCTION

Problem Statement

Nutrient pollution as a result of indiscriminate fertilizer application is of major concern for Florida's water resources. Numerous water bodies as well as sources of groundwater across the State of Florida already contain elevated levels of nutrients (Badruzzaman et al. 2012). The two nutrients of particular interest are the various chemical forms of nitrogen and phosphorus, both of which can lead to eutrophication in aquatic ecosystems, and are primary constituents in consumer fertilizers. Eutrophication, although ultimately a natural aging process of a water body, is greatly accelerated by human activities that cause an over-enrichment of water by nutrients (Millenium Ecosystem Assessment 2005). As a result, uncontrolled plant growth occurs, particularly favorable for algae bloom (i.e. phytoplankton), whose rapid increase in aquatic ecosystems results in decreased levels of dissolved oxygen. Eventually, these conditions escalate to a severity in which aquatic organisms can no longer survive (Ansari 2010). Of particular concern are harmful algal blooms (HABs), which in addition to leading to depleted oxygen levels, release natural toxins and other compounds that cause fatalities, often en masse, of fish and other aquatic animals. Furthermore, humans are also at risk as consumption of seafood contaminated with HABs is associated with a variety of types of shellfish poisoning (Carpenter et al. 1998).

Groundwater is the primary source of drinking water for more than half of drinking supplies in the United States (USGS 1996). Elevated levels of nutrients have also been detected in groundwater (USGS 2010). A nutrient of particular concern in drinking water supplies is nitrate, which has a direct effect on human health by compromising the oxygen-carrying capacity of the blood causing methemoglobinemia (USGS 2010). In addition to effluent from wastewater treatment plants, septic tanks, and natural nitrogen deposition, a major source of excessive nutrients in groundwater is the use of fertilizers in agricultural and urban areas (Mueller and Helsel 2013) Thus, the environmental impacts associated with excessive nutrients are of great concern, and the preservation of Florida's water bodies is becoming increasingly more important.

Nitrogen and phosphorus are both necessary nutrients for plant life; however, an inadequate supply of both of these nutrients limits the growth of plants, such as phytoplankton. As such, either phosphorus or nitrogen can be a limiting nutrient in a water body. In general, phosphorus has been found to be the primary limiting nutrient in freshwater bodies, while nitrogen is commonly limiting in marine ecosystems (Schindler 1978, Tomasky et al. 1999, Cloern 2001). This is not always the case, however, and there are often exceptions to this trend. In Florida, the limiting nutrient in freshwater lakes is believed to be phosphorus and as a result phosphorus control is considered a primary management strategy for preventing uncontrolled growth of algae (Florida Lakewatch 2000).

Numerous water bodies in the state of Florida, as well as all over the world, have been recognized as being polluted with excessive nutrients (Badruzzaman et al. 2012). Currently in Florida, the Florida Department of Environmental Protection (FDEP) has deemed these water bodies "impaired" and determined a maximum amount of a given pollutant that a water body can take in and still maintain water quality standards that protect aquatic ecosystems as well as human health. These limits on pollutants, or Total Maximum Daily Loads (TMDLs), are specific to each water body. Thus, basin-specific restoration initiatives referred to as Basin Management Action Plans (BMAPs) are developed. One of the goals of BMAPs is to reduce fertilizer runoff into water bodies by encouraging agencies such as the FDOT to adopt better fertilization practices.

Erosion is another significant contributor to eutrophication. As water travels over soil, it picks up soil particles as well as nutrients. As it continues to flow by gravity, the flowing water gradually amasses particles until it reaches a settled water body where the nutrients and sediment are deposited, The sediments accumulate within the water body and accelerate the conditions that lead to eutrophication. Although soil erosion is a naturally occurring process on earth, the activities of agriculture, deforestation, construction, and similar anthropogenic activities leave surface soil bare and extremely prone to erosion. There are a number of factors that influence soil erosion such as the soil erodibility (texture, structure, and amount of organic matter), vegetative cover, topography, climate, and time of year. Several methods of erosion control help prevent the loss of soil and subsequent water pollution such as rock riprap, geosynthetic reinforcements, as well as polymers are just a few methods of erosion control (State Erosion and Sediment Control Task Force 2013).

The most effective method of erosion control, however, is the successful growth of permanent vegetation. Vegetative cover protects soil from the impact of raindrops and eroding runoff by shielding the soil from the force of raindrops, while the roots help hold the soil particles in place. Vegetation also slows the velocity of runoff that flows through it, allowing the water to infiltrate into the soil, thus slowing or eliminating erosion, reducing the volume of surface runoff and eventual surface water pollution. In order to accelerate the establishment of vegetation and sustain future growth, fertilizer application may be necessary. Problems arise, however, when fertilizer is applied in excess. The applied fertilizer is likely to be washed off the vegetation by a rainfall event, which potentially increases the nutrient content in the runoff, eventually depositing excess nutrients into bodies of water. In addition, excess fertilization can have a reverse effect on plant growth; it can render soil unsuitable for plant growth. Virtually all fertilizers are salts, and their application increases the salt concentration in soil. High concentrations of salt in soil causes plant cells to lose water, restricts the availability of water to the plants, and can cause plant toxicity (Tisdale et al. 1985).

The Florida Department of Transportation applies turfgrasses to highway embankments and fertilizes them in order to promote the growth and establishment of vegetation. The vegetation provides resistance to soil erosion, aesthetic benefits, and prevents the washout of soil supporting the highway itself. In the past, FDOT's fertilization practice involved the application of a general-purpose 10-10-10 fertilizer, which represents the ratio of nitrogen, phosphorus, and potassium (N-P-K), respectively, present in the mixture. Recently, however, FDOT has discontinued using a general-purpose fertilizer, and switched to a slow-release (SR) 16-0-8 (N-P-K) fertilizer that contains no phosphorus. Slow-release fertilizers are capable of releasing nutrients gradually over a period of time, which reduces nutrient washout.

Chopra (2011) has recently completed a final report for the Florida Department of Transportation evaluating the change in nutrient losses between the aforementioned 10-10-10

(N-P-K) and slow-release 16-0-8 (N-P-K) fertilizers on two different soil and sod combination typically found in southern and central Florida as well as northern Florida. In southern and central Florida, Argentine Bahia is more prevalent, while in northern Florida, Pensacola Bahia is more common. The corresponding soil types are A-3, a sandy soil found in central and southern Florida, and A-2-4, a silty-sandy soil found in northern Florida. The soil classifications are in accordance to the American Association of State Highway and Transportation Officials (AASHTO) system. Chopra (2011) performed this study at rainfall intensities of 0.5 in/hr, 1 in/hr, and 3 in/hr on slopes that closely replicate the conditions on Florida's highway embankments of 25%, 33%, and 50%.

Objective

The purpose of this study was to evaluate the loss of nutrients from fertilized slopes that were modeled after the soil and sod systems typically used by FDOT on highway shoulders and embankments. As a follow-up to Chopra (2011), this analysis utilized a lower slope and lower rainfall intensities typically found in Florida while taking into account overland flow from adjacent road surfaces. This study in addition to quantifying the reduction in nutrient loss as a result of switching fertilizers also attempted to improve the current practice. This improvement was done by measuring the existing fertility of the soil as well as taking into account the nutrient uptake rate of the vegetation that was grown on it and the physical and chemical processes that occurred in the soil. This study will be performed at rainfall intensities of 0.25 in/hr and 0.1 in/hr, on a combination of slopes that reflects a typical highway cross-section in Florida (Figure 1).

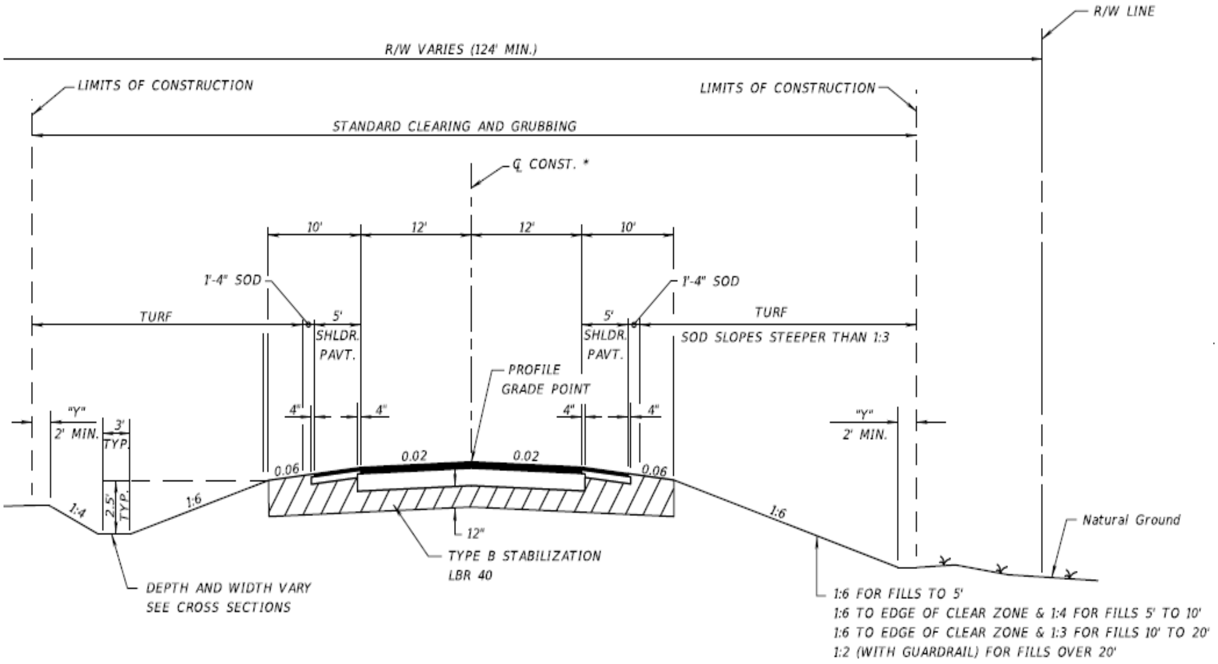


Figure 1: Typical Highway Cross-section in Florida (Florida Department of Transportation 2009)

Hypotheses

- There will be an overall reduction in nutrient losses between the two fertilizers
- The lower intensity of rainfall will result in a reduction in mass of nutrients in runoff, but not necessarily in baseflow

Roadmap

Examples of harmful effects resulting from excessive nutrient loadings in surface water bodies and groundwater as well as additional background information are presented in chapter one, accompanied by the study objectives and hypotheses. Chapter two contains additional and detailed background information on nitrogen and phosphorus transformations occurring in soil, nutrient regulations in Florida, fertilizer information, and more information on the previous fertilizer study. Presented in chapter three are the methodology and experimental design. Chapter four contains the experimental results and discussion. The conclusions from this study as well as recommendations for further research are presented in chapter five.

CHAPTER 2: LITERATURE REVIEW

Fertilizer as a Source of Nutrient Pollution in Surface Waters and Groundwater

In urbanized areas, the desire for luscious lawns and gardens has led to excessive fertilizer use. Fertilizer overload also occurs in instances where sod is applied for erosion control followed by subsequent fertilizer application in order to maintain sufficient vegetative coverage. Excess fertilizer not utilized by plants has a marked potential to wash off lawns during irrigation or rainfall events, eventually reaching water bodies where the excess nutrients cause algal blooms and eventual ecological impairment. Furthermore, excess nutrients from fertilizer can move downward through the soil into groundwater and underlying aquifers (Capel et al. 2004). Excess nutrient loadings as a result of indiscriminate fertilizer use are considered nonpoint sources of pollution. Nonpoint source pollution is caused by rainfall or snowmelt moving over the ground picking up and transporting natural and human-made pollutants. Sources of nonpoint pollution are typically widespread and include but are not limited to excess fertilizers from agricultural lands and residential areas, oil, grease, and toxic chemicals from urban runoff, sediment from construction sites, etc. This type of pollution, in the context of excess fertilization, results in over-enrichment of surface water bodies as well as groundwater with nitrogen and phosphorus (EPA 2012).

Observations on Fertilizer Nutrients in Water Bodies and Groundwater

In recent years, the levels of nutrients in groundwater have been increasing (USGS 2010). In addition to effluent from wastewater treatment plants, septic tanks, and natural nitrogen deposition, a major source of excessive nutrients in groundwater is the use of fertilizers in agricultural and urban areas (Mueller and Helsel 2013). Panno et al. (2001) collected water samples from several large karst aquifers and performed isotopic and chemical analysis on the nitrates present in the samples. The results showed definitively that the sources of nitrate in the spring water were of mostly fertilizer origin, with some influence of atmospheric as well as human and/or animal waste nitrogen. Another study, this time in China, also used isotopic tracers to trace the source of nitrates and found its occurrence in groundwater closely related to chemical fertilizer application (Pang et al. 2013).

Other studies focused on quantifying the amount of nitrate leaching from turfgrass after fertilization. Bowman et al. (2002) compared six warm-season turf grasses for nitrate leaching and nitrogen use efficiency. After allowing sod to establish itself and then fertilizing, they found that leaching losses varied between turf grass species, ranging from 48 to 100% of the applied nitrate and 4 to 16% of applied ammonia after the first application. A subsequent application, however, showed a reduction in losses which the authors attributed to the development of a more extensive root system.

Observations on Fertilizer Nutrient Loss in Surface Runoff and Leaching from Turf Grass

According to Chopra (2011), there are several factors influencing the rate at which nutrients are lost in soil through surface runoff and leaching:

- The fertilizer type and its chemical characteristics

- soil chemical characteristics such as pH, mineral composition, cation exchange capacity, etc.
- soil physical characteristics such as clay content, moisture content, grain size distribution, etc.
- biological considerations such as type of vegetation and activity of microorganisms, etc.
- soil topographical conditions such as proximity to surface water bodies, surface slope, etc.
- atmospheric conditions such as precipitation, temperature, daylight hours, etc

Nitrogen is highly susceptible to leaching in soils. The ammonium ion, NH_4^+, although cationic in nature and with the ability to adsorb and be retained by soil, is not free from leaching. If the soil does not have a sufficient exchange capacity, such as sandy soil, the ammonium will travel through the soil column freely. Conversely, nitrate (NO_3^-) is highly mobile in soil and moves with the soil water (Tisdale et al. 1985).

Phosphorus is in general not easily leached from soils; however, once the capacity of the soil to adsorb phosphorus is exceeded, the excess will move freely with water down the soil column (Domagalski and Johnson 2012). According to Tisdale et al. (1985), several factors influence the retention of phosphorus in soils. These include the nature and quantity of soil components such as hydrous metal oxides of iron and aluminum, the amount of clay present in the soil, and the soil pH, among several other physicochemical characteristics. Soils that contain large amounts of clay have the ability to retain more phosphorus than those with lower amounts. In addition, more phosphorus is retained by clay that is classified as 1:1 than 2:1. These classifications represent the specific structure of the clay, for example, 1:1 clays are composed of a larger amount of hydrated oxides of iron and aluminum, both of which allow for greater sorption, or retention of phosphorus. The influence of pH on soil adsorption of soluble phosphorus is such that there is a decrease in capacity of iron and aluminum oxides capable of being adsorbed at increasing pH levels. In general, phosphorus availability to plants is greatest at a pH range of 6.0 to 6.5 and declines outside of this range.

Both nitrogen and phosphorus are susceptible to movement with surface runoff if heavy rains occur after fertilizer application. This problem is exacerbated if fertilizer is placed on a moist soil, or if there is considerable slope. In addition, the fraction of nitrogen and phosphorus that adsorbs to soil particles will remain adsorbed and travel with the particles that are transported by water flow on the surface of the soil (Baird 1990, Domagalski and Johnson 2012).

There have been several studies observing the effects of irrigation and/or precipitation on nutrient leaching from various types of turf under different conditions. Shuman (2001) conducted a greenhouse experiment on golf greens (Bermuda grass) to determine the rates of phosphorus and nitrogen leaching from different fertilizer sources. The fertilizers used were a slow-release 13-13-13 (N-P-K) and the other a water-soluble, quick-release 20-20-20 (N-P-K). The slow-release type of fertilizer nitrogen was from NH_4 and urea. The quick-release (water-soluble) nitrogen was from potassium nitrate, ammonium phosphate, and urea. Irrigation was performed totaling 0.63 cm or was adjusted to 1.25 cm per day depending on volume of leachate collected. Shuman (2001) found that the concentrations of nitrogen and phosphorus were lower for the slow-release fertilizer than quick-release. In addition, it was discovered that for the entire 23 week experiment, nitrogen leaching was exhausted by the 15th week while phosphorus continued to leach gradually for the entire 23-week duration, indicating that phosphorus leaches at a slower rate than nitrogen, regardless of fertilizer type. The study concluded that phosphorus leaching is a problem only when quick-release fertilizers are applied at a high rate; however, nitrogen is readily leached regardless of fertilizer source.

Shuman (2002) also examined the effect of a quick-release 10-10-10 (N-P-K) fertilizer at three separate application rates and rainfall events on phosphorus and nitrate nitrogen in runoff after application to golf greens (Bermuda grass). They found that runoff volume was directly related to soil moisture and rainfall intensity. In addition, phosphorus concentration in runoff was highest during the first rainfall event and decreased at subsequent events, whereas nitrate nitrogen concentrations were low for the first three runoff events and highest later on, which was attributed to the time required for the conversion to nitrate from ammonia. It was concluded that turf grass fertilization should be followed by minimum irrigation, and application should be avoided before intense rainfall or if the soil is already moist.

Again, Shuman (2003) examined the effect of phosphate and nitrate nitrogen leaching through golf greens, this time using eight different types of fertilizers. They found that most fertilizers were similar in terms of leaching, with the highly soluble sources resulting in more leaching. Nitate nitrogen began leaching earlier than phosphorus and was highest for the highly soluble sources as well as liquid sources. Sulfur-coated and poly-coated, both slow-release fertilizers, showed lower nitrate nitrogen concentrations in runoff.

Shuman (2006) looked at the effect of different fertilizer source, rate of application, and irrigation schemes on nitrogen leaching from golf greens. They found that while fertilizer sources (slow-release versus quick-release) and rates make a difference in nitrate nitrogen leaching, leaching increased significantly at flush-like (high-intensity) irrigation schemes.

Erickson et al. (2001) compared nitrogen runoff and leaching between St. Augustine grass and a lower maintenance alternative (non-turf) vegetation. While this particular study observed insignificant nitrogen losses from surface runoff, they found that more than 30% of applied fertilizer nitrogen leached from the alternative vegetation, while very little leached from the St. Augustine grass. The authors concluded that lack of vegetation density and longer establishing period required by the alternative landscape were the reasons behind its apparent inferior efficiency to St. Augustine grass.

Trenholm et al. (2013) evaluated the influence of nitrogen application and irrigation rates on nitrate leaching as well as turf grass quality in newly sodded St. Augustine grass. The study observed that the percentage of nitrate leached was an average of 73.4% on the day of sodding, and 56.4% nitrate leached 30 days after sod application. Fertilizer was applied both times. A subsequent trial a year later on a new batch of sod yielded similar results: 51% of nitrate leached on the day of sod application, and 33.9% leached 30 days after sod application. Results of this research suggest that fertilizing should be withheld for at least 30 to 60 days after sod application to reduce nitrate leaching.

Erickson et al. (2005) assessed phosphorus leaching from two different residential landscape models that were established on a sandy soil. Common management practices were applied to four replications of St. Augustinegrass and a mixed-species landscape involving bimonthly granular fertilization throughout the study for the St. Augustinegrass, and only during establishment for the mixed-species landscape. While losses from surface runoff were negligible, leaching losses were high during establishment and after precipitation with St. Augustinegrass exhibiting lower losses than the mixed-species landscape, thus heightening concern over potential ecological impacts.

In a later study, Erickson et al. (2010) examined the effects of sod type, fertilization practice, and irrigation rate on turf quality and phosphorus leaching from St. Augustine grass. Sod type varied from muck produced to sand produced, and fertilization method varied from no fertilization, fertilization at installation, and thirty days after installation. In addition, the sod was subjected to various irrigation regimes. They observed less phosphorus leaching from sod grown in muck than in sandy soil, as well as a significant reduction in leaching at reduced irrigation rates. Furthermore, fertilization at 30 days after installation resulted in significantly less phosphorus leaching than fertilization on the day of installation.

Other studies that evaluated the effects of irrigation and fertilizer regimes on leaching include that of Barton et al. (2006), Barton and Colmer (2006), Brown et al. (1982), Kunimatsu (1999), and Petrovic (1990).

While there have been several studies that examined nutrient losses from residential landscapes and golf courses, research on nutrient washout from fertilized highway slopes has not been studied extensively. Kakuturu (2013) simulated the conditions found in Florida that result in the loss of nutrients from fertilized highway slopes, such as rainfall intensity, highway slope, soil type, and sod type. The study was performed using a field-scale test bed and rainfall simulator at the Stormwater Management Academy Research and Testing Laboratory (SMARTL) located in Orlando, Florida. The test bed, measuring 30 feet long by 8 feet wide, was filled with 1 foot of soil, and was hydraulically adjusted to a desired slope. The soil types used in the study are those typically used in the construction of highway embankments in Florida, specifically A-3 (sandy soil) and A-2-4 (silty-sandy soil) type soils, as classified by AASHTO. Two varieties of Bahia grass were used, Argentine Bahia and Pensacola Bahia. The former, Argentine Bahia, was planted on A-3 type soil, which is more prevalent in central and southern Florida, while the latter was planted on A-2-4 type soil, which is more prevalent in northern Florida. The fertilizer types were a common 10-10-10 (N-P-K) fertilizer and a slow-release 16-0-8 (N-P-K) fertilizer, reflecting the change in fertilization practice by the Florida Department of Transportation. The rainfall intensities as well as the slopes chosen were also those closely representing conditions found in Florida.

Comparing the results, the study found that switching to a slow-release 16-0-8 (N-P-K) fertilizer resulted in a 66.5% reduction in total nitrogen lost to the environment. The total phosphorus collected using the 10-10-10 (N-P-K) fertilizer was approximately 22.9 grams versus 0.73 grams of total phosphorus collected using the 16-0-8 (N-P-K) fertilizer. In addition, the growth of grass was comparable in both cases, even without the additional phosphorus component in the 16-0-8 (N-P-K) fertilizer.

Stormwater Runoff from Highways and Nutrient Regulations in Florida

Nutrient loadings present in stormwater runoff, especially nitrogen and phosphorus, are a major concern in Florida. These loadings can lead to eutrophication of surface water bodies as well as groundwater contamination. Highway runoff, generated by rainfall, occurs as a thin sheet of water across the surface of the roadway called sheet flow. Once sheet flow reaches land it is referred to as overland flow and its erosive force can dislodge pollutants such as sediment and nutrients and transport these particles to bodies of water downstream. On its own, highway runoff contains several pollutants that result from atmospheric deposition, exhaust from vehicles, roadway degradation, and vehicular accidents (Mangani et al. 2005). The average concentration of total nitrogen and total phosphorus from the National Stormwater Quality Database are 2.28 mg/L and 0.25 mg/L, respectively (Pitt et al. 2004). Specific to Florida, these values are 1.37 mg/L and 0.167 mg/L total nitrogen and total phosphorus, respectively, according to the Florida Runoff Concentration Database (Harper 2011).

The Florida Department of Transportation (FDOT) fertilizes its highway embankments in order to promote the establishment of utility turf grass to prevent soil erosion and for aesthetic benefits. Considering that stormwater runoff from highways already contains nitrogen and phosphorus, fertilized highway slopes potentially contribute to the existing problem of nutrient overloading to water bodies. Steep side slopes found on highway embankments, Florida’s intensive rainfall, and the drainage of highways that eventually joins water bodies, heightens this problem.

The Florida Department of Environmental Protection (FDEP) and Florida Water Management Districts are reviewing a Statewide Stormwater Treatment Rule that will be implemented through the Environmental Resource Permit program that regulates activities that alter the flow of surface water such as new construction. This rule will require new construction activities to reduce the amount of total phosphorus (TP) and total nitrogen (TN) in stormwater runoff to the lesser of: (i) "an 85% reduction of the post-development average annual loading of total nitrogen and total phosphorus from the project; or, (ii) a reduction such that the post-development average annual loading of total nitrogen and total phosphorus does not exceed the nutrient loading from the project area's natural vegetative community types" (FDEP and Water Management Districs 2010). Currently, stormwater discharges must be treated to a level such that the receiving water body does not exceed the standards in FDEP's Surface Water Quality Standards.

Fertilizers, Soils, and Turf Grasses Utilized in This Study

Fertilizers Utilized in This Study

Fertilizers can be divided into two categories: organic and inorganic. While organic fertilizers are composed of plant or animal matter, inorganic fertilizers are produced synthetically. Synthetic fertilizers typically provide the three macronutrients essential for plant growth: nitrogen, phosphorus, and potassium. On a standard commercial fertilizer label, the amount of each macronutrient is expressed as the ratio N-P-K (Nitrogen-Phosphorus-Potassium) representing the proportion of each nutrient present (Sartain 1998). Fertilizers are available as quick-release, which are highly water soluble and immediately available for plant use, and slow-release (SR), which are slowly soluble thus providing nutrients gradually. These fertilizers are typically polymer or sulfur coated urea. Another benefit of slow-release, in addition to providing a gradual supply of nutrients, is the reduction of leaching (Tisdale et al. 1985). The fertilizers used in this study are an all-purpose, 10-10-10 (N-P-K) fertilizer, containing equal parts of each nutrient, and a slow-release 16-0-8 (N-P-K) fertilizer, containing no phosphorus.

Considering the nutrient overloading to water bodies, FDOT has changed the way it fertilizes its highway embankments. Specifically, FDOT has discontinued the use of quick-release, 10-10-10 (N-P-K) fertilizers, and began applying slow-release 16-0-8 (N-P-K) fertilizers. In addition, FDOT has reduced the application rate from 1 lb N per 1000 ft^2 to 0.5 lb N per 1000 ft^2 (Chopra 2011).

Soil and Turf Grass Utilized in This Study

Two types of soils were chosen for this study based on availability and their appropriateness for highway construction. FDOT classifies soils based on the AASHTO system. Typically, highways in central and southern parts of Florida are constructed with AASHTO A-3 soil, which is a sandy, granulated soil, very suitable for use as a subgrade. Highways in northern parts of Florida are constructed with AASHTO A-2-4 soil, which is a silty, sandy soil.

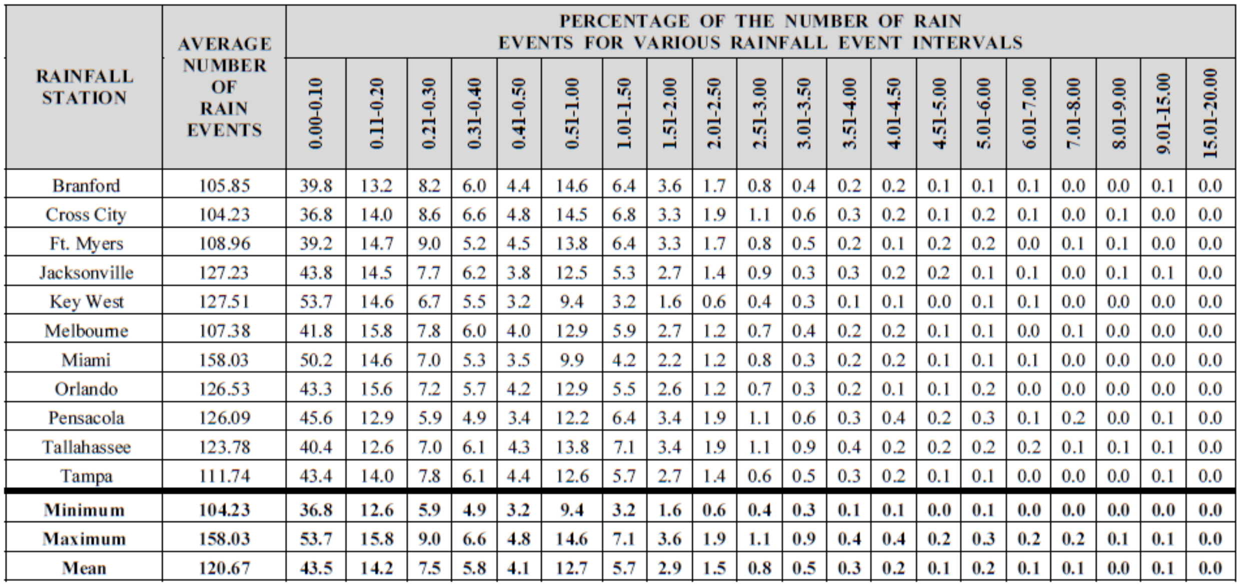
FDOT uses utility turf for soil stabilization along roadways because of their low growing heights and their ability to form a dense, low-growing, uniform ground cover with little maintenance. The species most suitable for Florida's soil conditions is Bahia grass, which is a tough, course-textured, wear-resistant utility turf that thrives in sandy, infertile soils, and drought conditions (Ferrell et al. 2012). This study uses two varieties of Bahia grass: Argentine and Pensacola. Argentine Bahia was tested over AASHTO A-3 soil, representing typical conditions in central and southern Florida, while Pensacola Bahia was tested over AASHTO A-2-4 soil representing typical conditions in northern Florida.

Rainfall Intensity and Slope

The effect of slope on nutrient losses is intuitive: the higher the slope, the greater the erosive power of water traveling downhill. Chopra (2011) conducted tests on three relatively high slopes of 25%, 33%, and 50%. While these slopes are not commonly found in Florida, they do occur on certain highway side slopes, shoulders, and embankments. Typically, however, the slope of highway shoulders and embankments in Florida is designed to be 16.67%. Studies on the effect of slope on nutrient losses have been completed by Easton and Petrovic (2004), Erickson et al. (1999). These studies were done on average slopes found in residential landscapes and golf courses. While highway slopes are much steeper, they are compacted to attain high shear strength, and covered with low-maintenance turf grasses to prevent erosion.

Chopra (2011) evaluated the effect of relatively high rainfall intensities on fertilizer losses of 0.5 in/hr, 1 in/hr, and 3 in/hr. Table 1 shows the percentage of rain events that occur within various rainfall event intervals. In addition, this table is based on a variable inter-event dry period. Thus, when cumulative hourly rainfall is equal to 0.25 inches or more, an inter-event dry period of six hours applies. This means that rainfall that occurs less than six hours after the previous rainfall is assumed part of the same rainfall event. For cumulative rainfall of less than 0.25 inches, an inter-event dry period of three hours applies, which means that rainfall that occurs less than three hours after the previous rainfall is assumed part of the same rainfall event. On average, in Florida, 75.1% of rainfall events are equal to 0.5 inches or less (Harper and Baker 2007).

Table 1: Percentage of Annual Rain Events Occurring in Various Rainfall Event Intervals (Harper and Baker 2007)



RAINFALL STATION	AVERAGE NUMBER OF RAIN EVENTS	PERCENTAGE OF THE NUMBER OF RAIN EVENTS FOR VARIOUS RAINFALL EVENT INTERVALS																			
		0.00-0.10	0.11-0.20	0.21-0.30	0.31-0.40	0.41-0.50	0.51-1.00	1.01-1.50	1.51-2.00	2.01-2.50	2.51-3.00	3.01-3.50	3.51-4.00	4.01-4.50	4.51-5.00	5.01-6.00	6.01-7.00	7.01-8.00	8.01-9.00	9.01-15.00	15.01-20.00
Branford	105.85	39.8	13.2	8.2	6.0	4.4	14.6	6.4	3.6	1.7	0.8	0.4	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.1	0.0
Cross City	104.23	36.8	14.0	8.6	6.6	4.8	14.5	6.8	3.3	1.9	1.1	0.6	0.3	0.2	0.1	0.2	0.1	0.0	0.1	0.0	0.0
Ft. Myers	108.96	39.2	14.7	9.0	5.2	4.5	13.8	6.4	3.3	1.7	0.8	0.5	0.2	0.1	0.2	0.2	0.0	0.1	0.1	0.0	0.0
Jacksonville	127.23	43.8	14.5	7.7	6.2	3.8	12.5	5.3	2.7	1.4	0.9	0.3	0.3	0.2	0.2	0.1	0.1	0.0	0.1	0.1	0.0
Key West	127.51	53.7	14.6	6.7	5.5	3.2	9.4	3.2	1.6	0.6	0.4	0.3	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0
Melboume	107.38	41.8	15.8	7.8	6.0	4.0	12.9	5.9	2.7	1.2	0.7	0.4	0.2	0.2	0.1	0.1	0.0	0.1	0.0	0.0	0.0
Miami	158.03	50.2	14.6	7.0	5.3	3.5	9.9	4.2	2.2	1.2	0.8	0.3	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Orlando	126.53	43.3	15.6	7.2	5.7	4.2	12.9	5.5	2.6	1.2	0.7	0.3	0.2	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0
Pensacola	126.09	45.6	12.9	5.9	4.9	3.4	12.2	6.4	3.4	1.9	1.1	0.6	0.3	0.4	0.2	0.3	0.1	0.2	0.0	0.1	0.0
Tallahassee	123.78	40.4	12.6	7.0	6.1	4.3	13.8	7.1	3.4	1.9	1.1	0.9	0.4	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.0
Tampa	111.74	43.4	14.0	7.8	6.1	4.4	12.6	5.7	2.7	1.4	0.6	0.5	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.0
Minimum	**104.23**	**36.8**	**12.6**	**5.9**	**4.9**	**3.2**	**9.4**	**3.2**	**1.6**	**0.6**	**0.4**	**0.3**	**0.1**	**0.1**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Maximum	**158.03**	**53.7**	**15.8**	**9.0**	**6.6**	**4.8**	**14.6**	**7.1**	**3.6**	**1.9**	**1.1**	**0.9**	**0.4**	**0.4**	**0.2**	**0.3**	**0.2**	**0.2**	**0.1**	**0.1**	**0.0**
Mean	**120.67**	**43.5**	**14.2**	**7.5**	**5.8**	**4.1**	**12.7**	**5.7**	**2.9**	**1.5**	**0.8**	**0.5**	**0.3**	**0.2**	**0.1**	**0.2**	**0.1**	**0.1**	**0.0**	**0.1**	**0.0**

Nitrogen and Phosphorus Behavior in Soil

Nitrogen in Soil

One of the most important nutrients necessary for plant growth is nitrogen. It is the most utilized by plants of all the major nutrients from soil. It encourages rapid growth, increased leaf size and quality, crop maturity, and fruit and seed development. It is also a vital part of photosynthesis, because it is an essential part of chlorophyll production (Tucker 1999).

Sources of Nitrogen

Nitrogen in its elemental form cannot be utilized directly by plants and instead must be converted into compounds that can then be assimilated. This process, called fixation, has several pathways. Certain prokaryotic microorganisms live either freely in the soil, or symbiotically with plants, such as rhizobia (Tisdale et al. 1985). These organisms convert elemental nitrogen to ammonia via fixation, which allows nitrification to occur within the soil matrix, with both forms absorbable by plants. Another way in which elemental nitrogen is fixed is by the energy from lightning causing elemental nitrogen and water to combine and form ammonia and nitrates in the atmosphere which are carried down to earth via rainfall in readily assimilable form. Nitrogen is also fixated industrially, in the form of industrial fertilizers, this form being the most common source of nitrogen for commercial agriculture (Tisdale et al. 1985).

Nitrogen naturally present in the soil is classified as organic or inorganic, with the vast majority occurring in organic form of animal or plant origin (Tisdale et al. 1985). The most common inorganic forms of nitrogen found naturally in soil are ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), nitrous oxide (N_2O), and nitric oxide (NO). Organic forms of soil nitrogen typically occur as consolidated amino acids or proteins, free amino acids, amino sugars, and other complex compounds (Tisdale et al. 1985). Common forms of nitrogen found in commercial fertilizers include nitrate nitrogen, which includes all of the nitrate forms of nitrogen in fertilizer, ammoniacal nitrogen, which includes all of the ammonium forms of nitrogen in fertilizer, water soluble nitrogen, urea nitrogen, and water insoluble nitrogen (Sartain 1998). Because ammoniacal nitrogen and urea nitrogen are the two sources of nitrogen present in the fertilizers used in this study, this discussion focuses on the behavior of only these two sources.

Nitrogen Transformation in Soil

Urea nitrogen, upon application, hydrolyzes to ammonium carbamate via urease before it is further broken down into ammonia and carbon dioxide, whereas the ammonia present in ammoniacal nitrogen fertilizers is readily available to undergo further transformations. In the presence of water, or other hydrogen donors, ammonia is converted to ammonium (Tisdale et al. 1985). The ammonium released into the soil has a number of different fates such as:

- Direct absorption by plants.
- Conversion to nitrate or nitrite through nitrification by microorganisms.
- Utilization by microorganisms present in the soil.
- Immobilization by microorganisms or plants
- Release back into the atmosphere via volatilization as elemental nitrogen
- Retention in soil

The nitrogen cycle, from Tisdale et al. (1985), as it occurs in soil is depicted in Figure 2.

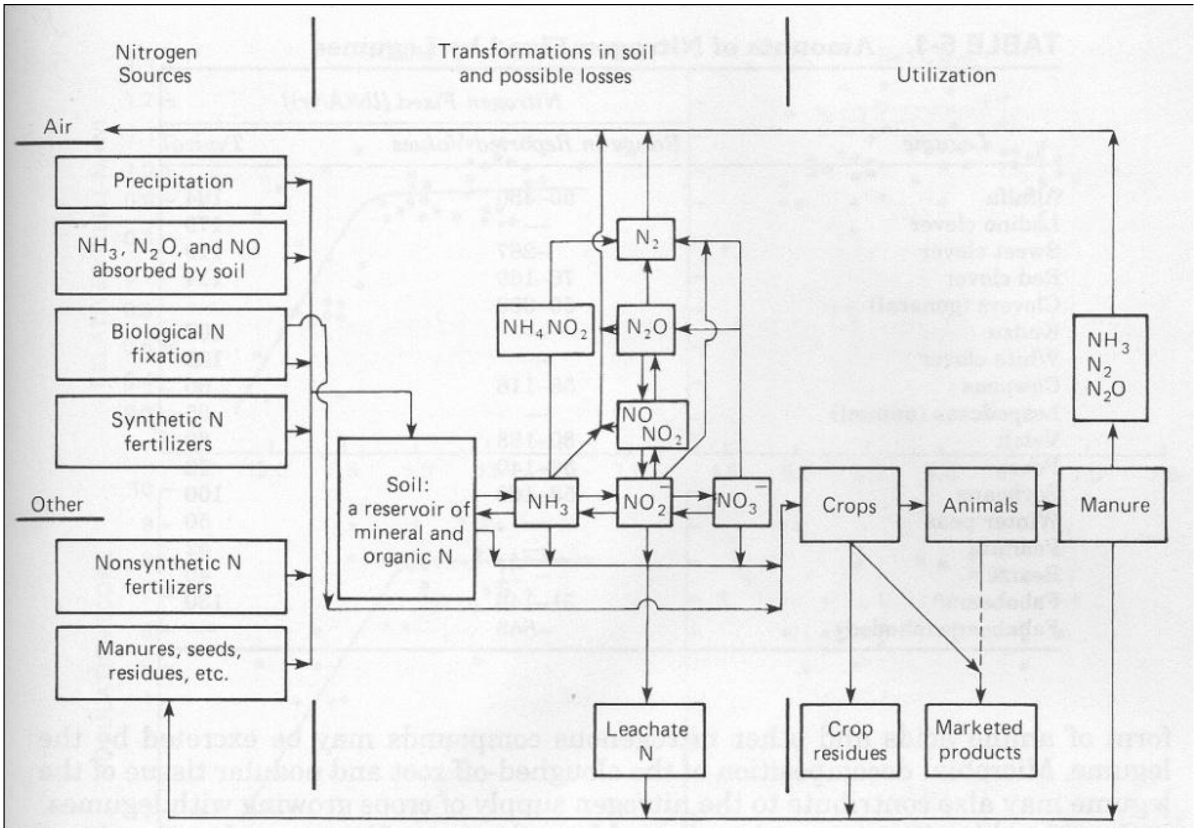


Figure 2: The Soil Nitrogen Cycle (Tisdale et al. 1985)

Absorption by Plants

The two dominant forms of nitrogen taken up by plants are nitrate (NO_3^-) and ammonium (NH_4^+). Preference for one form over the other depends on several factors such as age, type of plant, and soil environment. Nitrate is generally the dominant source of nitrogen for plants due to its high mobility in the soil which allows it to reach plant roots quickly. Additionally, pH also plays a role in species preference, as nitrate uptake is favored in low-pH conditions, and plant uptake of ammonium is best at near neutral pH values and decreases with increasing acidity

(Tisdale et al. 1985). The amount of daylight is also important for plant uptake of nutrients. In general, as plants receive more daylight, the higher their capacity to photosynthesize. As photosynthesis increases, so does nutrient uptake (The University of Arizona 1998).

Nitrification

Nitrification occurs as a two-step process performed by two distinct species of autotrophic bacteria present in the soil during which ammonia is converted to nitrite (NO_2^-), and then nitrate (NO_3^-), which is often the dominant source of nitrogen for plants (Tisdale et al. 1985) Nitrification is also performed by fungi present in the soil, but to a lesser extent than nitrifying bacteria (Hora and Iyengar 1960). There are several factors that affect nitrification such as adequate supply of ammonium, population of nitrifying organisms in the soil, soil pH, soil aeration, moisture content, and temperature. The pH range over which nitrification takes place is 5.5 to 10, with the optimum pH around 8.5 (Tisdale et al. 1985). Soil aeration also plays a major role in the nitrification potential within a soil because nitrobacteria, the species responsible for the majority of nitrification occurring in soil, are aerobic and as a result require oxygen to produce nitrates. When soils lack oxygen, denitrification occurs which can lead to gaseous losses of nitrogen. In addition to pH and aeration, the moisture content of soil also affects nitrification. At increasing moisture content, mineralization of organic nitrogen tends to decline; however, low soil moisture content causes cell dehydration as well as decreased supply of substrate (Tisdale et al. 1985, Stark and Firestone 1994).

Gaseous Losses of Nitrogen

Gaseous losses of nitrogen occur primarily as nitrous oxide (N_2O), nitric oxide (NO), elemental nitrogen (N_2), and ammonia (NH_3). Both nitrous oxide and nitric oxide are lost through the process of nitrification, and all forms of nitrogen with the exception of ammonia are lost during denitrification. The rate of denitrification in a soil is influenced by the amount of organic matter present, the soil moisture content, soil aeration, pH, and temperature. Soil moisture content affects denitrification rates when soil becomes waterlogged, thus reducing soil aeration which is necessary for nitrification to occur.

Soil pH affects the rate of denitrification because many of the species of bacteria responsible for denitrification are sensitive to low pH values, with optimum denitrification occurring at a pH of 8.0 to 8.6 (Tisdale et al. 1985). Denitrification occurs in the same temperature range (25°- 60°C) as nitrification; however, it occurs at higher rates. (Tisdale et al. 1985).

The rate of ammonia volatilization is influenced by soil pH, cation exchange capacity, temperature, moisture content, and species of ammoniacal nitrogen fertilizer applied. In addition, the rate and depth of ammonium application play a role in nitrogen losses by ammonia volatilization (Tisdale et al. 1985).

Ammonia losses tend to become greater as soil pH and temperature increase (Tisdale et al. 1985). As pH increases, the chemical equilibrium between NH_4^+ (ammonium) and NH_3 (ammonia) shifts and the percentage of free ammonia in the soil increases rapidly (Parr and

Engibous 1966, Fan et al. 2011). Similarly, as temperature increases, ammonia volatilization increases significantly. Soil temperature influences ammonium absorption, the conversion of ammonium to ammonia, and increases ammonia's rate of diffusion (Avnimelech and Laher 1977, He et al. 1999). He et al. (1999) reported that volatilization doubled when temperatures were increased from 5°C to 25°C and tripled from 25°C to 45°C.

The moisture content of the soil also influences ammonia volatilization. Al-Kanani et al. (1991) examined NH_3 volatilization from surface-applied urea and ammonium nitrate fertilizers on two soil varieties, one loamy and one sandy. The study found that ammonia volatilization increased as soil moisture content increased. It was also discovered that soil with increased clay content showed reduced NH_3 loss, most likely because of increased NH_4^+ adsorption. In addition, the rate of NH_3 volatilization followed first-order kinetics, regardless of soil texture.

The species of ammonium-containing or ammonium-forming fertilizer salt in addition to the rate of application and depth of incorporation also have effects on ammonia loss through volatilization (Tisdale et al. 1985). It is widely accepted that gaseous emissions from urea are greater than other fertilizers, and it is estimated that in general between 10-20% of nitrogen in fertilizers applied as urea is lost to the environment, whereas less than 4% of nitrogen applied as ammonium nitrate is lost (Harrison and Webb 2001). Whitehead and Raistrick (1990) measured the volatilization of ammonia from five nitrogen compounds applied to five distinct soils. Soil samples, adjusted for moisture content, immediately after fertilizer application were placed in columns, through which air was passed for eight days and the levels of gaseous ammonia measured every two days. They found that for all soil and fertilizer types, volatilization increased with rising soil pH. In addition, they found that the maximum rate of volatilization occurred on day 1 for ammonium salt fertilizer, whereas maximum volatilization occurred on days 2 to 4 for urea fertilizer.

Assimilation by Microorganisms

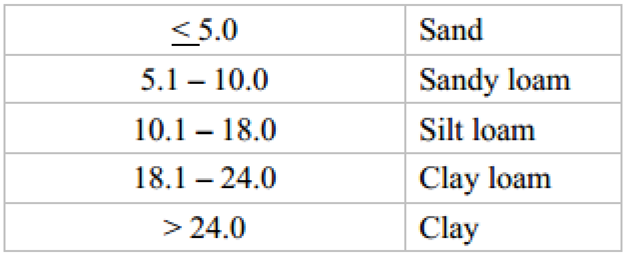
Nitrogen assimilation by microorganisms occurs when inorganic and organic constituents present in the soil are taken up and accumulated in the biomass. The preferred form of nitrogen for microorganisms is ammonium, however both bacteria and fungi are capable of using both organic and inorganic forms of nitrogen such as nitrate/nitrite, urea, and amino acids as a nitrogen source (Myrold and Posavatz 2007).

Soil Adsorption and Cation Exchange Capacity

All soils have the ability of adsorbing various elements and compounds to various degrees. This phenomenon is referred to as ion exchange, meaning that a cation or anion in the solid phase, such as those adsorbed to soil particles, is exchanged with a cation or anion in the liquid phase, such as those present in water percolating through soil. Cations and anions are held by the clay, silt, and colloidal organic matter present in soils and can be replaced by other cations and anions. Cation exchange capacity (CEC) is generally more significant than anion exchange capacity because most soils have a larger capacity to store cations than anions (Tisdale et al. 1985). In the absence of cation exchange, nutrients would simply leach through the soil and be lost; therefore, it is one of the most important indicators of soil fertility (Radulov et al. 2011).

Cation exchange capacity of soil varies depending on the nature as well as amount of mineral and organic colloid present. In general, soils with large amounts of clay and organic matter have a higher exchange capacity than sandy soils low in organic matter (Tisdale et al. 1985). Table 2 shows typical CEC values and corresponding soil types. Cation exchange capacity is typically reported as meq/100 g. Soils with low exchange capacity have a CEC of less than 5 meq/20000 g, while soils with high exchange capacity have a CEC of greater than 10 meq/100 g (Mengel 2014). These are summarized in Table 3.

Table 2: CEC values and Corresponding Soil Types (Buchholz 1983)



≤ 5.0	Sand
5.1 – 10.0	Sandy loam
10.1 – 18.0	Silt loam
18.1 – 24.0	Clay loam
> 24.0	Clay

Table 3: High and Low Values of Soil CEC

Low	< 5 meq/20000 g
High	> 10 meq/100 g

Hosking (1948) evaluated the contribution of sand, silt, and clay fractions of soil to its exchange capacity. They discovered that while there is a decline in exchange capacity between colloid and silt fractions of soil, the contribution of the silt fraction is appreciable. In addition, the exchange capacities of silt and sand are related to the concentrations of clay minerals, which are present in all fractions of soil.

The cation exchange capacity of soil is also pH dependent, and decreases as pH decreases (Tisdale et al. 1985). Helling et al. (1964) determined the effect of a buffered saturating solution at pH ranging from 2.5 to 8.0 on the cation exchange capacity of 60 different soils found in Wisconsin. They found that the CEC of both clay and organic matter increased linearly with pH.

Soil Compaction

Compaction of soil also plays a role in a soil's ability to retain nutrients by altering the aeration of the soil as well as soil permeability and other hydraulic characteristics, which in turn affects the transport of nutrients to plant roots (Stepniewski and Glinski 1985, Wolkowski 1990). Soil compaction also results in smaller pore sizes, which can inhibit root growth (Wolkowski 1990). Conversely, moderate compaction can have a positive effect in well-watered, fertile soils by increasing nutrient availability per unit of root length (Lipiec and Stepniewski 1995).

Compaction affects the soil nitrogen balance by altering the aeration of the soil. At lower oxygen levels, denitrification increases which leads to higher gaseous losses of nitrogen as well as a decrease in the rate of mineralization. In addition, because the hydraulic properties of the soil are altered, nitrogen transport and leaching are affected, which influences nutrient availability and uptake (Wolkowski 1990, Lipiec and Stepniewski 1995).

FDOT compacts highway shoulders and embankments prior to applying sod to minimize erosion and potential highway collapse. The compaction procedure follows standard highway construction practices.

Mass Balance Model of Nitrogen Processes, Transport, and Leaching

This study utilizes a nutrient mass balance to estimate the amount of nutrients available within the test bed prior to each test. The purpose of performing a mass balance based on literature models is to compare the results from models to results from actual soil nutrient analyses.

Naturally occurring and applied nutrients undergo continuous transformations in soil which alter their state from soluble or insoluble, fixed, or free. These transformations are based on characteristics such as temperature, duration of daylight, pH, soil air content, and moisture content. These characteristics must be considered in order to predict the change that occurs within the test bed over time in and establish a rational basis for comparing the effects of fertilizer type, soil type, and rainfall intensity.

There are several models available to quantify the effects of these transformations and processes occurring in the soil such as ammonia volatilization, nitrification and denitrification, mineralization and immobilization, adsorption by soil, microbial assimilation, and leaching. One of the widely known deterministic models for simulating nitrogen dynamics in soil is LEACHM (Leaching Estimation and Chemistry Model) developed by Hutson and Wagenet (1991). This model includes a nitrogen component LEACHN, which takes into consideration the transformations of urea, ammonium, nitrate, and organic nitrogen pools occurring in the soil based on the influence of temperature and water content. Recently, LEACHN was successfully used by Paramasivam et al. (2000) and Singh and Sondhi (2001). Paramasivam et al. (2000)

studied the transport of nitrate and ammonium in a sandy soil in Lake Alfred, Florida using liquid ammonium nitrate. They found that the concentration of each species was adequately predicted at various depths within the entire soil profile. Singh and Sondhi (2001) used LEACHN to predict water and nitrogen transport in clayey loam and loamy sand in India after application of urea. They found that the calculated nitrate nitrogen, soil moisture profiles, and nitrogen uptake matched well with data observed in the field suggesting the capability of the model to assist in nitrogen management. Other important models include the Soil and Water Assessment Tool (SWAT), Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) , DRAINMOD-N II, and APSIM-N. These models have been used successfully by Pohlert et al. (2007), Cao and Wang (2007), Salazar et al. (2009), and Milroy et al. (2008), respectively. Because the experimental site of Paramasivam et al. (2000) is near Orlando, and the experimental site of Singh and Sondhi (2001) is in Punjab India, the LEACHM model was adopted for Chopra (2011) as well as this study because of the similar weather conditions in both locations.

In this study, the soil moisture, air content, and the seepage between tests estimated by a soil water balance were used. The parameters used were originally adopted from Chopra (2011) and are based on studies by Paramasivam et al. (2000) and Singh and Sondhi (2001). Several physicochemical assumptions were made such as uniform moisture content within the test bed, uniform nutrient concentrations, etc. These parameters are ammonia volatilization constant (k_{volati}), nitrification constant (k_{nitri}), and denitrification constant ($k_{denitri}$), all adjusted for weather conditions in Orlando. Follett (2008) discussed ammonia volatilization and its increase with temperature and pH, noting that gaseous losses increase by an order of magnitude for each unit of pH above 6.0. Based on this data, as well as experimental observations, this ammonia volatilization constant parameter, (k_{volati}), that was adopted from Chopra (2011) is as follows:

$$\boldsymbol{k_{volatil} = 0 \qquad for\, pH \leq 6} \tag{1}$$

$$\boldsymbol{k_{volatil} = 0.0001(pH-6)^2(T-50)} \qquad \boldsymbol{for\, pH} > 6 \tag{2}$$

where T is the daily average temperature in Fahrenheit.

The remaining two parameters, the nitrification constant (k_{nitri}), and denitrification constant ($k_{denitri}$), were developed from literature for Chopra (2011). Similarly, the ammonia volatilization constants were adopted as:

$$\boldsymbol{k_{nitri} = \alpha\theta_{air}^{n}} \tag{3}$$

$$\boldsymbol{k_{denitri} = \beta(1-\theta_{air})^{d}} \tag{4}$$

where the constants α, β, n, and d are 0.3, 0.002, 0.5, and 2, respectively. These constants are dependent on soil aeration, which in turn varies with soil gradation, compaction, moisture content, etc. The transformation and transport processes of nitrogen are depicted in Figure 3.

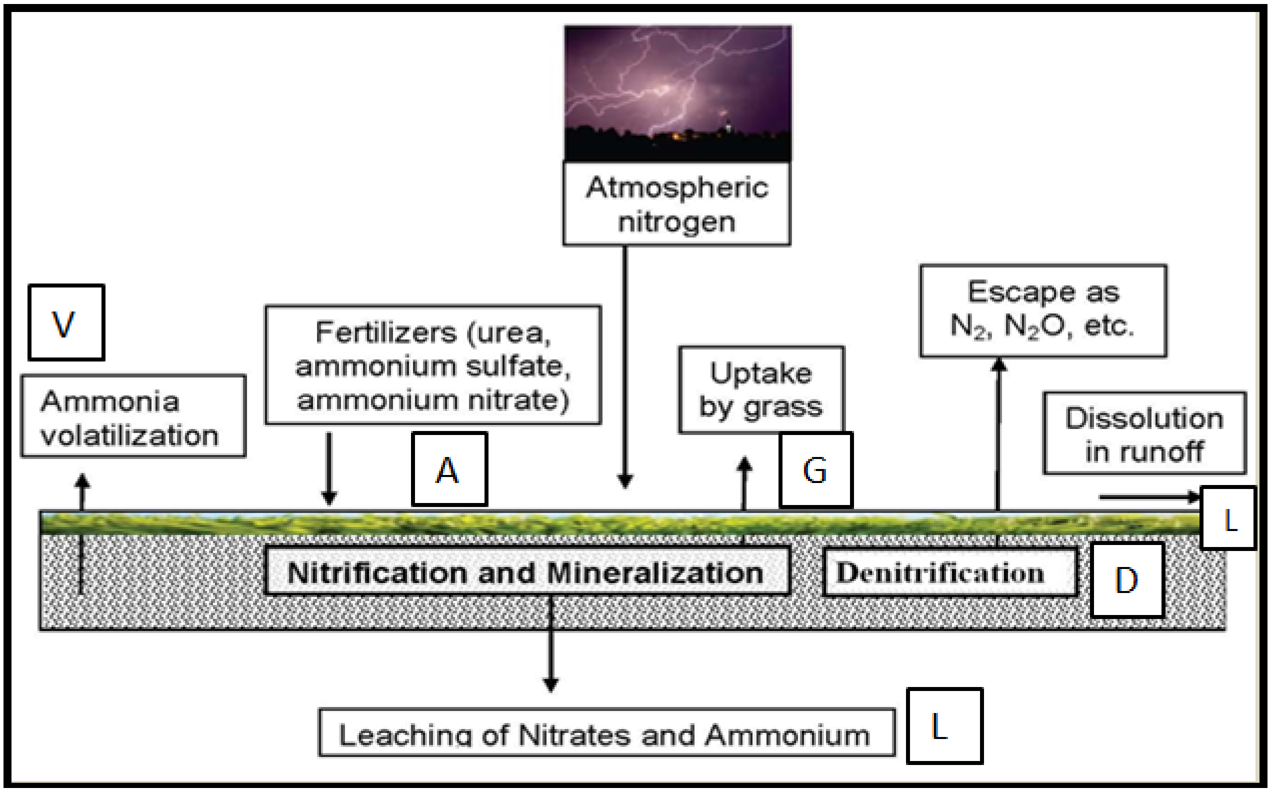


Figure 3: Mass Balance of Nitrogen in the Test Bed, Modified from Chopra (2011)

The nitrogen mass balance was developed around the test bed boundary, excluding the sod portion with the exception of the uptake of nitrogen by the sod. Atmospheric nitrogen is considered negligible. The variables assigned to each process are: v = ammonia volatilization (g/day), a = applied fertilizer (g/day), d = denitrification (g/day), g = grass uptake (g/day), l = total nitrogen lost from the test bed (g/day), and M_n = ammoniacal nitrogen and nitrate in test bed (g). The mass balance equation was developed as:

$$\frac{d(M_N)}{dt} = a + v + d + g - l \tag{5}$$

With the assumption of a finite time difference the equation becomes:

$$\frac{\Delta(M_N)}{\Delta t} = a + v + d + g - l \quad (6)$$

Once multiplied by the time step the rate terms became mass terms and the mass balance equation becomes:

$$\Delta(M_N) = A + V + D + G - L \quad (7)$$

The nutrient uptake by Bahia grass was estimated. While there are no nitrogen uptake rates found in literature for Bahia grass, the uptake rate for Bahia grass was assumed based on data for Centipede grass reported by Bowman et al. (2002), which examined the nutrient uptake of six warm-season turf grasses in sandy soils near Raleigh, North Carolina. The mathematical function adopted from Chopra (2011) for the total nitrogen uptake by Bahia grass in Florida is:

$$U_{TN-Bahia} = 0.2775\,(D - D_{min}) \quad (8)$$

where $U_{TN\text{-}Bahia}$ is the total nitrogen uptake by Bahia grass per test bed, per day, D is the duration of daylight in hours, with D_{min} = 11 hours in Orlando on winter solstice. This equation was developed based on the similarity and proximity between North Carolina and Florida, the dormancy of grass in winter, and the 11-15 hour range of daylight in Florida.

Phosphorus in Soil

Phosphorus, like nitrogen, is essential for plant growth. It is a constituent of plant cells, necessary for cell division, and its absence or deficiency causes stunted plant and root growth (Tisdale et al. 1985). It is not naturally as abundant as nitrogen, and of the phosphorus available, only a portion is accessible for plant growth with the remaining portion immobile because of adsorption, precipitation, or conversion to forms unusable by plants (Holford 1997).

Phosphorus found in soil can be classified under two categories: organic or inorganic, with the majority frequently found in the inorganic form. Organic forms of phosphorus, similarly to nitrogen, are found in both inactive and active forms, however unlike nitrogen, phosphorus is not present in the atmosphere, hence does not volatilize. Plants can absorb phosphorus in the form of the primary (first dissociation of orthophosphoric acid) $H_2PO_4^-$ ion or the secondary (second dissociation of orthophosphoric acid) HPO_4^{2-} ion, with the primary ion being most prevalent at the neutral pH levels found in soil (Tisdale et al. 1985).

Phosphorus Transformation in Soil

Organic phosphorus occurs naturally as esters of orthophosphoric acid as well as mono- and diesters. Similarly to nitrogen, it is converted to inorganic phosphate through the process of mineralization. Inorganic phosphorus, also the form found in synthetic fertilizers, is subject to several fates such as:

- Formation of compounds within the soil that range in solubility (precipitation).
- Sorption to soil surfaces (adsorption)
- Plant uptake (absorption)
- Leaching
- Utilization by microorganisms present in the soil.

The phosphorus cycle, from Tisdale et al. (1985), as it occurs in soil is shown in Figure 4.

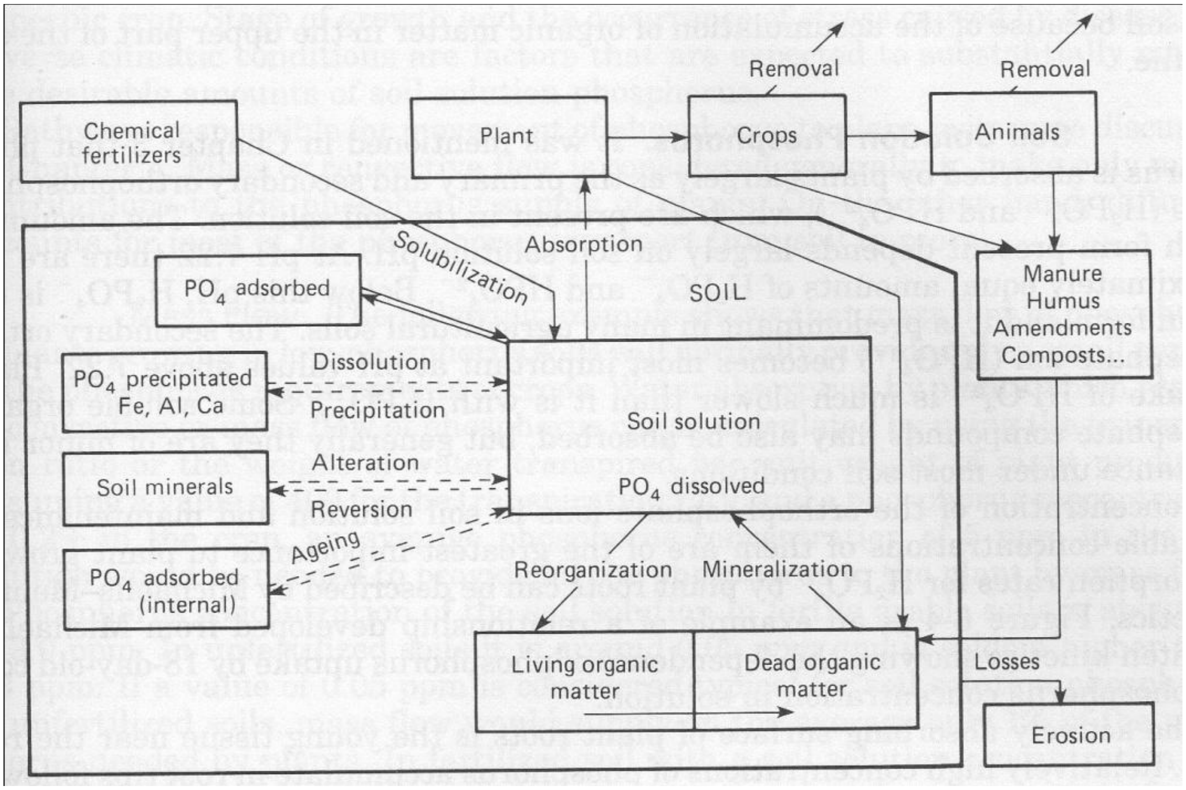


Figure 4 The Soil Phosphorus Cycle (Tisdale et al. 1985)

Precipitation of Phosphorus Compounds of Varying Solubility

Inorganic phosphorus reacts with soil components to produce less soluble forms. The amount of soluble and insoluble phosphorus that forms is highly dependent on soil characteristics such as pH, concentrations of metals such as iron and aluminum, and carbonates of calcium and magnesium in the soil (Holford 1997).

Sorption to Soil Surface

When inorganic phosphorus is applied in the form of synthetic fertilizer, phosphorus is removed from solution and retained. Phosphate ions tend to adsorb onto two types of surfaces: (1) Surfaces of constant charge, such as crystalline clay materials that contain Ca^{2+}, Al^{3+}, polymers of aluminum and iron, and (2) Surfaces of variable charge such as hydrated iron and aluminum oxides (Tisdale et al. 1985)

Absorption by Plants

Plants absorb phosphorus in $H_2PO_4^-$ or HPO_4^{2-} forms. Absorption of the $H_2PO_4^-$ ion tends to be higher because it is more prevalent in the normal pH range found in soil. Furthermore, some studies have shown that roots of certain plants have more absorption sites for $H_2PO_4^-$ than HPO_4^{2-} (Tisdale et al. 1985).

Utilization by Microorganisms Present in the Soil

Microorganisms play an important role in the soil phosphorus cycle by improving the ability of plants to acquire phosphorus from soil. This is performed by several mechanisms such as a symbiotic relationship between fungi and the roots of the plant increasing root growth or by hormonal stimulation promoting root growth, branching, and root hair development. Essentially, microorganisms, through the actions of solubilization, mineralization, and immobilization, convert phosphorus previously unavailable to plants into the available pool (Richardson and Simpson 2011).

Mass Balance Model of Phosphorus Processes, Transport, and Leaching

This study utilizes a phosphorus mass balance to estimate the amount of nutrients available within the test bed prior to each test. The purpose of performing a mass balance based on literature models is to compare the results from models to results from actual soil nutrient analyses.

The mechanistic model used in this study and Chopra (2011) to calculate the phosphorus level in the soil was originally developed by Greenwood et al. (2001). This model considered the interactions in the soil between extractable and non-extractable phosphorus, individual plant characteristics and its phosphorus uptake, and pertinent soil and weather data such as daily rainfall, average air temperature, and evaporation. Subsequently, Greenwood et al. (2001b) discussed the calibration of the model for different species and independent testing against the results on the same soil type. Karpinets et al. (2004) improved upon this model, making it suitable for long-term phosphorus mass balance calculations. This model takes into account extractable phosphorus, which is readily available for plant uptake or leaching (X), soil-adsorbed, non-extractable phosphorus (Y), mineral phosphorus that provides solubility-type buffering of extractable phosphorus (P_{buffer}), and the interactions between them. This model assumes that the applied phosphorus gets partitioned into X and Y, with the majority going to the X pool. In addition, it assumes that grass uptake, leaching, and runoff losses are also from the X pool.

Karpinets et al. (2004) validated the model by comparing the predictions made with observed data from four different countries. One of these validations was from an experimental study conducted in Norfolk, North Carolina on loamy, sandy soil. The rate constants from the study were adopted because of the similarities between the study site and the one used in this study in Orlando, Florida. In addition to the rate constants, the conclusion from the study that the partitioning of applied phosphorus between X and Y is in the ratio of X and Y to their total was also adopted. The interactions between the three pools of phosphorus and the environment are depicted in Figure 5.

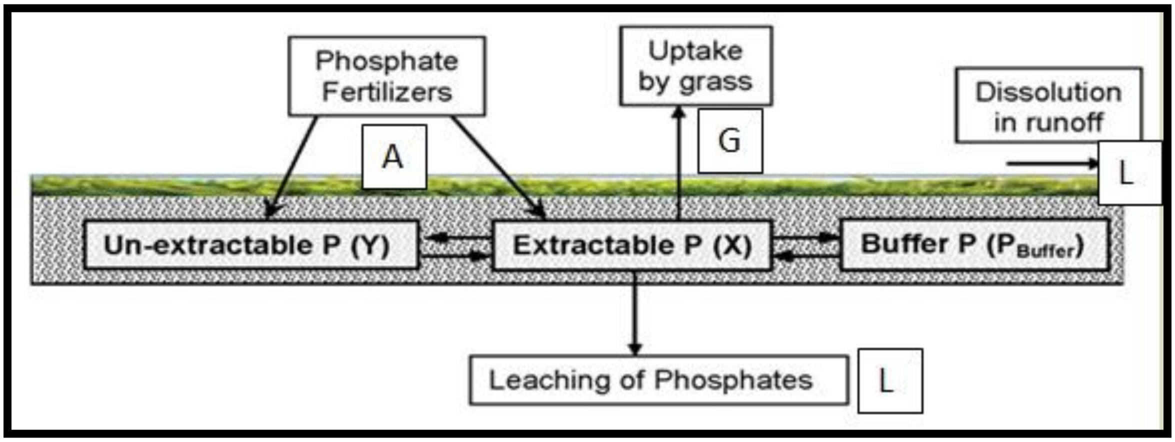


Figure 5: Mass Balance of Phosphates in the Test Bed, Modified from Chopra (2011)

The phosphorus mass balance was developed with the boundary around the test bed, excluding the sod portion with the exception of uptake of phosphorus by the sod. The variables assigned to each process are: a = applied phosphorus in fertilizer (g/day), g = grass uptake (g/day), l = total phosphorus lost from the test bed (g/day), and M_p = extractable, un-extractable, and buffer phosphorus in test bed (g). The mass balance equation was developed as:

$$\frac{dM_p}{dt} = a - g - l \quad (9)$$

With the assumption of a finite time difference the equation becomes:

$$\frac{\Delta M_p}{\Delta t} = a - g - l \tag{10}$$

Once multiplied by the time step the rate terms became mass terms and the mass balance equation becomes:

$$\Delta M_p = A - G - L \tag{11}$$

Because the phosphorus uptake by plants is much less than nitrogen, in this study, the total phosphorus uptake by Bahia grass is taken to be 20% of the total nitrogen uptake. Thus, the mathematical function for the total phosphorus uptake for Bahia grass adopted Chopra (2011) is:

$$U_{TP-Bahia} = 0.0555(D - D_{min}) \tag{12}$$

where $U_{TP\text{-}Bahia}$ is the total phosphorus uptake by Bahia grass per test bed, per day, D is the duration of daylight in hours, with D_{min} = 11 hours in Orlando on winter solstice. This equation was developed based on the similarity and proximity between North Carolina and Florida, the dormancy of grass in winter, and the 11-15 hour range of daylight in Florida.

Moisture Balance of the Test Bed

In addition to nitrogen and phosphorus mass balances, this study utilizes a moisture mass balance. Because the test bed was exposed to the atmosphere, the soil moisture content and associated transformation and transport processes were affected. The soil moisture content depended on evapotranspiration, naturally occurring rainfall between tests, and simulated rainfall. Evapotranspiration in addition to the nutrient dynamics occurring in the test bed are influenced by daily weather conditions such as temperature, duration of daylight, and precipitation. All of these parameters were obtained from local weather data for all days, including the days of the test as well as days between tests. For simplicity, the moisture content was considered uniform throughout the test bed.

Irmak et al. (2005) measured evapotranspiration from Bahia grass fields at the Plant Science Research Education Unit of the University of Florida in Citra, Florida. Based on this location's proximity to Orlando, Florida, the mean temperature values, duration of daylight, grass type, and soil conditions are very similar. Thus, the observed range of evapotranspiration data, specifically 1 to 6 mm per day has been adopted in this study. However, because the mean temperature and duration of daylight varied, a mathematical function adopted from Chopra (2011) was used to estimate daily evapotranspiration:

$$\boldsymbol{ET = a + k(T - T_{min})^{b}(D - D_{min})^{c}} \tag{13}$$

where ET is evapotranspiration rate (mm/day), T is temperature in Fahrenheit, D is duration of daylight in hours, and a, b, c, and k are empirical constants. It is assumed that the average annual maximum and minimum temperatures are 90° F and 50°F, respectively, and the average annual maximum and minimum duration of daylight are 15 hours and 11 hours, respectively. Assuming a linear relationship for the observed range of evapotranspiration data (1 to 6 mm), *b* and *c* equal to 1, and *a* and *k* were worked out resulting in this equation for estimating the evapotranspiration on any given day:

$$\boldsymbol{ET = 1 + 0.03125(T - 50)(D - 11)} \tag{14}$$

The moisture balance also allowed for the estimation of seepage from the test bed that occurred between tests. It was also crucial in calculating the soil air content, which is important for quantifying the nitrogen transformations occurring in the soil. In addition, because the test bed was kept at a horizontal position between tests, it was assumed that no runoff occurred between tests. The processes affecting soil moisture content are depicted in Figure 6.

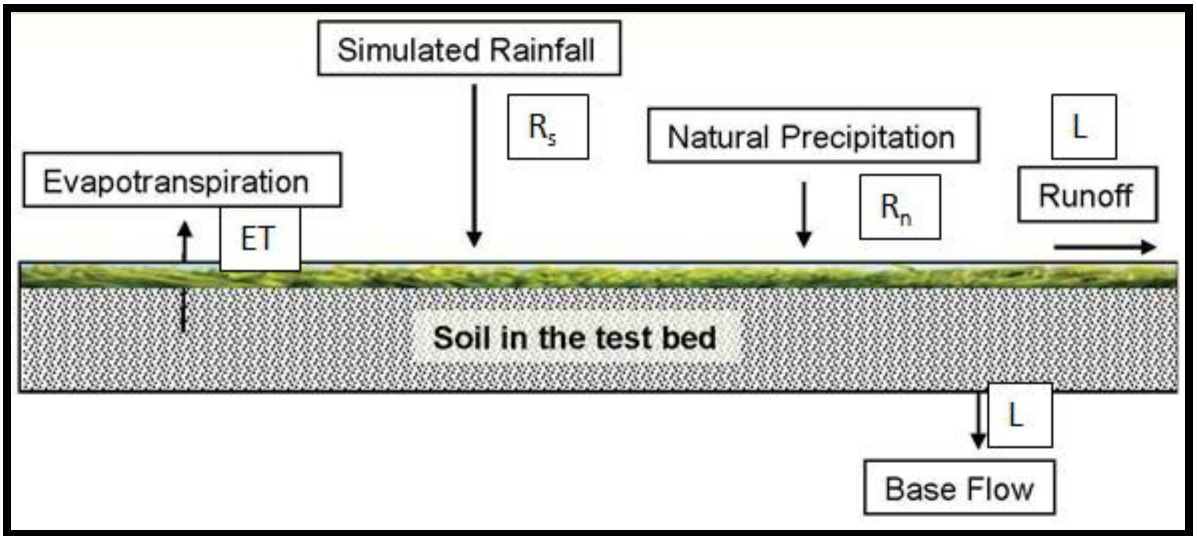


Figure 6: Mass balance of Moisture in the Test Bed, Modified from Chopra (2011)

The water balance was developed with the boundary around the test bed. The variables assigned to each process are: r_s = simulated rainfall (L/day), r_n = natural rainfall (L/day), et = evapotranspiration (L/day), and l = water lost from the test bed in runoff and baseflow (L/day), and V = volume of water in test bed (L). The water balance equation was developed as:

$$\frac{dV}{dt} = r_s + r_n - et - l \tag{15}$$

With the assumption of a finite time difference the equation becomes:

$$\boldsymbol{\frac{\Delta V}{\Delta t} = r_s + r_n - et - l} \tag{16}$$

Once multiplied by the time step the rate terms became volume terms and the water balance equation becomes:

$$\boldsymbol{\Delta V = R_S + R_N - ET - L} \tag{17}$$

CHAPTER 3: METHODOLOGY

Introduction

This study was performed at the Stormwater Management Academy's Research and Testing Laboratory (SMARTL) in Orlando, Florida. In order to evaluate the loss of nutrients from fertilized slopes, a field-scale, slope-adjustable test bed, and a computer-controlled rainfall simulator were utilized (Figure 7).

Figure 7: Side View of Test Bed, Rainfall Simulator, and Gantry Crane

Experimental Setup

Two different soil and sod combinations were used that are typically utilized by FDOT for highway stabilization. These are Argentine Bahia on AASHTO A-3 (sandy) soil and Pensacola Bahia on A-2-4 (silty-sandy) soil. Both of these soil/sod combinations were initially tested with no fertilizer to establish a nutrient baseline, then 10-10-10 (N-P-K) fertilizer, or a slow-release 16-0-8 (N-P-K) fertilizer applied at a rate consistent with FDOT highway shoulder and embankment fertilization practices. The application rate of fertilizer was 0.5 lb of N per 1000 ft^2. The rainfall intensities generated were 0.1 in/hr and 0.25 in/hr. In addition to single-day tests, seven-day tests were also performed in order to evaluate the change occurring in the soil over time with respect to nutrient uptake and transformations. Seven-day tests, however, were only performed at the 0.25 in/hr intensity. In addition, each test, with the exception of seven-day tests, was performed twice, while the seven-day tests were performed only once for each soil and sod combination as well as fertilizer type. The testing matrices for single-day and seven-day tests are shown in Figure 8 and Figure 9, respectively. Tests at the 0.1 in/hr rainfall intensity on A-3 soil with slow-release 16-0-8 (N-P-K) fertilizer were not performed due to equipment failure and are marked with a red ‘x’ in the single-day testing matrix.

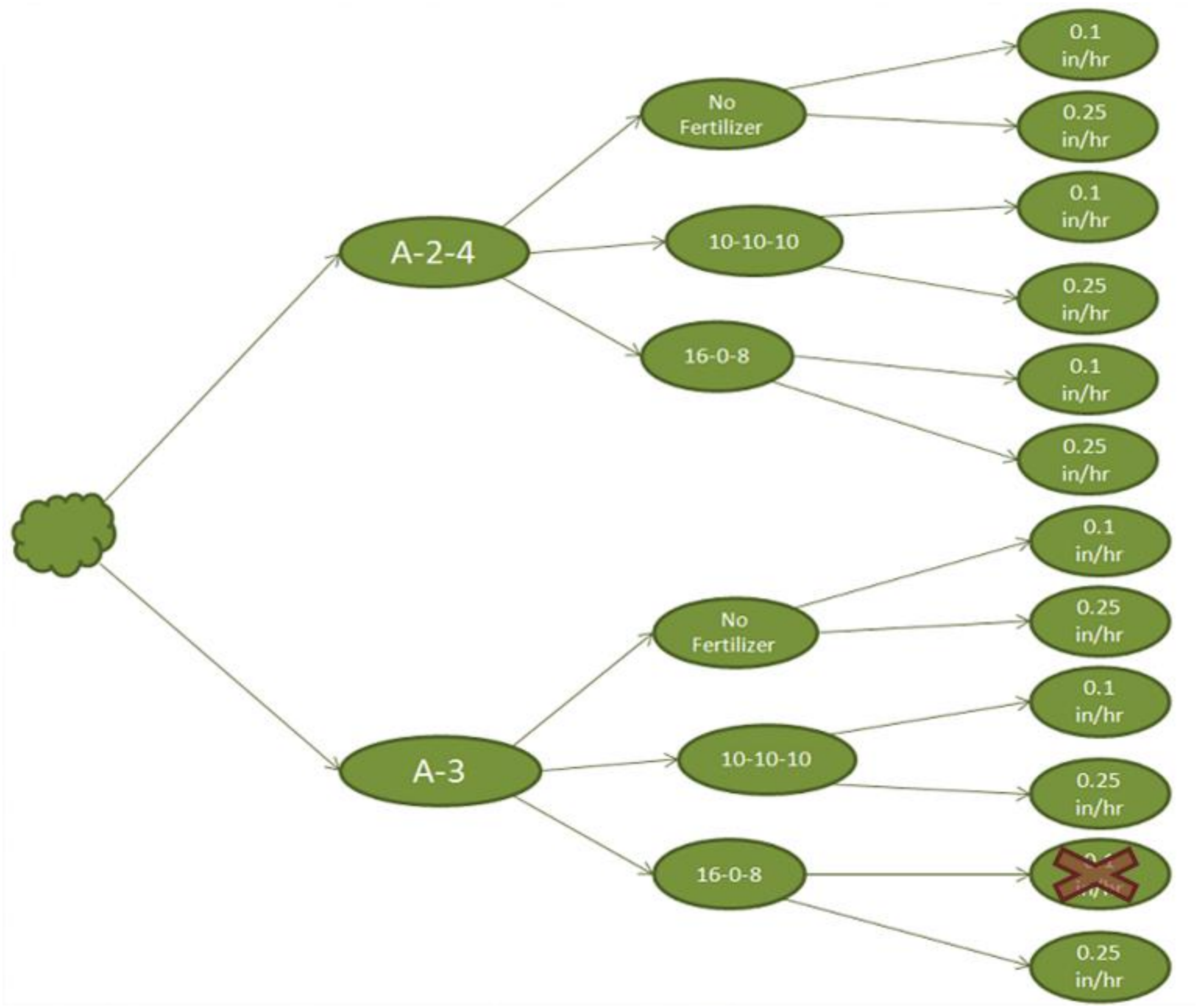


Figure 8: Single-day Testing Matrix

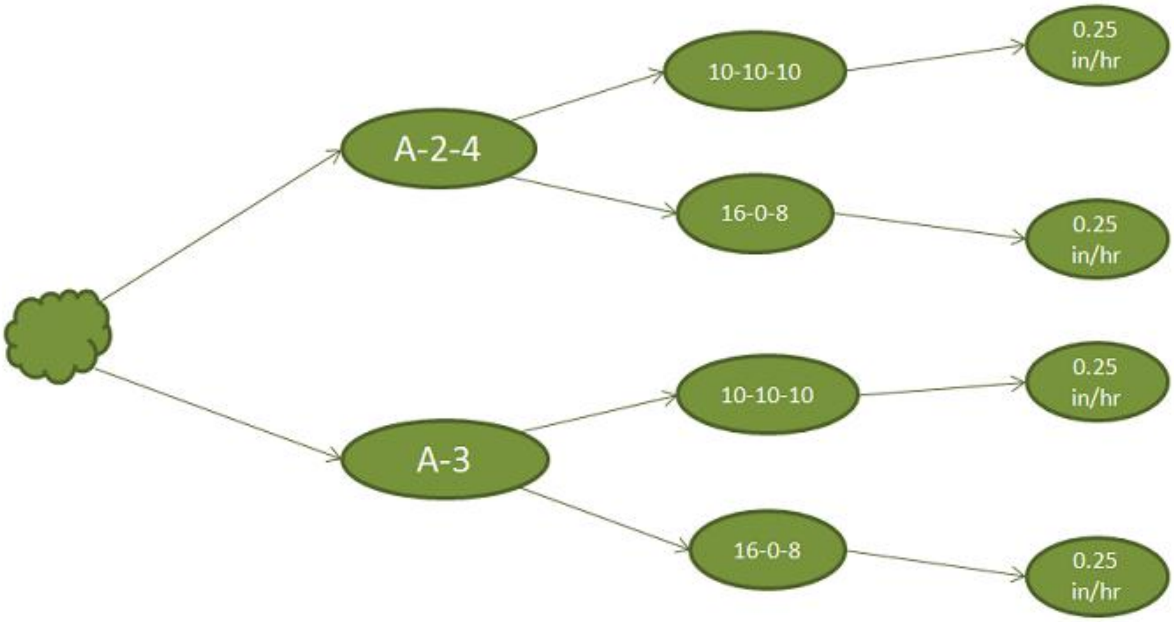


Figure 9: Seven-day Testing Matrix

After each test with fertilizer, all remaining fertilizer had to be washed out of the test bed prior to the commencement of the next test. This was done by performing a flush event at a rainfall intensity of 3 in/hr for two hours. Samples of runoff and baseflow were taken at the end of the flush event to ensure that pre-fertilization conditions were met.

Similarly to Chopra (2011), this study also developed nutrient and water balances around the test bed to determine the fate of the nutrients applied to the soil/sod combination. Thus, several factors were taken into consideration. A nutrient mass balance requires the quantification of preexisting nutrients in the soil before and after fertilization, vegetative nutrient uptake rate, volatilization and biological activity, and other environmental factors. Because testing was performed on an open system, the quantification of certain parameters, particularly volatilization and biological processes occurring within the soil, relied heavily on previous research and literature values, as well as careful monitoring of environmental processes occurring during testing such as amount of natural rainfall occurring between tests, amount of sunlight, and ambient temperature. A water balance takes into consideration the moisture content of the soil before and after testing, the volume of water in runoff and baseflow, and the amount of rainfall simulated. Environmental factors such as the volume of rainfall occurring between tests and evapotranspiration rates are also considered.

In addition to a nutrient and water balance, soil samples were taken throughout the study and analyzed for total nitrogen, total phosphorus, and cation exchange capacity. Prior to each test, soil samples were taken in two locations and analyzed for the aforementioned parameters as well as moisture content. Sample locations are shown in Figure 10. Knowing the cation exchange capacity aids in the understanding of how soil fertility changes and is impacted over time as a result of fertilization. Assessing the changing soil fertility as a result of fertilization allows for understanding its nutrient retention capacity and by extension the capacity of the soil to protect groundwater from cation contamination. Determining these factors aids in the adjustment of fertilizer application frequency and quantity.

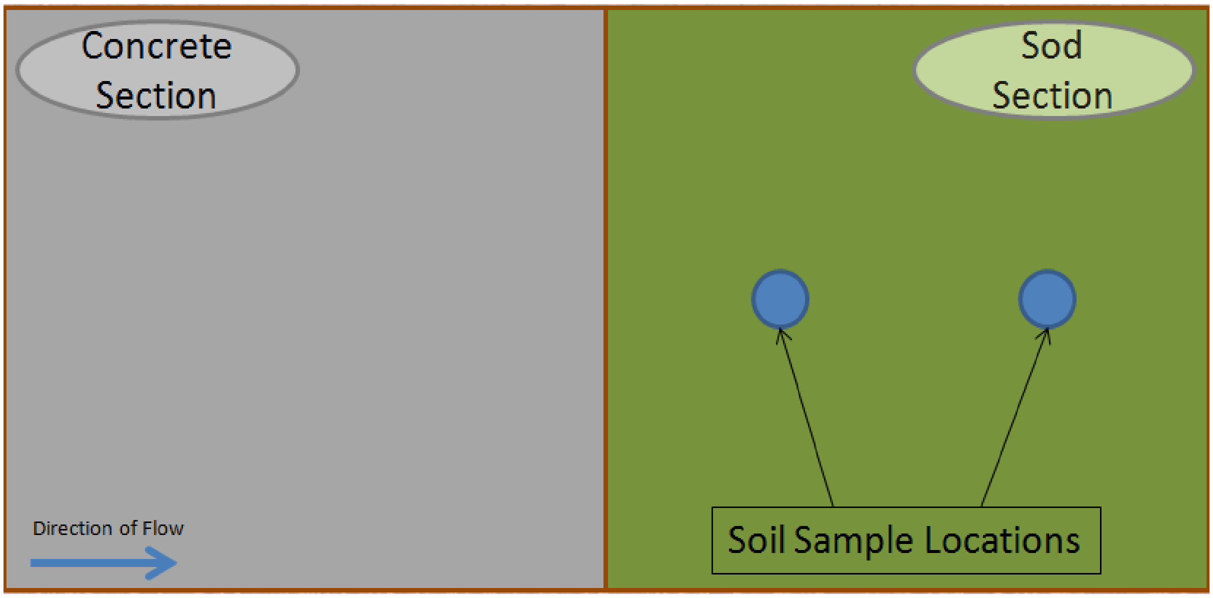


Figure 10: Soil Sample and Moisture Content Locations

Test Bed Construction, Operation, and Rainfall Simulation

The test bed was constructed to represent a typical highway shoulder and embankment and measured 30 feet long and 8 feet wide as shown in Figure 11. Half (15 feet) of the test bed contained concrete placed on compacted soil. The purpose of the concrete section is to generate overland flow which simulates actual conditions occurring on a highway during rainfall. The remaining half of the test bed contained compacted soil at a depth of 3 feet. Standard compaction procedures were followed when adding the soil to the test bed. The soil was compacted at each lift (approximately 6 inches) using a 6.5 HP Compact Vibrator Plate manufactured by Central Machinery of Camarillo, CA. The compaction was verified using a nuclear density probe (MC-1 Density and Moisture Gauge; CPN International Inc., Raleigh, NC) in accordance with

AASHTO T-310; ASTM D-6031 method as well as by the sand-cone method (AASHTO T-191; ASTM D-1556). The compacted soil was scarified to a depth of 1 to 2 inches prior to the application of purchased sod tiles. The sod was then watered every day for several weeks (unless there was natural rainfall) allowing time for the sod to establish itself in the compacted soil prior to commencement of testing.

Figure 11: Side View of Elevated Test Bed

In order to accurately represent a typical highway cross-section found in Florida, the test bed was constructed at a variety of slopes. The combination of slopes, ultimately achieved by a hydraulic ram that lifted the test bed, of the concrete and sod combination was as follows: the 15-foot concrete slab was at a 2% slope, followed by a 6% slope of the first 5 feet of the soil/sod section, and the remaining 10 feet was at a 1:6 slope, or 16.67%, yielding a total flow path of 30 feet. An aerial view of the top of the test bed including the concrete section is shown in Figure 12.

Figure 12: Aerial View of Test Bed

Rainfall was generated by a 34 foot (10.36 m) rainfall simulator that is computer-controlled to consistently achieve the desired rainfall intensity while also producing raindrop sizes of a realistic diameter. The rainfall simulator was hoisted and positioned with a gantry crane above the test bed to the appropriate height of 7 feet (2.13 m) and slope as shown in Figure 7. Actual rainfall intensities that were applied to the test bed were based on the measurement of twelve rain gauges set up on the test bed. Rain gauge configuration is shown in Figure 13, and rain gauges as they were set up on the test bed is shown in Figure 14.

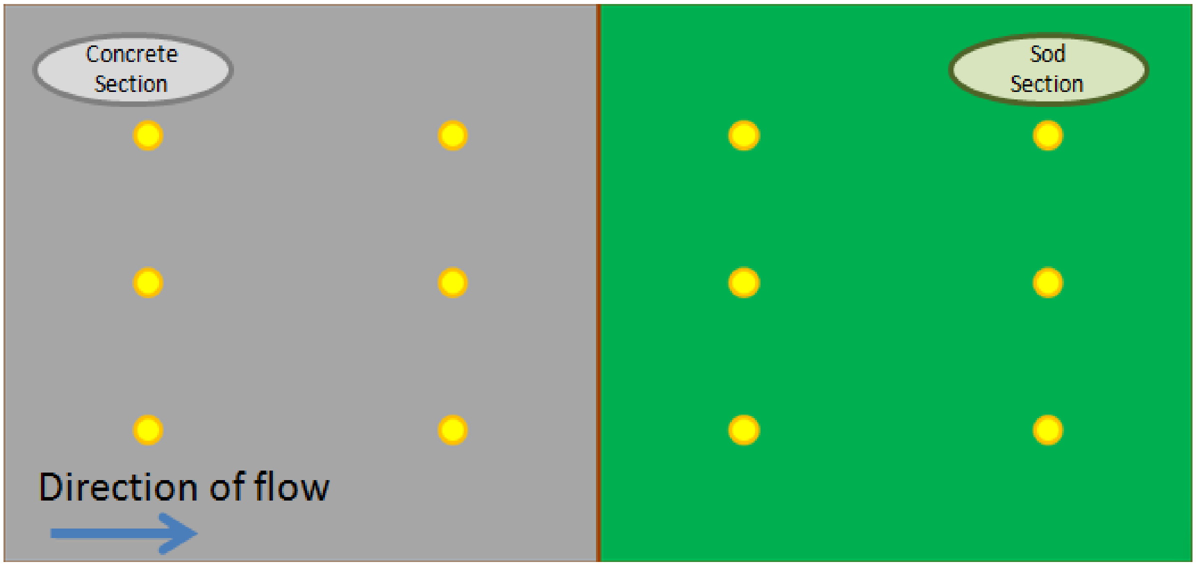


Figure 13: Rain Gauge (in yellow) Configuration

Figure 14: Rain Gauges on Test Bed

Soil Characterization

Soil characterization tests were conducted on each soil type used in the study in order to determine particle size distribution in order to ensure proper soil classification, maximum compaction, maximum dry density, and specific gravity. Results from all of these tests are presented in Appendix A.

Soil Classification

Soil classification was determined using the AASHTO system as specified in AASHTO M 145-91. Classification was based on particle size characteristics; the liquid limit and plasticity index were not considered. Particle size characteristics were determined using a sieve analysis as specified by AASHTO T-88; ASTM C 136-01. The sieve test was conducted using sieve numbers 10, 20, 40, 60, 100, 140, and 200. In addition, washed sieve analysis (AASHTO T-11; ASTM C-117) was performed on A-2-4 because of its silt and clay content.

Maximum Dry Density

The moisture-density relationship of both soil types was determined using the standard Proctor test as described in AASHTO T-99; ASTM D 698 Method A. This test method establishes the relationship between the density of soil and its respective moisture content and determines the optimal moisture content at which a soil will achieve its maximum dry density.

Specific Gravity

The specific gravity of each soil type was determined using AASHTO T-100; ASTM D-854. Specific gravity was determined in order to establish the porosity of the soil in the test bed.

Moisture Content

Moisture content samples were taken according to AASHTO T-265; ASTM D 2216. Prior to each test, core samples were taken at a depth of six to eight inches at two locations as shown in Figure 10. The moisture content value used was based on the averages from both soil samples.

Collection and Analysis of Effluent

Effluent samples were collected from surface runoff as well as from baseflow. Troughs, located at the downstream end of the test bed collected surface runoff as shown in Figure 15. Tubes underneath the test bed collected baseflow into two barrels: one located upstream, just after the concrete section; the second located downstream towards the end of the test bed as shown in Figure 16. Effluent from the test bed was collected throughout the duration of the entire test. Cumulative samples were collected from both baseflow and runoff at the end of each test and handled as requested by Environmental Research and Design, Inc in Orlando, Florida where they were subsequently analyzed. Sample handling included preservation with sulfuric acid if needed, and/or filtration a 0.45 micron nylon filter.

Figure 15: Downstream Collection Troughs and Sinks

Figure 16: Baseflow Collection Tubes and Barrels

Collection and Analysis of Soil Samples

As discussed earlier, soil samples were collected from two locations shown in Figure 10. The upstream location was located approximately five feet away from the concrete section, and the downstream location was also located five feet away from the end of the test bed. Soil removed for sampling was replaced by either A-2-4 soil or A-3 soil, depending on the type of soil present in the test bed. All samples were analyzed for total nitrogen, total phosphorus, and cation exchange capacity at Environmental Research and Design, Inc. located in Orlando, Florida.

Weather Data Acquisition

Local weather data was obtained from Weather Underground which reports weather conditions for the UCF area using an on-campus Personal Weather Station owned by UCF's radio station, WUCF-FM. The station, located approximately 2 miles from the testing site, uses an Ultimeter 2100 to acquire typically reported weather data (Weather Underground 2014). The average daily temperatures as well as total daily precipitation data were gathered from this station and used in the water balance. The duration of daylight, from sunrise to sunset was gathered from NOAA, the National Climatic Data Center, which is reported by The Florida Climate Center (Florida Climate Center 2014).

Soil and Sod Acquisition

Both the soil and sod were sourced locally and from the northern Florida panhandle. The A-2-4 soil was purchased from Bucky's Hauling located in Orlando, Florida, while the A-3 soil was from the UCF campus. Prior to adding them to the test bed, both soil type varieties were verified according to the AASHTO system as specified in AASHTO M 145-91. The Argentine bahiagrass sod was supplied locally by Duda Sod in Oviedo, Florida, while the Pensacola bahiagrass sod was supplied by Chipola Turf Farms in Kinard, Florida, which is located in the northern Florida panhandle.

Limitations of Nutrient and Moisture Balance as well as Field Scale Testing

The mass balances adopted for this study have several limitations due to the availability of models in literature as well as the assumption of parametric values from literature. The model that was ultimately used, LEACHM, was developed by Hutson and Wagenet (1991).The model parameters used in the mass balances were developed mostly based on studies that were conducted using quick-release fertilizers and different soils than those used in this study (Paramasivam et al. 2000, Singh and Sondhi 2001). Additionally, Paramasivam et al. (2000) and Singh and Sondhi (2001) used fertilizer for reasons other than highway fertilization such as home lawns and golf courses. The parameters that influenced the nutrient mass balances and field testing, as well as how they were taken into account are discussed individually below.

Weather and Seasonal Conditions

Weather data used in this study was obtained from a weather station nearest to the test site. The parameters used were average daily temperature and total daily rainfall. Despite the stations close proximity, however, these values may not exactly represent the actual conditions at the test site. Because average temperature values were used, in reality the soil and sod were exposed to higher and lower temperatures throughout each day. Ammonia volatilization as well as other nitrogen transformations may be enhanced along with an increase in nutrient uptake because of improved photosynthesis. Therefore, using the average temperature values in the mass balance calculations may not be completely accurate and only an estimate.

Higher temperatures also reduce the viscosity of water resulting in increased permeability of water through the soil which affects the leaching of nutrients and volume of baseflow collected. Additionally, despite the measurement of applied rainfall via rain gauges placed on the test bed, higher temperatures and high wind speed increase evaporation from the soil as well as grass which can result in slightly less water penetrating the soil than what was measured; however, because of the relatively short duration of tests, these effects are assumed minimal.

Soil Compaction and Gradation

Prior to sod application, the soil in the test bed is compacted similarly to the highway compaction methods of FDOT in order to strengthen and stiffen the soil. There is no tillage of side slopes prior to sod application. Tillage, along with compaction, can result in less soil aeration, shallower root growth, reduced infiltration, and lower fertilizer entry into soils. These circumstances can promote anaerobic conditions in the soil which leads to denitrification and increased gaseous losses of nitrogen.

Soil characteristics also play a role in influencing nutrient loss. Soils with coarser gradation have increased permeability resulting in higher volumes of baseflow as well as nutrient losses in baseflow. In this study A-3 soil was more coarsely graded than A-2-4 soil. This can decrease nutrient-soil interactions and increase nutrient losses. In addition, soils with a higher clay and/or silt content have a higher CEC value, which increases adsorbed NH_4^+ and phosphorus. Higher clay and/or silt content can also decrease permeability, which decreases infiltration and subsequent loss of nutrients in baseflow such as nitrates.

Field conditions are also constantly changing certain characteristics of the soil. A major source of variability in this study stemmed from not knowing exactly how much fertilizer/nutrients are introduced to the system from new sod. In addition, soil that is more saturated prior to testing experiences higher rates of runoff and loss of nutrients. In addition, the saturated soil has less air in the pore spaces which can create anaerobic conditions and denitrification.

CHAPTER 4: RESULTS AND DISCUSSIONS

Results of the field-scale tests are presented herein. A total of thirty-four tests were performed on two different soil and sod combinations at two different rainfall intensities, initially with no fertilizer, then 10-10-10 (N-P-K) fertilizer and later slow-release 16-0-8 (N-P-K) fertilizer. The soil and sod combinations examined were Pensacola Bahia with silty-sandy (A-2-4) soil and Argentine Bahia with sandy (A-3) soil. The rainfall intensities examined were 0.1 in/hr and 0.25 in/hr. Testing took place over the course of one year. Originally, thirty-six tests were scheduled; however, due to equipment failure the last two remaining tests with slow-release 16-0-8 (N-P-K) fertilizer at 0.1 in/hr rainfall intensity were discarded. Due to the nature of field testing, tests were performed during all weather seasons with varying temperatures, daylight hours, and starting soil conditions. All of these factors were discussed in chapter 3. Table 4 displays the chronological sequence of tests performed and the respective dates.

Table 4: Chronological Sequence of Tests

Test #	Soil Type	Bahia Sod Type	Fertilizer Type	Rainfall Intensity	Date Completed
1	A-2-4	Pensacola	None	0.25	2/20/2013
2	A-2-4	Pensacola	None	0.25	2/23/2013
3	A-2-4	Pensacola	None	0.1	2/27/2013
4	A-2-4	Pensacola	None	0.1	3/13/2013
5	A-2-4	Pensacola	10-10-10	0.25	3/16/2013
6	A-2-4	Pensacola	10-10-10	0.25*	3/27/2013
7	A-2-4	Pensacola	10-10-10	0.25*	4/3/2013
8	A-2-4	Pensacola	10-10-10	0.25	4/6/2013
9	A-2-4	Pensacola	10-10-10	0.1	4/10/2013
10	A-2-4	Pensacola	10-10-10	0.1	5/11/2013
Soil Change 1					
11	A-2-4	Pensacola	16-0-8	0.25	6/12/2013

Test #	Soil Type	Bahia Sod Type	Fertilizer Type	Rainfall Intensity	Date Completed
12	A-2-4	Pensacola	16-0-8	0.25	6/15/2013
13	A-2-4	Pensacola	16-0-8	0.1	6/19/2013
14	A-2-4	Pensacola	16-0-8	0.1	6/22/2013
15	A-2-4	Pensacola	16-0-8	0.25*	6/26/2014
16	A-2-4	Pensacola	16-0-8	0.25*	7/3/2013
Soil Change 2					
17	A-3	Argentine	None	0.25	9/7/2013
18	A-3	Argentine	None	0.25	9/11/2013
19	A-3	Argentine	None	0.1	9/14/2013
20	A-3	Argentine	None	0.1	9/18/2013
21	A-3	Argentine	10-10-10	0.25	9/29/2013
22	A-3	Argentine	10-10-10	0.25	10/2/2013
23	A-3	Argentine	10-10-10	0.1	10/5/2013
24	A-3	Argentine	10-10-10	0.1	10/9/2013
25	A-3	Argentine	10-10-10	0.25*	10/16/2013
26	A-3	Argentine	10-10-10	0.25*	10/23/2013
Soil Change 3					
27	A-3	Argentine	None	0.25	1/13/2014
28	A-3	Argentine	None	0.25	1/16/2014
29	A-3	Argentine	None	0.1	1/20/2014
30	A-3	Argentine	None	0.1	1/23/2014
31	A-3	Argentine	16-0-8	0.25	1/28/2014
32	A-3	Argentine	16-0-8	0.25	2/3/2014
33	A-3	Argentine	16-0-8	0.25*	2/13/2014
34	A-3	Argentine	16-0-8	0.25*	2/20/2014

*Indicates the seven-day test

AASHTO A-2-4 Soil with Pensacola Bahia –Water Quality Results

No Application of Fertilizer

As shown in Table 4, four tests were performed without fertilizer application in order to establish a baseline for this soil/sod combination. These tests were run at both rainfall intensities

(0.25 in/hr and 0.1 in/hr). The purpose of establishing a baseline was to determine the level of nutrients in the soil as well in the sod.

The actual rainfall intensities applied to the test bed, with the corresponding applied water volumes, as well as the respective volumes of collected runoff and baseflow are presented in Table 5. It is important to note that for this series, runoff was generated for only one 0.1 in/hr rainfall intensity test. This variation in generated runoff is attributed to the much higher moisture content of the soil for that particular test as compared to the moisture content of the soil prior to the 0.25 in/hr rainfall intensity tests. The average soil moisture content is also shown in Table 5.

Table 5: Volumes of Applied Rainfall and Collected Runoff and Baseflow for A-2-4 Soil with No Fertilizer

	No Fertilizer	
Intended intensity (in/hr)	**0.1**	**0.25**
Average actual intensity (in/hr)	0.11	0.26
Flow Volumes in Liters (L)		
Applied	176.0	448.1
Baseflow Collected	36.8	163.8
Runoff Collected	33.7	0.0
Soil Moisture Content	14.6%	11%
Runoff as Percentage of Total	47.8%	0%

The average total solids and alkalinity measured in all four tests are presented in Table 6, which include the runoff and baseflow. The concentration of total solids in runoff at the 0.1 in/hr rainfall intensity was 161 mg/L, while the total solids in baseflow was found to be higher. Alkalinity was also higher in baseflow than runoff at this intensity. At 0.25 in/hr rainfall intensity the total solids in baseflow was 180.8 mg/L and alkalinity was 84 mg/L as $CaCO_3$. The pH was not measured during this series of tests and was adopted from Chopra (2011) that used the identical soil and sod combination. Based on the comparable alkalinity values of these tests and tests from Chopra (2011), the assumption was made that this soil and sod combination had similar chemical neutrality.

Table 6: Total Solids, Alkalinity, and pH for A-2-4 Soil with No Fertilizer

	No Fertilizer	
Intensity (in/hr)	**0.1**	**0.25**
Total Solids in Runoff (mg/L)	161	--
Total Solids in Baseflow (mg/L)	257	180.8
Alkalinity in Runoff (mg/L as $CaCO_3$)	69.3	--
Alkalinity in Baseflow (mg/L as $CaCO_3$)	162	84
pH	6.8*	6.8*

*Indicates average value adopted from corresponding soil/sod combination in Chopra (2011) with no fertilizer.

The purpose of performing tests with no fertilizer applied is to determine the amount of nutrients that are inherent to the clean soil and fresh sod. Thus, the masses and concentrations of total nitrogen (TN) and total phosphorus (TP) were measured and are presented in Table 7. The concentration of total nitrogen and phosphorus lost in runoff for this soil and sod combination is higher than the typical concentration of runoff from highways in Florida for both rainfall intensities indicating that a substantial amount of nutrients were already present in the sod.

Table 7: Total Nitrogen and Phosphorus Lost for A-2-4 Soil with No Fertilizer

	No Fertilizer			
Intensity (in/hr)	**0.1**	**0.25**	**0.1**	**0.25**
TN Mass (g as N)			TN Concentration (mg/L)	
Baseflow	0.23	1.09	0.618	7.19
Runoff	0.02	0	4.48	--
Total	0.25	1.09		
TP Mass (g as P)			TP Concentration (mg/L)	
Baseflow	0.001	0.008	0.66	0.047
Runoff	0.022	0	0.026	--
Total	0.024	0.008		

Figure 17 and Figure 18 show the losses of total nitrogen and total phosphorus, respectively, in runoff and baseflow at 0.1 in/hr and 0.25 in/hr rainfall intensities. Baseflow losses for total nitrogen increased at the 0.25 in/hr rainfall intensity. The total loss for phosphorus, however, decreased at the 0.25 in/hr intensity compared to the 0.1 in/hr rainfall intensity. This can be attributed to the lack of runoff generated at 0.25 in/hr rainfall intensity as the main pathway for total phosphorus loss is through runoff. The main pathway for total nitrogen loss, however, is baseflow.

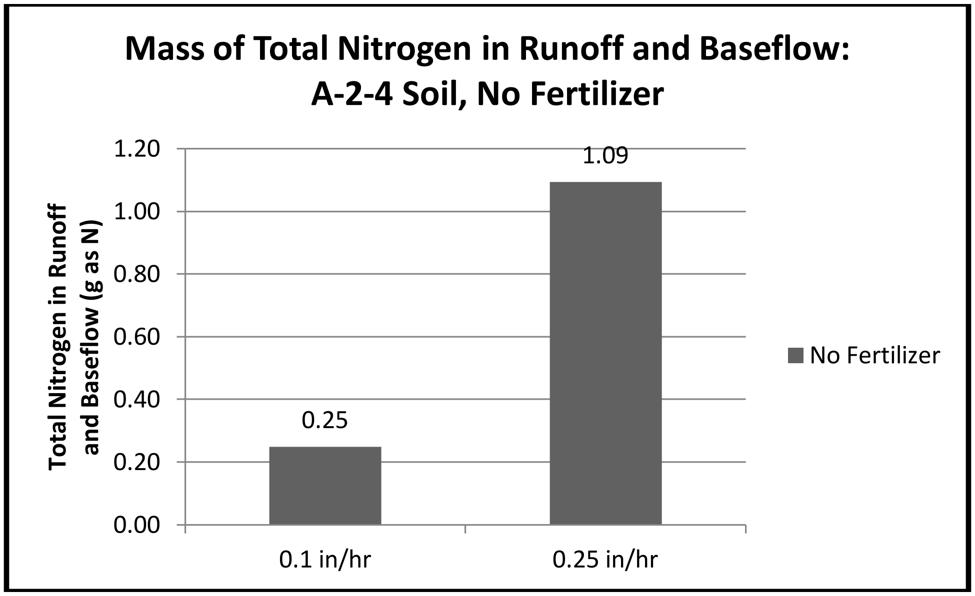


Figure 17: Mass of Total Nitrogen Collected for A-2-4 Soil with No Fertilizer

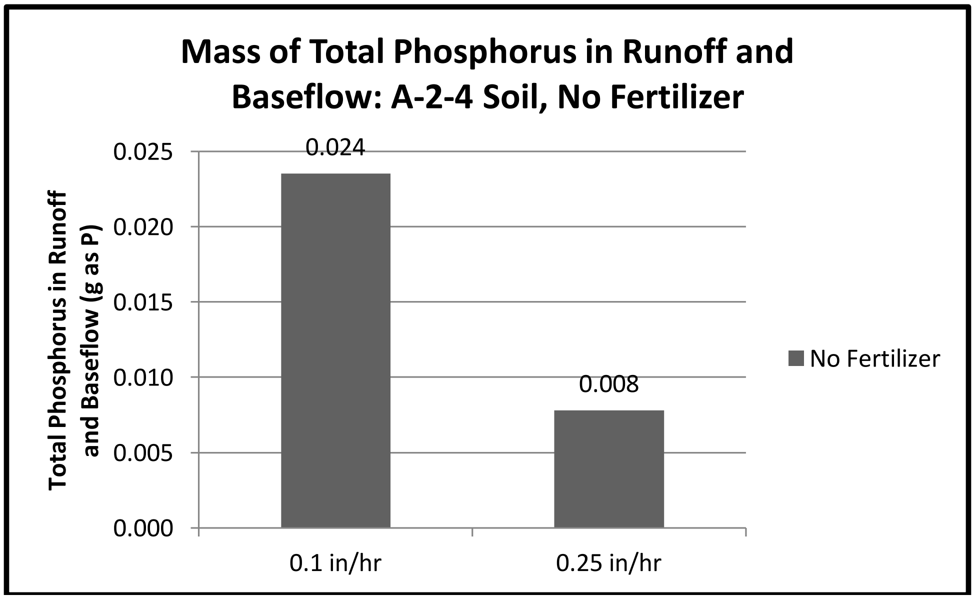


Figure 18: Mass of Total Phosphorus Collected for A-2-4 Soil with No Fertilizer

10-10-10 (N-P-K) Fertilizer

For this test series, 10-10-10 (N-P-K) fertilizer was applied to the sodded area of the test bed prior to each test at a rate of 0.5 lb N/1000 ft^2. As mentioned earlier, in addition to the single-day tests, there was a seven-day test performed on each soil and sod combination. In addition to two replicate single-day tests, seven-day tests were performed at both rainfall intensities. Although the single-day tests were replicated, seven-day tests were performed only once.

Single-Day Tests

As shown in Table 4, a total of four single-day tests were performed on A-2-4 soil and Pensacola Bahia sod with 10-10-10 (N-P-K) fertilizer applied. The actual rainfall intensities applied to the test bed, with corresponding applied water volumes, as well as respective volumes of collected runoff and baseflow are presented in Table 8. It is important to note that for this series, no runoff was generated during 0.1 in/hr rainfall intensity tests, however, at 0.25 in/hr rainfall intensity, the runoff collected was 53.6% of the total volume collected. While a higher intensity is more likely to produce runoff, this variation can also be attributed to the higher moisture content of the soil for the 0.25 in/hr rainfall intensity tests as compared to the moisture content of the soil prior to the 0.1 in/hr tests rainfall intensity. The average soil moisture content is also shown in Table 8.

Table 8: Volumes of Applied Rainfall and Collected Runoff and Baseflow for A-2-4 Soil with 10-10-10 (N-P-K)

	10-10-10 (N-P-K)	
Intended intensity (in/hr)	**0.1**	**0.25**
Average actual intensity (in/hr)	0.11	0.27
Flow Volumes in Liters (L)		
Applied	196.8	454.0
Baseflow Collected	26.8	122.28
Runoff Collected	0	141.2
Soil Moisture Content	10.9%	14.5%
Runoff as Percentage of Total	0%	53.6%

The average values of total solids and alkalinity measured in all four tests are presented in Table 9, which include runoff and baseflow. The concentration of total solids in runoff at the 0.25 in/hr rainfall intensity was 219.3 mg/L, while the total solids in baseflow were found to be higher. Alkalinity was also higher in baseflow than runoff at this intensity. At 0.1 in/hr rainfall intensity the total solids in baseflow was 208 mg/L and alkalinity was 96 mg/L as $CaCO_3$. The pH was not measured during this series of tests and was adopted from Chopra (2011) that used the identical soil and sod combination. Because the high alkalinity values of these tests are comparable to the tests from Chopra (2011), the assumption was made that this soil and sod combination had similar chemical neutrality.

Table 9: Total Solids, Alkalinity, and pH for A-2-4 Soil with 10-10-10 (N-P-K)

	10-10-10 (N-P-K)	
Intensity (in/hr)	**0.1**	**0.25**
Total Solids in Runoff (mg/L)	--	187
Total Solids in Baseflow (mg/L)	208	272
Alkalinity in Runoff (mg/L as $CaCO_3$)	--	77.3
Alkalinity in Baseflow (mg/L as $CaCO_3$)	96	205
pH	6.7*	6.7*

*Indicates average value adopted from corresponding soil/sod combination in Chopra (2011) with 10-10-10 (N-P-K).

As mentioned, prior to each test 10-10-10 (N-P-K) fertilizer was applied uniformly to the sodded portion of the test bed at a rate of 0.5 lb of N/1000 ft^2. The total mass of nitrogen applied to the test bed was 27.2 grams as N, and the total phosphorus applied was also 27.2 grams as PO_4^{-3}. The collected masses of total nitrogen and phosphorus are presented in Table 10. The masses and concentrations of total nitrogen and phosphorus collected at the 0.1 in/hr rainfall intensity were almost as low as those collected during the no fertilizer trials, while the masses collected at the 0.25 in/hr rainfall intensity were higher. Runoff generated at the 0.25 in/hr rainfall intensity was a large contributor to the amount of nutrients collected from the test bed. For total nitrogen, 77.1% of the total nitrogen mass collected was from runoff, and 89% for total phosphorus. The total nitrogen and phosphorus losses are depicted graphically in Figure 19 and Figure 20, respectively.

Table 10: Total Nitrogen and Phosphorus Lost for A-2-4 Soil with 10-10-10 (N-P-K)

	10-10-10 (N-P-K)			
Intensity (in/hr)	**0.1**	**0.25**	**0.1**	**0.25**
TN Mass (g as N)			TN Concentration (mg/L)	
Baseflow	0.29	1.15	5.3	6.5
Runoff	0	3.87	--	23.6
Total	0.29	5.02		
TP Mass (g as P)			TP Concentration (mg/L)	
Baseflow	0.012	0.21	0.19	0.62
Runoff	0	1.70	--	10.9
Total	0.012	1.91		

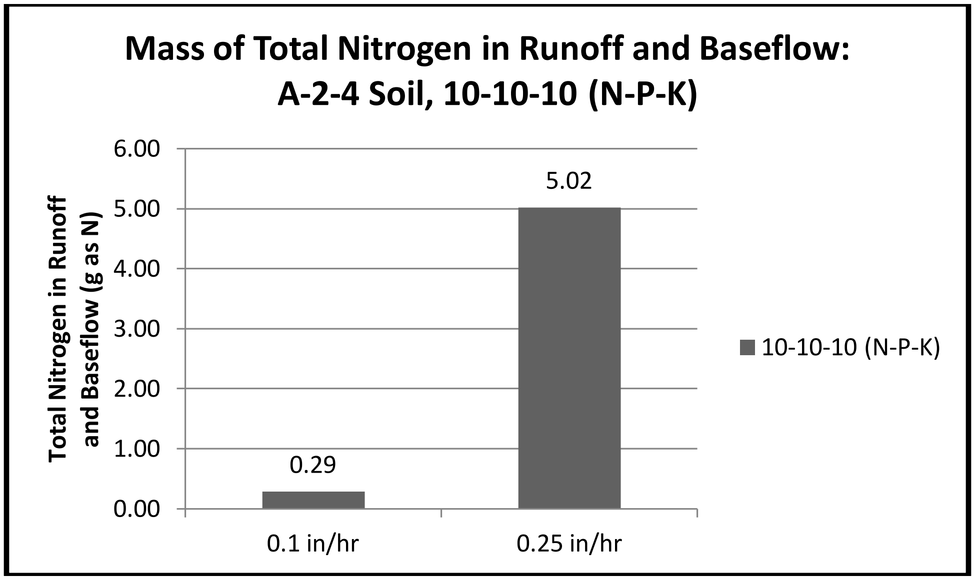


Figure 19: Mass of Total Nitrogen Collected for A-2-4 Soil with 10-10-10 (N-P-K)

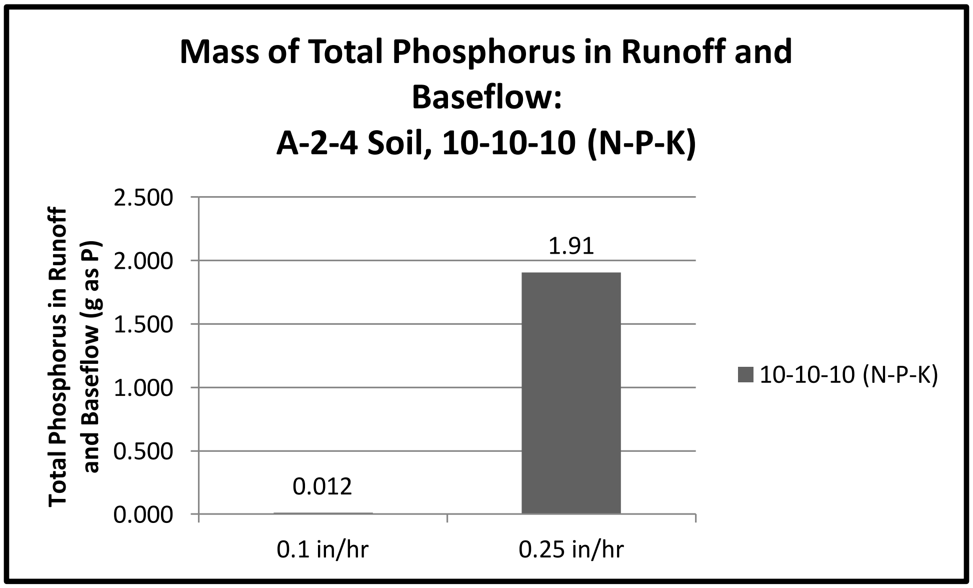


Figure 20: Mass of Total Phosphorus Collected for A-2-4 Soil with 10-10-10 (N-P-K)

Seven-Day Test

As shown in Table 4, two tests were performed for the seven-day test. The seven-day test involved the application of fertilizer on day 1 of testing, no flush afterwards, and another test performed on day 7 in order to evaluate the change occurring in the test bed over time. The seven-day test was also performed for only the 0.25 in/hr rainfall intensity. Table 11 shows the actual rainfall intensities applied to the test bed, along with corresponding applied water volumes, as well as respective volumes of collected runoff and baseflow. Runoff was only generated on day 1 of testing, which can be attributed to the higher soil moisture content at the commencement of testing. The lower moisture content on the seventh day resulted in a much lower collected baseflow volume on day 7 than on day 1. On day 1, the percentage of runoff collected was 66.8% of the total volume collected.

Table 11: Volumes of Applied Rainfall and Collected Runoff and Baseflow for A-2-4 Soil with 10-10-10 (N-P-K); Seven-day Test

	10-10-10 (N-P-K)Seven-day Test	
Intended intensity (in/hr)	**0.25**	**0.25**
Test Day	Day 1	Day 7
Average actual intensity (in/hr)	0.28	0.26
Flow Volumes in Liters (L)		
Applied	467.2	443.6
Baseflow Collected	111.7	24.9
Runoff Collected	225	0
Soil Moisture Content	13.5%	10.3%
Runoff as Percentage of Total	66.8%	0%

The average values of total solids and alkalinity measured in both tests are presented in Table 12, which include runoff and baseflow. At the 0.25 in/hr rainfall intensity, the concentration of total solids and alkalinity is higher in runoff than baseflow. Total solids and alkalinity in baseflow are higher on day 1 than on day 7. Similar to the single-day test, the pH was not measured during this series of tests and was adopted from Chopra (2011) that used the identical soil and sod combination. The assumption that this soil and sod combination had similar chemical neutrality was based on the high alkalinity values of this test.

Table 12: Total Solids, Alkalinity, and pH for A-2-4 Soil with 10-10-10 (N-P-K); Seven-day Test

	10-10-10 (N-P-K) Seven-day Test	
Intensity (in/hr)	**0.25**	**0.25**
Test Day	Day 1	Day 7
Total Solids in Runoff(mg/L)	307	--
Total Solids in Baseflow(mg/L)	201	221
Alkalinity in Runoff (mg/L as $CaCO_3$)	179	--
Alkalinity in Baseflow(mg/L as $CaCO_3$)	65	99.2
pH	6.7*	6.7*

*Indicates average value adopted from corresponding soil/sod combination in Chopra (2011) with 10-10-10 (N-P-K).

The total nitrogen applied to the test bed before testing began on day 1 was 27.2 grams as N, and the total phosphorus applied was 27.2 grams as PO_4^{-3}. Table 13 provides a summary of the total nitrogen and phosphorus collected on each day for both baseflow and runoff, if any was generated. On day 1 of testing, 2.51 grams more total nitrogen was collected than on day 7. Similarly, more total phosphorus was collected on day 1 than day 7. This is because the vast majority of nutrients lost were through runoff. Taking into account only the baseflow, however, there was 0.48 g more total nitrogen and 0.11 grams more total phosphorus collected on day 1 of testing than on day 7. This can be attributed to not only the role of runoff in washing nutrients off the test bed on the first day, but the subsequent adsorption of nutrients in the test bed, sod utilization, and the remaining physicochemical transformations that occurred in the test bed between days 1 and 7. The difference between day 1 and day 7 total nitrogen and phosphorus losses are depicted in Figure 21 and Figure 22, respectively.

Table 13: Total Nitrogen and Phosphorus Lost for A-2-4 Soil with 10-10-10 (N-P-K); Seven-day Test

	10-10-10 (N-P-K) Seven-day Test			
Intensity (in/hr)	**0.25**	**0.25**	**0.25**	**0.25**
Test Day	**Day 1**	**Day 7**	**Day 1**	**Day 7**
TN Mass (g as N)			TN Concentration (mg/L)	
Baseflow	0.66	0.18	6.2	7.3
Runoff	2.04	0	9.1	--
Total	2.69	0.18		
TP Mass (g as P)			TP Concentration (mg/L)	
Baseflow	0.11	0.0006	0.63	0.03
Runoff	1.19	0	5.3	--
Total	1.30	0.0006		

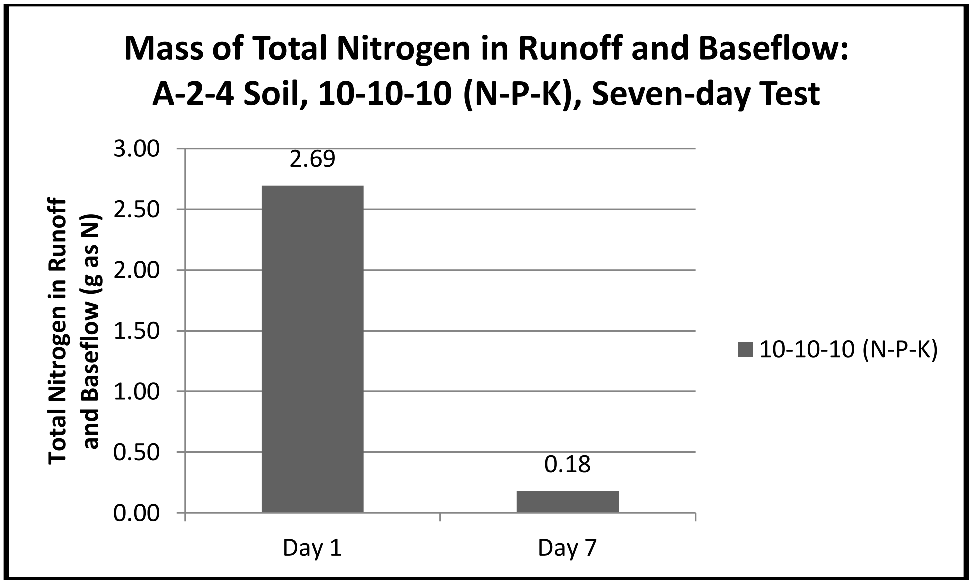


Figure 21: Mass of Total Nitrogen Collected for A-2-4 Soil with 10-10-10 (N-P-K); Seven-day Test

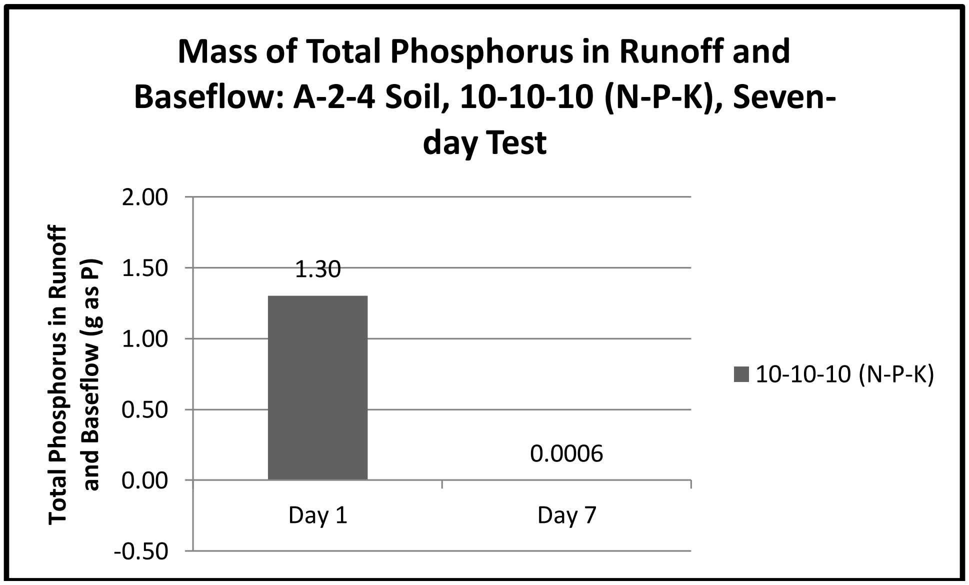


Figure 22: Mass of Total Phosphorus Collected for A-2-4 Soil with 10-10-10 (N-P-K); Seven-day Test

16-0-8 (N-P-K)Fertilizer

Following the 10-10-10 (N-P-K) fertilizer series, the soil and sod were removed from the test bed and replaced with fresh soil and new sod. Based on the assumption that the soil and sod starting conditions would be identical to those of the previous testing series, no fertilizer tests were run prior to the 16-0-8 (N-P-K) trials. This was discussed in more detail in the No Application of Fertilizer section of this study. As such, 16-0-8 (N-P-K) fertilizer was applied to the sodded area of the test bed prior to each test at a rate of 0.5 lb N/1000 ft^2. As mentioned earlier, in addition to the single-day tests, each fertilizer type underwent a seven-day test on each soil and sod combination. Two replicate single-day tests and a seven-day test were performed with both rainfall intensities. Although the single-day tests were replicated, seven-day tests were performed only once.

Single-Day Tests

As shown in Table 4, four single-day tests were performed with 16-0-8 (N-P-K) fertilizer applied. The actual rainfall intensities applied to the test bed, with the corresponding applied water volumes, and the respective volumes of collected runoff and baseflow are presented in Table 14. For this series of tests, no runoff was generated at the 0.1 in/hr rainfall intensity. The runoff collected at the 0.25 in/hr rainfall intensity was 39.2% of the total volume collected during the tests at that intensity.

Table 14: Volumes of Applied Rainfall and Collected Runoff and Baseflow for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K)

	16-0-8 (SR) (N-P-K)	
Intended intensity (in/hr)	**0.1**	**0.25**
Average actual intensity (in/hr)	0.125	0.26
Flow Volumes in Liters (L)		
Applied	243.1	517.5
Baseflow Collected	130.2	155.1
Runoff Collected	0	99.8
Soil Moisture Content	15.1%	16.1%
Runoff as Percentage of Total	0%	39.2%

The average values of total solids and alkalinity measured in all four tests are presented in Table 15, and include runoff and baseflow. The concentration of total solids in runoff at the 0.25 in/hr rainfall intensity was 226 mg/L, while the total solids in baseflow was found to be higher. Alkalinity was also higher in baseflow than runoff at this intensity. At 0.1 in/hr rainfall intensity the total solids in baseflow was 317.3 mg/L and alkalinity was 120 mg/L as $CaCO_3$. The pH was not measured during this series of tests and was adopted from Chopra (2011) that used the identical soil and sod combination. Based on the comparable alkalinity values of these tests and tests from Chopra (2011), the assumption was made that this soil and sod combination had similar chemical neutrality.

Table 15: Total Solids, Alkalinity, and pH for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K)

	16-0-8 (SR) (N-P-K)	
Intensity (in/hr)	**0.1**	**0.25**
Total Solids in Runoff (mg/L)	--	226
Total Solids in Baseflow (mg/L)	317.3	293
Alkalinity in Runoff (mg/L as $CaCO_3$)	--	86
Alkalinity in Baseflow (mg/L as $CaCO_3$)	120	131.1
pH	7.3*	7.3*

*Indicates average value adopted from corresponding soil/sod combination in Chopra (2011) with Slow-Release 16-0-8 (N-P-K)

Prior to each test, the 16-0-8 (N-P-K) fertilizer was applied to the sodded portion of the test bed. The total nitrogen applied was 27.2 grams as N. There is no phosphorus in the 16-0-8 (N-P-K) fertilizer, thus none was applied. The collected masses and concentrations of total nitrogen and phosphorus are presented in Table 16. The total masses of nitrogen collected at 0.1 in/hr and 0.25 in/hr rainfall intensities was 2.91 mg/L and 2.93 mg/L, respectively. Phosphorus losses were low for both runoff and baseflow. This was expected for phosphorus because there was none applied. The 35.5% of the total nitrogen collected at the 0.25 in/hr rainfall intensity was from runoff. The total phosphorus collected with 16-0-8 (N-P-K) fertilizer was slightly higher than what was collected during the no fertilizer tests (Table 7 versus Table 16). This suggests that the starting soil and sod conditions may not have been identical for this test series when compared to the previous test series, which is indicative that sod tends to be fertilized during production and prior to delivery. This could also be due to physicochemical differences in testing conditions such as temperature and soil moisture content. The total nitrogen and phosphorus mass losses are depicted graphically in Figure 23 and Figure 24.

Table 16: Total Nitrogen and Phosphorus Lost for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K)

	16-0-8 (SR) (N-P-K)			
Intensity (in/hr)	**0.1**	**0.25**	**0.1**	**0.25**
TN Mass (g as N)			TN Concentration (mg/L)	
Baseflow	2.91	1.89	19.4	11.7
Runoff	0	1.04	--	10.6
Total	2.91	2.93		
TP Mass (g as P)			TP Concentration (mg/L)	
Baseflow	0.02	0.02	0.13	0.1
Runoff	0	0.06	--	0.6
Total	0.02	0.08		

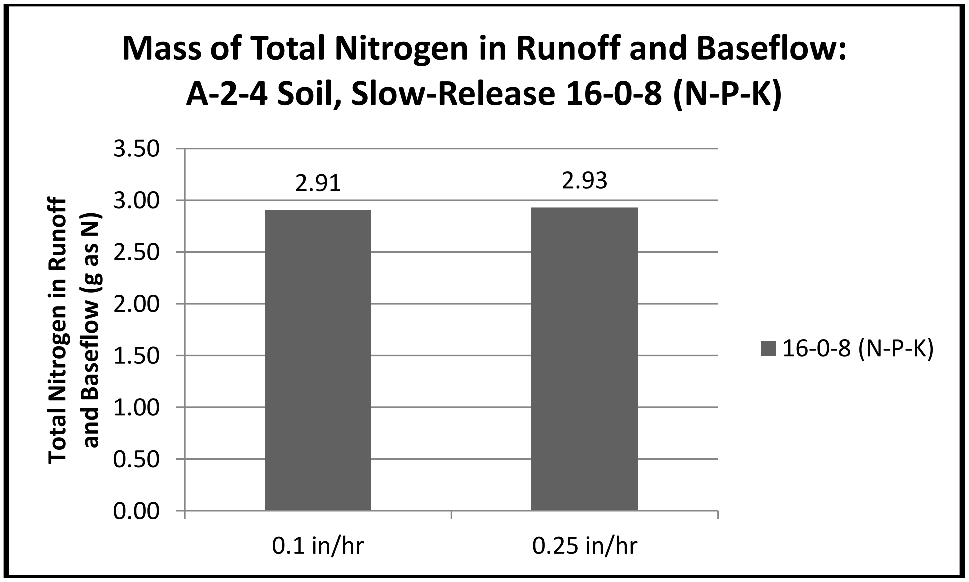


Figure 23: Mass of Total Nitrogen Collected for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K)

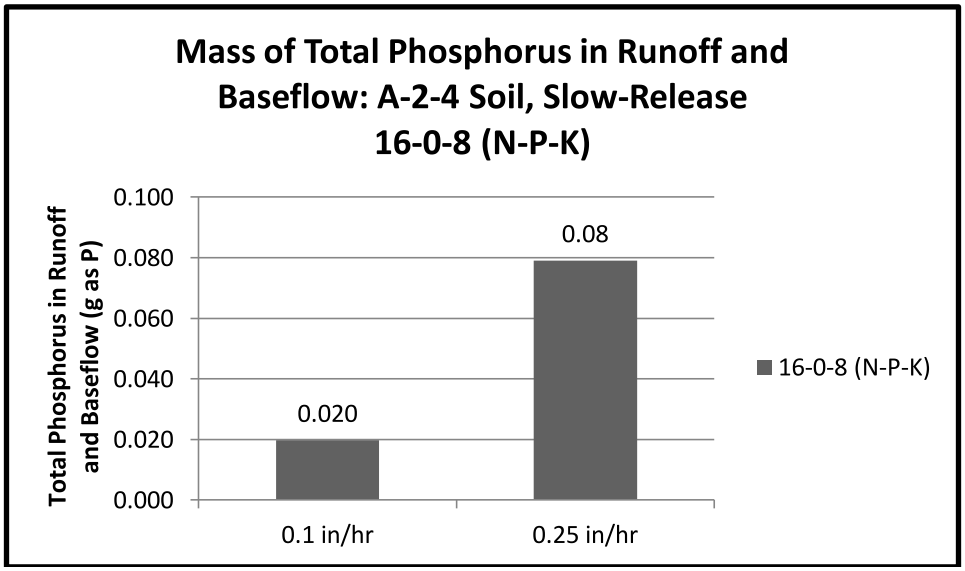


Figure 24: Mass of Total Phosphorus Collected for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K)

Seven-Day Test

As shown in Table 4, two seven-day tests were performed. The seven-day test involved the application of fertilizer on day 1 of testing, no flush afterwards, and another test performed on day 7 in order to evaluate the change occurring in the test bed over time. The seven-day test was performed only for the 0.25 in/hr rainfall intensity. Table 17 shows the actual rainfall intensities applied to the test bed, with the corresponding applied water volumes, as well as respective volumes of collected runoff and baseflow. Runoff was generated during both tests because of the soil's high moisture content at commencement of testing on both days. The moisture content, however, was slightly lower on day 7. On day 1, 66.4% of collected volume was runoff, whereas runoff comprised 28.6% of the total volume collected on day 7.

Table 17: Volumes of Applied Rainfall and Collected Runoff and Baseflow for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

	16-0-8 (SR) (N-P-K) Seven-day Test	
Intended intensity (in/hr)	**0.25**	**0.25**
Test Day	Day 1	Day 7
Average actual intensity (in/hr)	0.28	0.27
Flow Volumes in Liters (L)		
Applied	483.7	457.8
Baseflow Collected	52.1	149.5
Runoff Collected	103	60
Soil Moisture Content	14.7%	13.6%
Runoff as Percentage of Total	33.6%	28.6%

The average values of total solids, alkalinity, and pH measured in both tests are presented in Table 18 and include runoff and baseflow. Both total solids and alkalinity increased from day 1 to day 7. The pH was 7.3 on both days which shows the system was chemically neutral.

Table 18: Total Solids, Alkalinity, and pH for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

	16-0-8 (SR) (N-P-K) Seven-day Test	
Intensity (in/hr)	**0.25**	**0.25**
Test Day	Day 1	Day 7
Total Solids in Runoff (mg/L)	372	374
Total Solids in Baseflow (mg/L)	373	405
Alkalinity in Runoff (mg/L as $CaCO_3$)	64.2	122
Alkalinity in Baseflow (mg/L)	106	139
pH	7.3	7.3

As mentioned earlier, the total nitrogen applied to the test bed before testing began on day 1 was 27.2 grams as N, and no phosphorus was applied. No fertilizer was applied on day 7. Table 19 provides a summary of the total nitrogen and phosphorus masses and concentrations collected on each day for both baseflow and runoff. On day 1, 9.51 grams of total nitrogen mass was collected and 4.15 grams on day 7. There was no change in total phosphorus collected, as expected, since none was applied. On day 1, 41% of total nitrogen mass was collected in runoff, while 25.5% was collected in runoff on day 7. While runoff was a major source of nitrogen lost from the test bed, baseflow losses were even more considerable, accounting for 58.9% of losses at 0.1 in/hr rainfall intensity, and 74.5% of losses at 0.25 in/hr rainfall intensity. The reduction in nitrogen mass lost over the 7 days reflects the losses in runoff and baseflow that occurred on day 1, as well as soil adsorption and sod utilization that occurred between day 1 and 7. The difference between day 1 and day 7 total nitrogen and phosphorus mass losses are depicted in Figure 25 and Figure 26, respectively.

Table 19: Total Nitrogen and Phosphorus Lost for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

	16-0-8 (SR) (N-P-K) Seven-day Test			
Intensity (in/hr)	**0.25**	**0.25**	**0.25**	**0.25**
Test Day	**Day 1**	**Day 7**	**Day 1**	**Day 7**
TN Mass (g as N)			TN Concentration (mg/L)	
Baseflow	5.6	3.09	33.6	18.4
Runoff	3.91	1.06	37.9	17.7
Total	9.51	4.15		
TP Mass (g as P)			TP Concentration (mg/L)	
Baseflow	0.02	0.05	0.1	0.3
Runoff	0.09	0.05	0.8	0.9
Total	0.11	0.11		

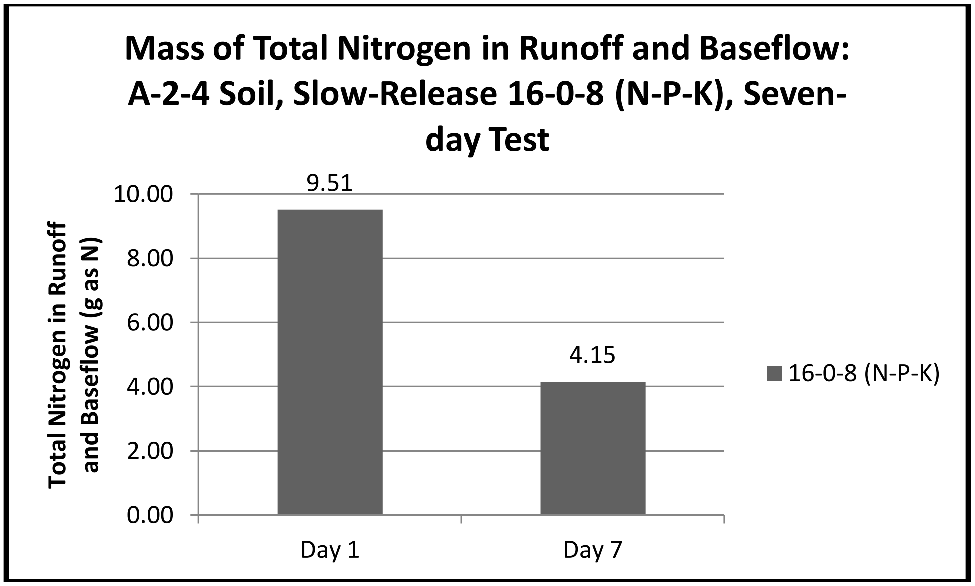


Figure 25: Mass of Total Nitrogen Collected for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

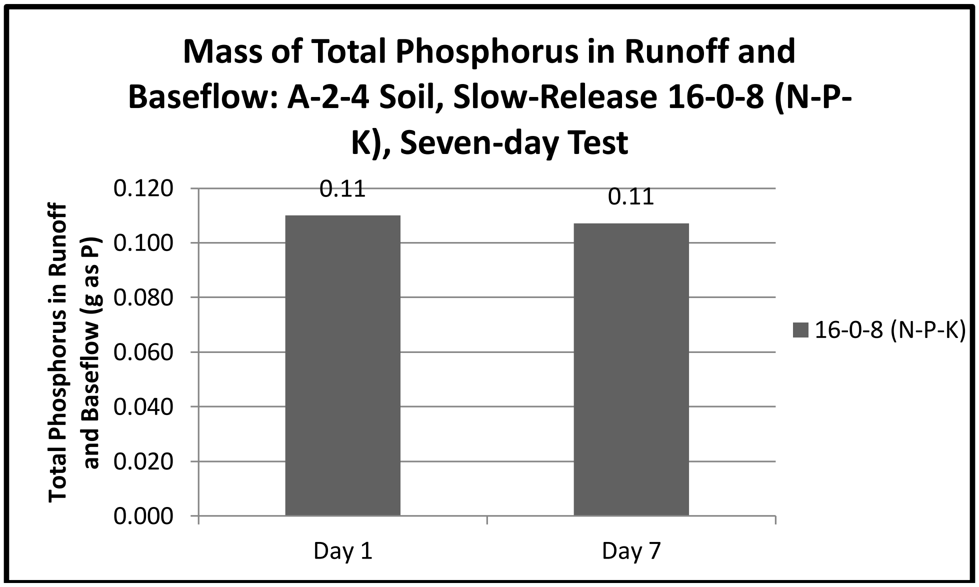


Figure 26: Mass of Total Phosphorus Collected for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

AASHTO A-2-4 Soil with Pensacola Bahia –Soil Analysis Results

Soil samples were collected before tests with no fertilizer and before and after the tests with the application of fertilizer. These were subsequently analyzed for total nitrogen, total phosphorus, and cation exchange capacity (CEC).

No Application of Fertilizer

The average total nitrogen and total phosphorus mass in the entire test bed as well as the cation exchange capacity of the A-2-4 soil prior to any fertilizer addition are presented in Table 20 for both rainfall intensities. These samples were collected before each no fertilizer test. The average value of total nitrogen was higher prior to the 0.25 in/hr rainfall intensity runs, however, the average total phosphorus was slightly lower. The average CEC of unfertilized A-2-4 soil was approximately 63 meq/100 g, which indicates that this is a high CEC soil (Typical values of high and low CEC values of soil are summarized in Table 3).

Table 20: Total Nitrogen, Total Phosphorus, and CEC for A-2-4 Soil with No Fertilizer

	No Fertilizer	
Intensity (in/hr)	**0.1**	**0.25**
Total Nitrogen (g as N)	216.7	305.5
Total Phosphorus (g as P)	328.4	277.3
CEC (meq/g)	0.63	0.64

10-10-10 (N-P-K) Fertilizer

The average total nitrogen and total phosphorus mass in the entire test bed as well as the cation exchange capacity of the A-2-4 soil during the 10-10-10 (N-P-K) fertilizer series are presented in Table 21 for both rainfall intensities. These samples were taken before each test (before fertilizer was applied) and after each test (after fertilizer and rainfall were applied). It is important to note that the 0.25 in/hr rainfall intensity trials were performed prior to the 0.1 in/hr rainfall intensity trials. The increasing value of total nitrogen and phosphorus in the soil from the 0.25 rainfall intensity in/hr series to the 0.1 in/hr rainfall intensity series shows that there was a gradual build-up of nutrients in the test bed despite ardent flush events. In addition, the cation exchange capacity of the soil decreased once the 0.1 in/hr rainfall intensity series began, indicating that the exchange capacity had been utilized by nutrients that were added to the test bed.

Table 21: Total Nitrogen, Total Phosphorus, and CEC for A-2-4 Soil with 10-10-10 (N-P-K)

	10-10-10 (N-P-K)	
Intensity (in/hr)	**0.1**	**0.25**
Total Nitrogen Before Test(g as N)	1333	821
Total Nitrogen After Test (g as N)	1337	1847
Total Phosphorus Before Test (g as P)	1131	575
Total Phosphorus After Test (g as P)	950	758
CEC Before Test(meq/g)	0.38	0.61
CEC After Test(meq/g)	0.43	0.66

16-0-8 (N-P-K) Fertilizer

The average total nitrogen and total phosphorus mass in the entire test bed as well as the cation exchange capacity of the A-2-4 soil during the slow-release 16-0-8 (N-P-K) fertilizer series are presented in Table 22 for both rainfall intensities. These samples were taken before each test (before fertilizer was applied) and after each test (after fertilizer and rainfall were applied). It is important to note that the 0.25 in/hr rainfall intensity trials were performed prior to the 0.1 rainfall intensity in/hr trials. Similar to the 10-10-10 (N-P-K) fertilizer series, the increasing value of total nitrogen and phosphorus in the soil from the 0.25 in/hr rainfall intensity series to the 0.1 in/hr rainfall intensity series shows that there was a gradual build-up of nutrients in the test bed despite ardent flush events. In addition, the cation exchange capacity of the soil decreased once the 0.1 in/hr rainfall intensity series began, indicating that the exchange capacity had begun to be utilized by nutrients that were added to the test bed.

Table 22: Total Nitrogen, Total Phosphorus, and CEC for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K)

	16-0-8 (SR) (N-P-K)	
Intensity (in/hr)	**0.1**	**0.25**
Total Nitrogen Before Test(g as N)	2168	1046
Total Nitrogen After Test (g as N)	486	491
Total Phosphorus Before Test (g as P)	792	568
Total Phosphorus After Test (g as P)	552	509
CEC Before Test(meq/g)	0.49	0.52
CEC After Test(meq/g)	0.43	0.50

Cation Exchange Capacity of A-2-4 Soil over Time

The cation exchange of A-2-4 soil with no fertilizer and 10-10-10 (N-P-K) fertilizer is presented chronologically in Figure 27. While the CEC does not show any changes with the no application of fertilizer, there appears to be a slight increase in the beginning of testing with the 10-10-10 (N-P-K) fertilizer followed by decrease after four tests. A similar trend occurred during testing with the 16-0-8 (N-P-K) fertilizer as shown in Figure 28. As mentioned earlier, there were no tests performed without fertilizer for the batch of A-2-4 soil and Pensacola Bahia sod that was used for the slow-release 16-0-8 (N-P-K) tests. Thus, a before and after fertilization comparison could not be established for that series. The trend after the application of 16-0-8 (N-P-K) fertilizer was similar to the trend after the application of 10-10-10 (N-P-K) fertilizer in that the CEC tended to decrease over time. This could be due to exchange sites being utilized by cations introduced to the soil via fertilizer, or a decline in soil pH as a result of nitrification and the subsequent release of H^+ ions, which also decreases CEC.

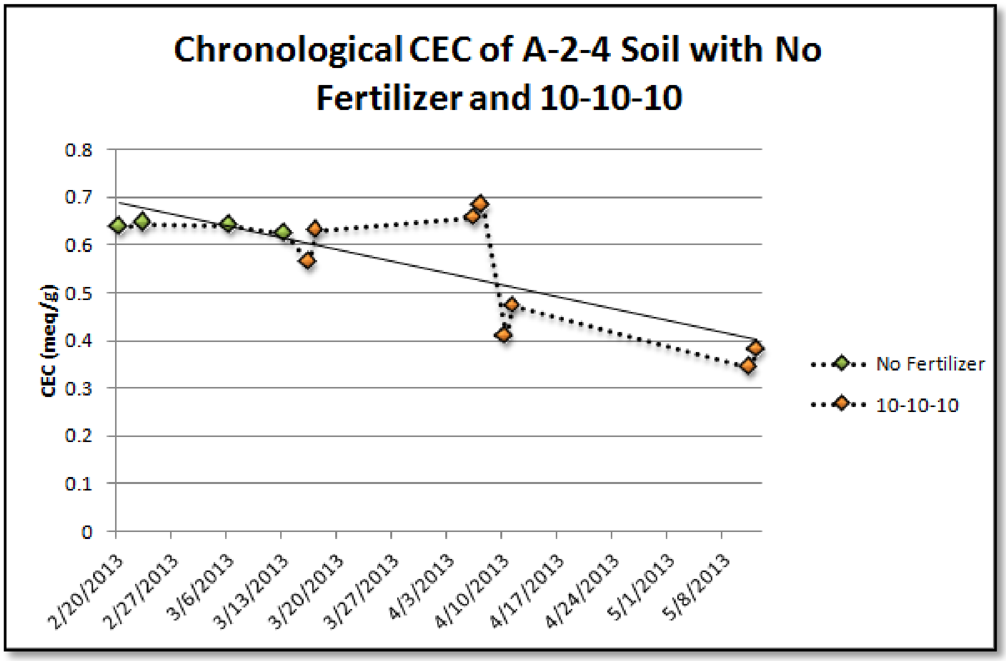


Figure 27: Chronological Sequence of CEC for A-2-4 Soil with No Fertilizer and 10-10-10 (N-P-K)

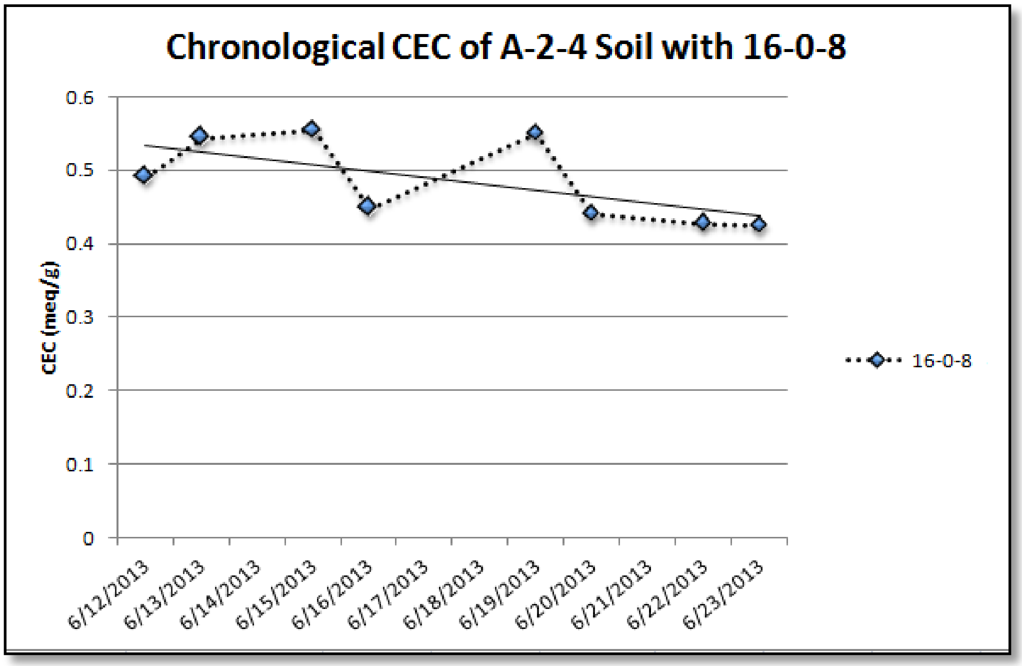


Figure 28: Chronological Sequence of CEC for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K)

Mass Balance of Nutrients on A-2-4 Soil with Pensacola Bahia

A-2-4 Soil Batch 1: No Fertilizer and 10-10-10 (N-P-K)

Table 23 shows the chronological sequence of tests performed on batch 1 of the A-2-4 soil. This batch of testing included tests with no fertilizer applied and 10-10-10 (N-P-K) fertilizer. The moisture balance, as well as the nitrogen and phosphorus mass balances is presented in Appendix D as Table 75, Table 76, and Table 77, respectively.

Table 23: Chronological Sequence of Tests on Batch 1 of A-2-4 Soil

Test #	Soil Type	Bahia Sod Type	Fertilizer Type	Rainfall Intensity (in/hr.)	Date Completed
1	A-2-4	Pensacola	None	0.25	2/20/2013
2	A-2-4	Pensacola	None	0.25	2/23/2013
3	A-2-4	Pensacola	None	0.1	2/27/2013
4	A-2-4	Pensacola	None	0.1	3/13/2013
5	A-2-4	Pensacola	10-10-10	0.25	3/16/2013
6	A-2-4	Pensacola	10-10-10	0.25*	3/27/2013
7	A-2-4	Pensacola	10-10-10	0.25*	4/3/2013
8	A-2-4	Pensacola	10-10-10	0.25	4/6/2013
9	A-2-4	Pensacola	10-10-10	0.1	4/10/2013
10	A-2-4	Pensacola	10-10-10	0.1	5/11/2013

* indicates a seven-day test

As mentioned earlier, this study utilized models developed from Chopra (2011) in order to predict nitrogen and phosphorus in the test bed during each test series. In this study, in addition to model predictions, soil samples were collected prior to the commencement of each test. The soil samples measured the values of nitrogen and phosphorus in the test bed directly. Because of this, comparisons can be made between the values predicted by the model and the measured values determined through soil analysis. Calculated total nitrogen is compared to measured values for batch 1 of the A-2-4 soil in Figure 29. Calculated total phosphorus versus measured values is subsequently presented in Figure 30. The vertical green line indicates the beginning of tests with applied fertilizer. The calculated total nitrogen mass, although slowly decreases in the soil, remains relatively stable. The calculated total phosphorus mass also remains relatively stable but increases gradually as time progresses. The measured values of both total nitrogen and phosphorus are initially similar to the calculated values; however the measured values increase as time progresses. This is likely because of a higher accumulation of these nutrients in the soil than the model predicted. A comparison between the calculated and measured total nitrogen and phosphorus was made using the Wilcoxon Rank Sum Test. Results from this analysis showed that for the calculated and measured values, for both nitrogen and phosphorus, there was not enough evidence to show they are significantly different at a 95% confidence interval. Statistical analysis results are presented in Appendix E.

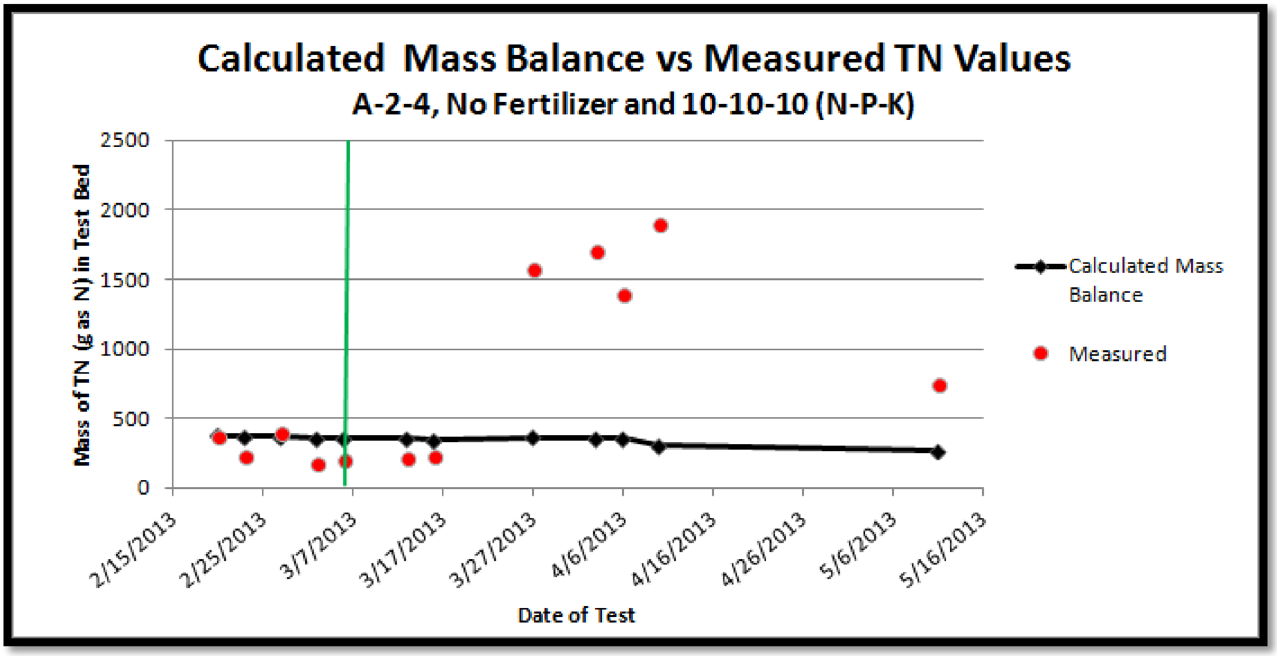


Figure 29: Model Predicted TN vs Measured Values for A-2-4 Soil with No Fertilizer and 10-10-10 (N-P-K)

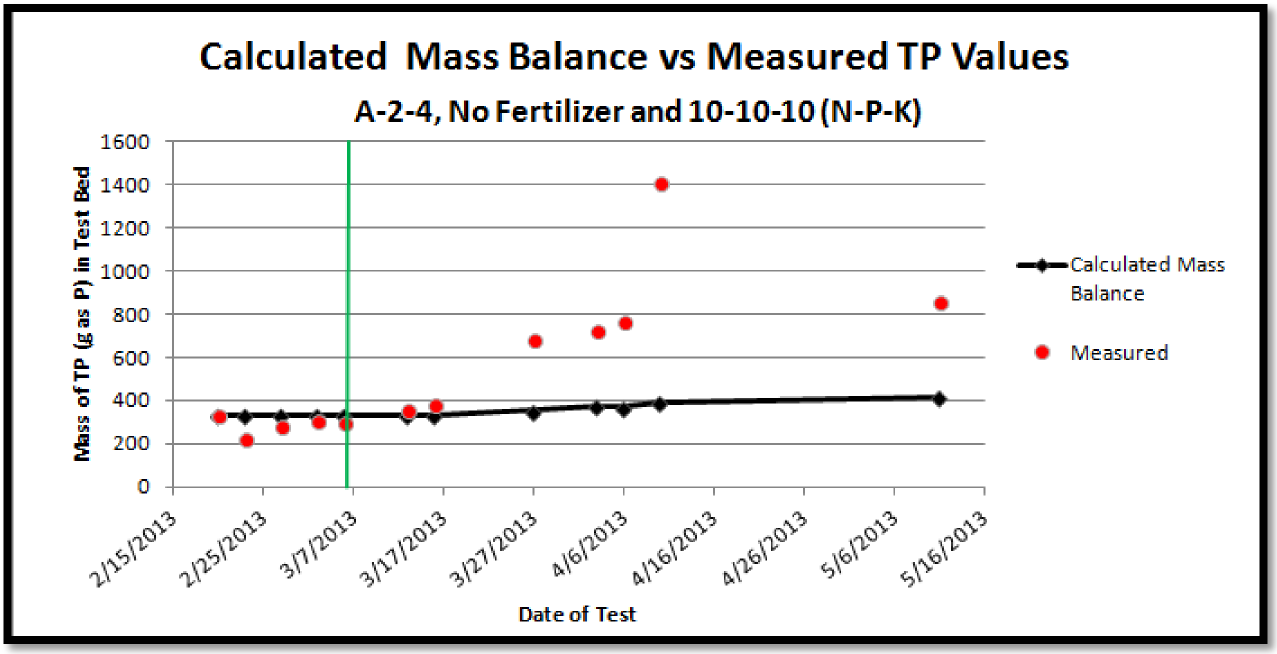


Figure 30: Model Predicted TP vs Measured Values for A-2-4 Soil with No Fertilizer and 10-10-10 (N-P-K)

<u>A-2-4 Soil Batch 2: 16-0-8 (N-P-K)</u>

The chronological sequence of tests performed on batch 2 of the A-2-4 soil is shown in Table 24. This particular test series was subjected to testing only with 16-0-8 (N-P-K) fertilizer. The moisture balance as well as the nitrogen and phosphorus mass balances is presented in Appendix D as Table 78, Table 79, and Table 80, respectively.

Table 24: Chronological Sequence of Tests on A-2-4 Batch 2

Test #	Soil Type	Bahia Sod Type	Fertilizer Type	Rainfall Intensity (in/hr.)	Date Completed
1	A-2-4	Pensacola	16-0-8	0.25	6/12/2013
2	A-2-4	Pensacola	16-0-8	0.25	6/15/2013
3	A-2-4	Pensacola	16-0-8	0.1	6/19/2013
4	A-2-4	Pensacola	16-0-8	0.1	6/22/2013
5	A-2-4	Pensacola	16-0-8	0.25*	6/26/2014
6	A-2-4	Pensacola	16-0-8	0.25*	7/3/2013

* indicates a seven-day test

The comparison of calculated mass balance values versus measured values of total nitrogen and total phosphorus in the test bed are shown in Figure 31 and Figure 32, respectively. The calculated total nitrogen shown in Figure 31 appears stable, but steadily decreases over time, whereas the calculated total phosphorus shown in Figure 32 also appeared stable but steadily increases over time. The measured total nitrogen and total phosphorus masses do not appear to follow any trends. However, based on the Wilcoxon Rank Sum Test results, there was not enough evidence to show there is a significant difference between calculated and measured values of total nitrogen and phosphorus at a 95% confidence interval. Statistical analysis results are presented in Appendix E.

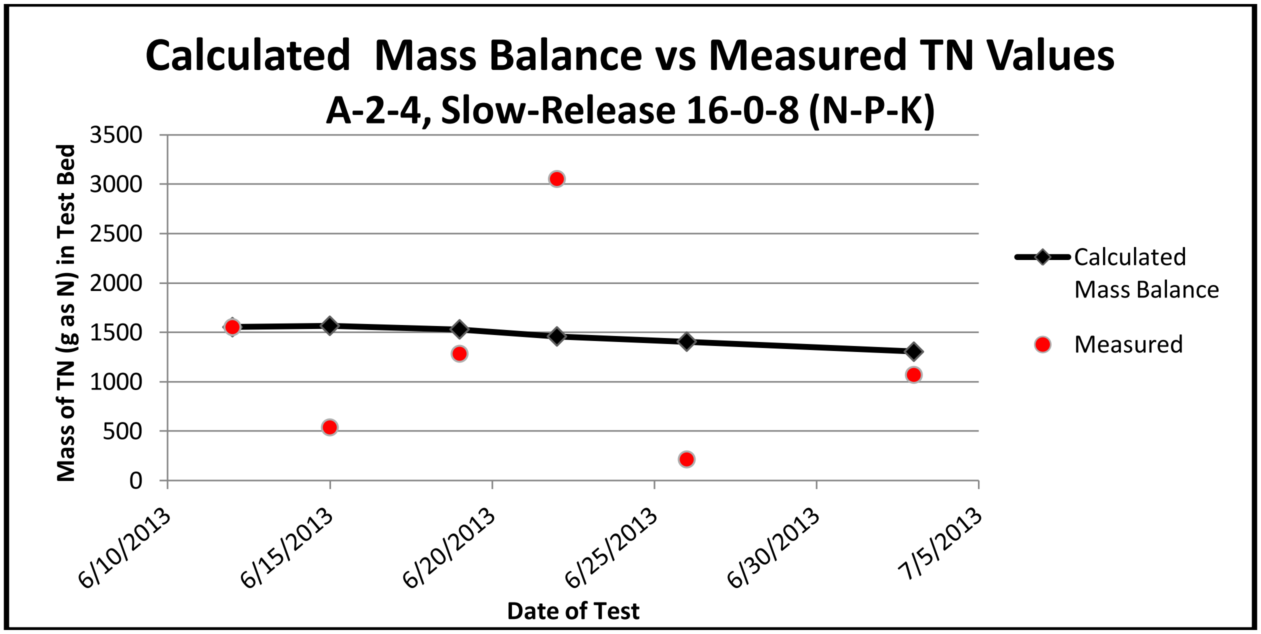


Figure 31: Model Predicted TN vs Measured Values for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K)

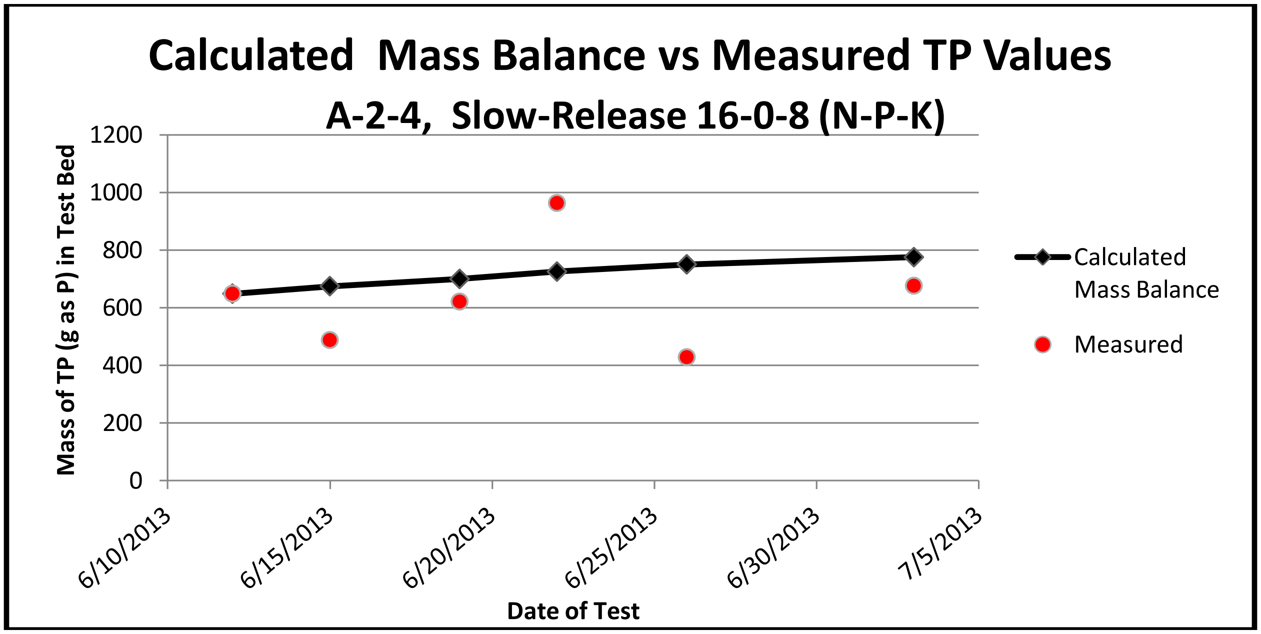


Figure 32: Model Predicted TP vs Measured Values for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K)

AASHTO A-3 Soil with Argentine Bahia –Water Quality Results

Table 4 shows the chronological sequence of tests performed on A-3 soil with Argentine Bahia. It is important to note that the A-2-4 soil test series had tests with no fertilizer prior to the 10-10-10 (N-P-K) fertilizer runs, but not the 16-0-8 (N-P-K) fertilizer runs based on the assumption that the soil and sod conditions were very similar. Further analysis of these tests showed that the assumption may not have been accurate. Because of this, for the A-3 soil with Argentine Bahia series, tests without fertilizer were run prior to application of 10-10-10 (N-P-K) fertilizer and 16-0-8 (N-P-K) fertilizer (after each soil and sod replacement).

It is also important to note that for all of the tests on A-3 soil, there was no runoff generated at either intensity. This was true regardless of soil moisture content and is attributed to a combination of the low rainfall intensities and the high infiltration capacity of A-3 soil.

No Application of Fertilizer

As shown in Table 4, eight tests, four after each soil and sod change, were performed without fertilizer application in order to establish a baseline for this soil/sod combination. These tests were performed at both rainfall intensities (0.25 in/hr and 0.1 in/hr). The purpose of establishing a baseline is to determine the level of nutrients in the soil as well as in the sod.

No Fertilizer Test Prior to 10-10-10 (N-P-K) Application

The actual rainfall intensities applied to the test bed, with the corresponding applied water volumes, and the respective volume of collected baseflow are presented in Table 25. As mentioned earlier, no runoff was generated for any tests on A-3 soil.

Table 25: Volumes of Applied Rainfall and Collected Runoff and Baseflow for A-3 Soil with No Fertilizer prior to 10-10-10 (N-P-K)

	No Fertilizer	
Intended intensity (in/hr)	**0.1**	**0.25**
Average actual intensity (in/hr)	0.115	0.22
Flow Volumes in Liters (L)		
Applied	155.9	306.8
Baseflow Collected	66.8	91.3
Soil Moisture Content	9.08%	8.65%

The average values of total solids, alkalinity, and pH measured in all four tests are presented in Table 26. As mentioned earlier, no runoff was generated for any tests on A-3 soil. Total solids ranged from 720.8 to 761.3 mg/L, and alkalinity was 328.5 and 329.5 mg/L. The pH was 7.3 for both tests, indicating that the system was chemically neutral.

Table 26: Total Solids, Alkalinity, and pH for A-3 Soil with No Fertilizer prior to 10-10-10 (N-P-K)

	No Fertilizer	
Intensity (in/hr)	**0.1**	**0.25**
Total Solids (mg/L)	720.8	761.3
Alkalinity (mg/L as $CaCO_3$)	328.5	329.5
pH	7.3	7.3

The purpose of performing tests with no fertilizer applied is to determine the amount of nutrients that are inherent to the clean soil and fresh sod. Thus, the masses and concentrations of total nitrogen (TN) and total phosphorus (TP) lost were measured and are presented in Table 27. The total nitrogen and phosphorus losses were slightly greater at the 0.25 in/hr rainfall intensity than the 0.1 in/hr rainfall intensity. This can be attributed to the greater intensity causing more nutrients in the soil to be carried away by the baseflow. The total nitrogen and phosphorus losses are depicted in Figure 33 and Figure 34, respectively.

Table 27: Total Nitrogen and Phosphorus Lost for A-3 Soil with No Fertilizer prior to 10-10-10 (N-P-K)

	No Fertilizer			
Intensity (in/hr)	**0.1**	**0.25**	**0.1**	**0.25**
TN Mass (g as N)			TN Concentration (mg/L)	
Total	1.09	1.93	18.1	20.2
TP Mass (g as P)			TP Concentration (mg/L)	
Total	0.005	0.008	0.08	0.09

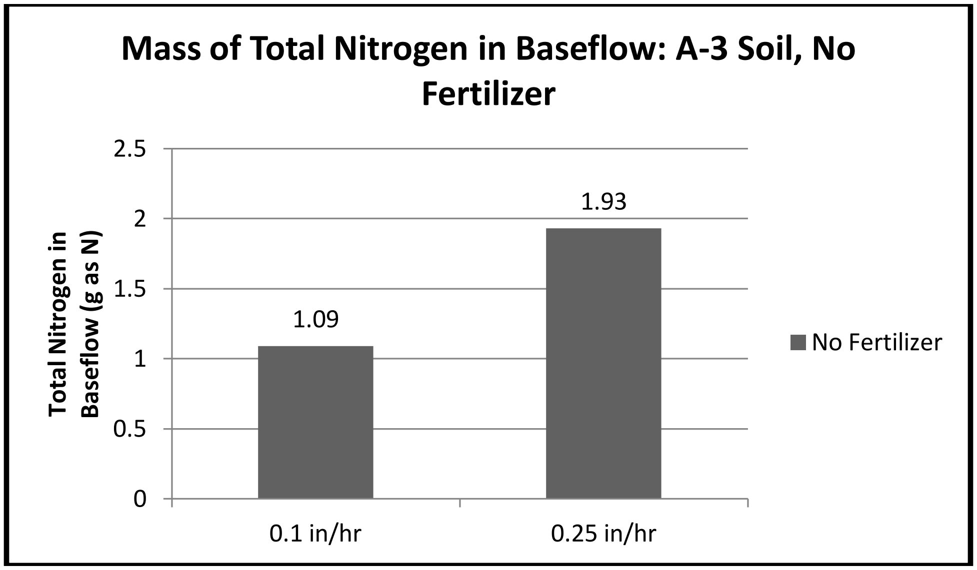


Figure 33: Mass of Total Nitrogen Collected for A-3 Soil with No Fertilizer prior to 10-10-10 (N-P-K)

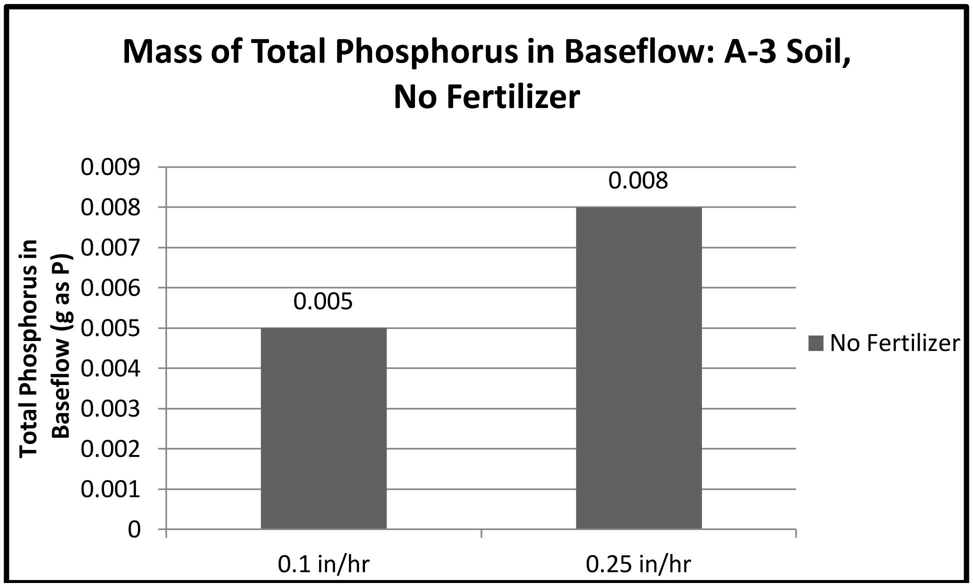


Figure 34: Mass of Total Phosphorus Collected for A-3 Soil with No Fertilizer prior to 10-10-10 (N-P-K)

No Fertilizer Prior to 16-0-8 (N-P-K) Application

The actual rainfall intensities applied to the test bed, with the corresponding applied water volumes, and the volume of collected baseflow are presented in Table 28. As mentioned earlier, no runoff was generated for any tests on A-3 soil.

Table 28: Volumes of Applied Rainfall and Collected Runoff and Baseflow for A-3 Soil with No Fertilizer prior to Slow-Release 16-0-8 (N-P-K)

	No Fertilizer	
Intended intensity (in/hr)	**0.1**	**0.25**
Average actual intensity (in/hr)	0.13	0.27
Flow Volumes in Liters (L)		
Applied	218.3	455.4
Baseflow Collected	49.4	22.6
Soil Moisture Content	10.4%	8.75%

The average values of total solids, alkalinity, and pH measured in all four tests are presented in Table 29. Total solids ranged from 316.5 to 399.5 mg/L, and alkalinity was 220 and 242 mg/L as $CaCO_3$. The pH was 7.5 and 7.7 for 0.1 in/hr and 0.25 in/hr indicating that for these tests, the soil and sod system was chemically neutral.

Table 29: Total Solids, Alkalinity, and pH for A-3 Soil with No Fertilizer prior to Slow-Release 16-0-8 (N-P-K)

	No Fertilizer	
Intensity (in/hr)	**0.1**	**0.25**
Total Solids (mg/L)	316.5	399.5
Alkalinity (mg/L)	220	242
pH	7.5	7.7

The masses and concentrations of total nitrogen (TN) and total phosphorus (TP) lost were measured and are presented in Table 30. For this series, the total nitrogen and total phosphorus masses were higher at the 0.25 in/hr rainfall intensity than the 0.1 in/hr rainfall intensity. Figure 35 and Figure 36 show graphically the difference in collected total nitrogen and phosphorus, respectively, at 0.1 in/hr and 0.25 in/hr rainfall intensities.

Table 30: Total Nitrogen and Phosphorus Lost for A-3 Soil with No Fertilizer prior to Slow-Release 16-0-8 (N-P-K)

	No Fertilizer			
Intensity (in/hr)	**0.1**	**0.25**	**0.1**	**0.25**
TN Mass (g as N)			TN Concentration (mg/L)	
Total	1.09	1.93	2.4	5.7
TP Mass (g as P)			TP Concentration (mg/L)	
Total	0.005	0.008	0.04	0.05

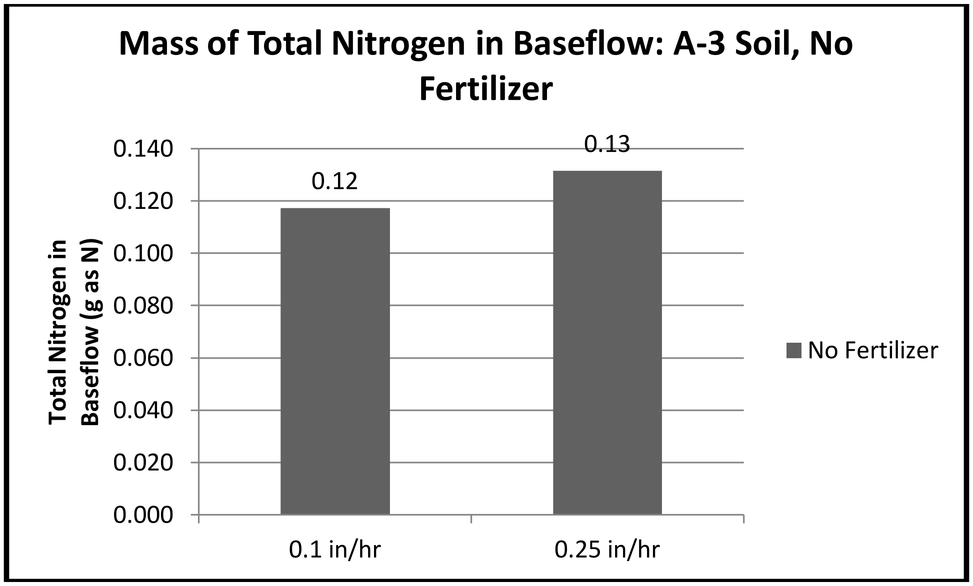


Figure 35: Mass of Total Nitrogen Collected. A-3, No Fertilizer prior to Slow-Release 16-0-8 (N-P-K)

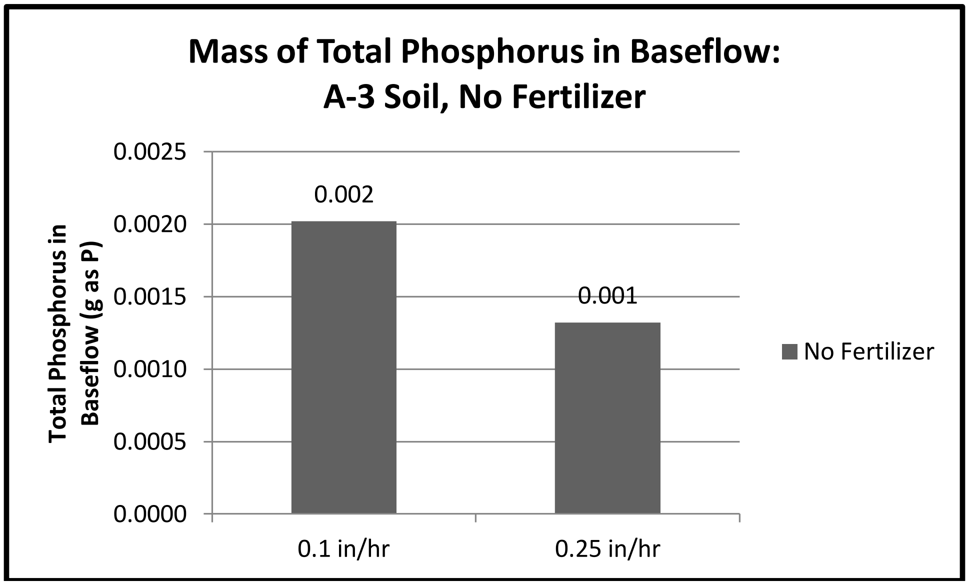


Figure 36: Mass of Total Phosphorus Collected. A-3, No Fertilizer prior to Slow-Release 16-0-8 (N-P-K)

10-10-10 (N-P-K) Fertilizer

Single-Day Tests

As shown in Table 4, a total of four single-day tests were performed on A-3 soil with Argentine Bahia sod and 10-10-10 (N-P-K) fertilizer applied. The actual rainfall intensities applied to the test bed, with the corresponding applied water volumes, and the volume of collected baseflow are presented in Table 31.

Table 31: Volumes of Applied Rainfall and Collected Baseflow for A-3 Soil with 10-10-10 (N-P-K)

	10-10-10 (N-P-K)	
Intended intensity (in/hr)	**0.1**	**0.25**
Average actual intensity (in/hr)	0.125	0.26
Flow Volumes in Liters (L)		
Applied	206.5	296.1
Baseflow Collected	86.4	115.11
Soil Moisture Content	8.98%	9.54%

The average values of total solids, alkalinity, and pH measured in all four tests are presented in Table 32. Total solids ranged from 502 to 563 mg/L, and alkalinity ranged from 262 to 285 mg/L as $CaCO_3$. The pH was near neutral for both intensities.

Table 32: Total Solids, Alkalinity, and pH for A-3 Soil with 10-10-10 (N-P-K)

	10-10-10 (N-P-K)	
Intensity (in/hr)	**0.1**	**0.25**
Total Solids (mg/L)	502	563
Alkalinity (mg/L)	262	285
pH	7.5	7.3

Prior to each test 10-10-10 (N-P-K) fertilizer was applied uniformly to the sodded portion of the test bed at the 0.5 lb/1000 ft^2 rate. The total nitrogen applied was 27.2 grams as N, and the total phosphorus applied was also 27.2 grams as PO_4^{-3}. The collected masses of total nitrogen and phosphorus are presented in Table 33. Both the total nitrogen and total phosphorus masses collected were higher at the 0.25 in/hr rainfall intensity than the 0.1 in/hr rainfall intensity. However, when comparing these values to those of the no fertilizer tests (Table 27), the total nitrogen is lower in spite of the addition of fertilizer. This suggests that the sod tiles were already heavily fertilized prior to planting. The total nitrogen and phosphorus losses are depicted in Figure 37 and Figure 38, respectively.

Table 33: Total Nitrogen and Phosphorus Lost for A-3 Soil with 10-10-10 (N-P-K)

	10-10-10 (N-P-K)			
Intensity (in/hr)	**0.1**	**0.25**	**0.1**	**0.25**
TN Mass (g as N)			TN Concentration (mg/L)	
Total	0.29	0.71	5.4	8.5
TP Mass (g as P)			TP Concentration (mg/L)	
Total	0.005	0.02	0.1	0.17

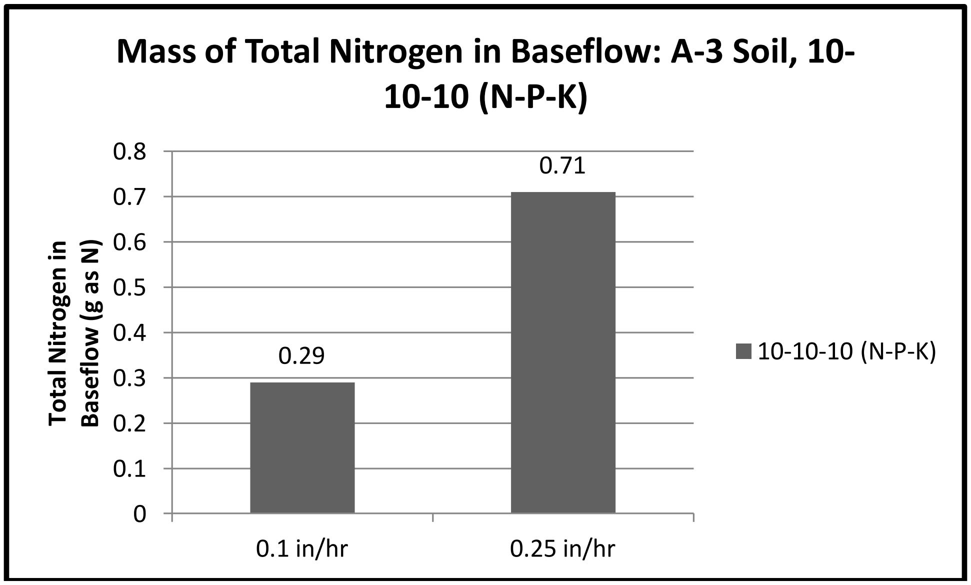


Figure 37: Mass of Total Nitrogen Collected for A-3 Soil with 10-10-10 (N-P-K)

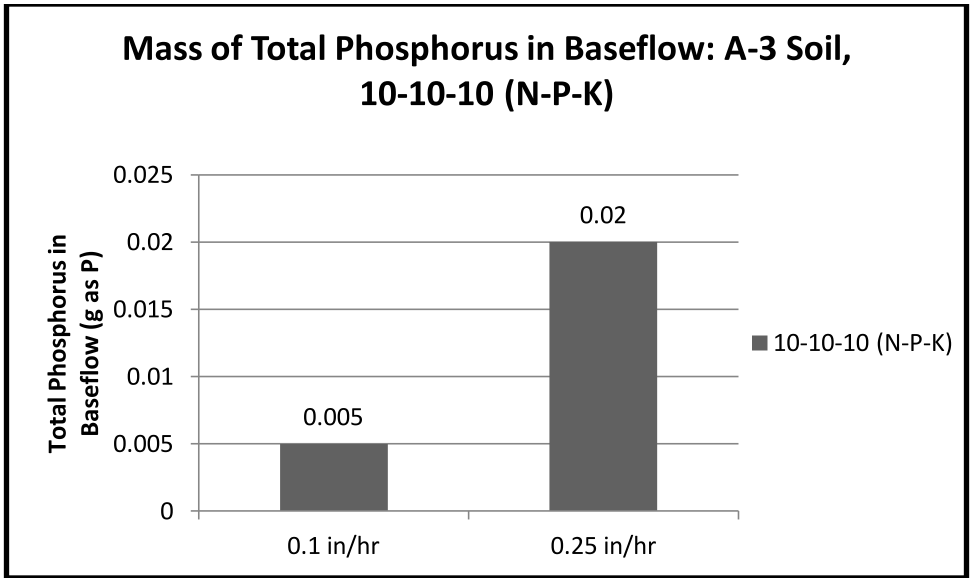


Figure 38: Mass of Total Phosphorus Collected for A-3 Soil with 10-10-10 (N-P-K)

Seven-Day Test

As shown in Table 4, two tests were performed for the seven-day test for this soil and sod combination with the 10-10-10 (N-P-K) fertilizer application. The seven-day test involved the application of fertilizer on day 1 of testing, no flush afterwards, and another rain event performed on day 7 in order to evaluate the change occurring in the test bed over time. It should be noted that the seven-day test was only performed for the 0.25 in/hr rainfall intensity. Table 34 shows the actual rainfall intensities applied to the test bed, along with corresponding applied water volumes, as well as respective volumes of collected baseflow.

Table 34: Volumes of Applied Rainfall and Collected Baseflow for A-3 Soil with 10-10-10 (N-P-K), Seven-day Test

	10-10-10 (N-P-K) Seven-day Test	
Intended intensity (in/hr)	**0.25**	**0.25**
Test Day	Day 1	Day 7
Average actual intensity (in/hr)	0.25	0.22
Flow Volumes in Liters (L)		
Applied	280.8	311.5
Baseflow Collected	82.3	81.5
Soil Moisture Content	9.68%	8.31%

The average values of total solids, alkalinity, and pH measured in both tests are presented in Table 35. Total solids ranged from 473 to 482 mg/L, and alkalinity ranged from 265 to 268 mg/L. These parameters did not vary significantly from day 1 to day 7. The pH was 7.3 on day 1 and 7.1 on day 7, which indicates the chemical neutrality of the system.

Table 35: Total Solids, Alkalinity, and pH forA-3 Soil with 10-10-10 (N-P-K), Seven-day Test

	10-10-10 (N-P-K) Seven-day Test	
Intensity (in/hr)	**0.25**	**0.25**
Test Day	Day 1	Day 7
Total Solids (mg/L)	473	482
Alkalinity (mg/L as $CaCO_3$)	268	265
pH	7.3	7.1

The total nitrogen applied to the test bed before testing began on day 1 was 27.2 grams as N, and no phosphorus was applied. Table 36 provides a summary of the total nitrogen and phosphorus masses as well as concentrations collected on each day. On day 7, 0.27 grams of total nitrogen mass were collected while on day 1, 0.24 grams were collected. Total phosphorus mass decreased from day 1 to day 7 by 0.002 grams. The difference between day 1 and day 7 total nitrogen and phosphorus losses are depicted in Figure 39 and Figure 40, respectively.

Table 36: Total Nitrogen and Phosphorus Lost for A-3 Soil with 10-10-10 (N-P-K), Seven-day Test

	10-10-10 (N-P-K) Seven-day Test			
Intensity (in/hr)	**0.25**	**0.25**	**0.25**	**0.25**
Test Day	Day 1	Day 7	Day 1	Day 7
TN Mass (g as N)			TN Concentration (mg/L)	
Total	0.24	0.27	6.2	7.3
TP Mass (g as P)			TP Concentration (mg/L)	
Total	0.005	0.003	0.07	0.06

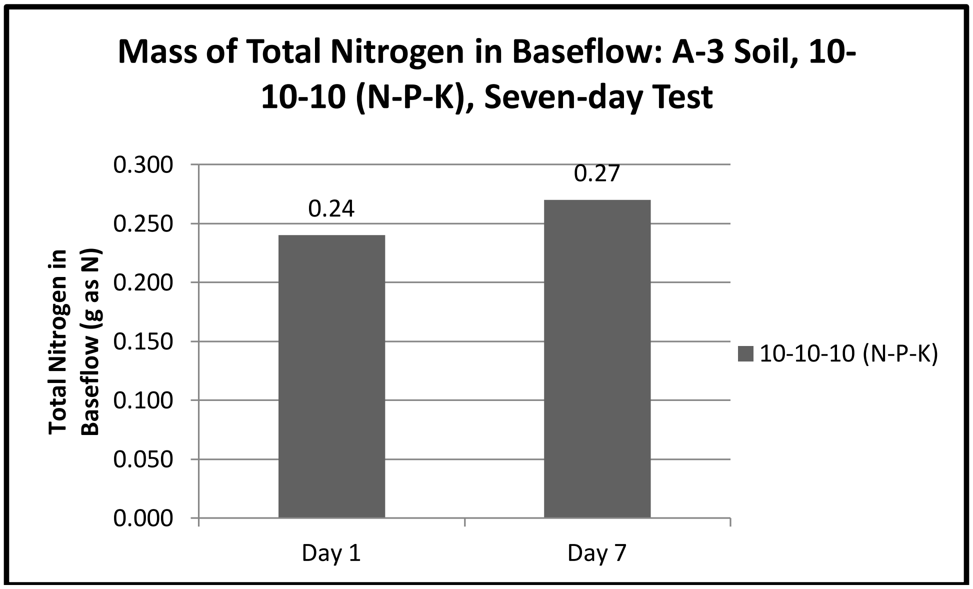


Figure 39: Mass of Total Nitrogen Collected for A-3 Soil with 10-10-10 (N-P-K), Seven-day Test

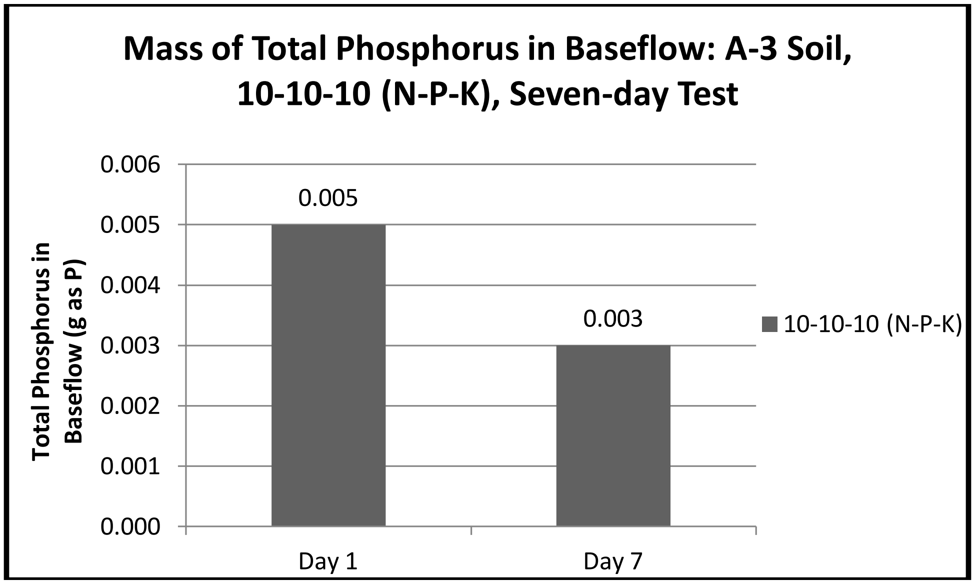


Figure 40: Mass of Total Phosphorus Collected for A-3 Soil with 10-10-10 (N-P-K), Seven-day Test

<u>16-0-8 (N-P-K) Fertilizer</u>

Following the 10-10-10 (N-P-K) fertilizer series, the soil and sod were removed from the test bed and replaced with fresh soil and new sod. Contrary to the A-2-4 soil and Pensacola Bahia test series, tests with no fertilizer were performed prior to the addition of 16-0-8 (N-P-K) fertilizer in order to establish a baseline for this soil/sod combination. Once tests with no fertilizer were completed, 16-0-8 (N-P-K) fertilizer was applied to the sodded area of the test bed prior to each test at a rate of 0.5 lb N/1000 ft^2. As mentioned earlier, in addition to the single-day tests, each fertilizer type was subjected to a seven-day test on each soil and sod combination. In addition to two replicate single-day tests, seven-day tests were performed on both rainfall intensities. Although the single-day tests were replicated, seven-day tests were performed only once.

Single-Day Tests

As shown in Table 4, a total of four single-day tests were performed with 16-0-8 (N-P-K) fertilizer applied. The actual rainfall intensities applied to the test bed, along with corresponding applied water volumes, and the volume of collected baseflow are presented in Table 37.

Table 37: Volumes of Applied Rainfall and Collected Baseflow for A-3 Soil with Slow-Release 16-0-8 (N-P-K)

	16-0-8 (SR) (N-P-K)
Intended intensity (in/hr)	**0.25**
Average actual intensity (in/hr)	0.27
Flow Volumes in Liters (L)	
Applied	385.8
Baseflow Collected	66.8
Soil Moisture Content	8.77%

The average values of total solids, alkalinity, and pH measured in all four tests are presented in Table 38. The concentration of total solids was 271 mg/L, while the alkalinity was 179 mg/L as CaCO3. The pH was 7.4 which is indicative of the chemical neutrality of the soil and sod system.

Table 38: Total Solids, Alkalinity, and pH for A-3 Soil with Slow-Release 16-0-8 (N-P-K)

	16-0-8 (SR) (N-P-K)
Intensity (in/hr)	**0.25**
Total Solids (mg/L)	271
Alkalinity (mg/L)	179
pH	7.4

The total nitrogen applied was 27.2 grams as N. Because there is no phosphorus in the slow-release 16-0-8 (N-P-K) fertilizer, none was applied. The collected masses and concentrations of total nitrogen and total phosphorus are presented in Table 39.

Table 39: Total Nitrogen and Phosphorus Lost for A-3 Soil with Slow-Release 16-0-8 (N-P-K)

	16-0-8 (SR) (N-P-K)	
Intensity (in/hr)	**0.25**	**0.25**
	TN Mass (g as N)	TN Concentration (mg/L)
Total	0.23	4.10
	TP Mass (g as P)	TP Concentration (mg/L)
Total	0.004	0.070

Seven-Day Test

As shown in Table 4, two tests were performed for the seven-day test. The seven-day test involved the application of fertilizer on day 1 of testing, no flush afterwards, and another test performed on day 7 in order to evaluate the change occurring in the test bed over time. It should be noted that the seven-day test was only performed for the 0.25 in/hr rainfall intensity. Table 40 shows the actual rainfall intensities applied to the test bed, along with corresponding applied water volumes, as well as respective volumes of collected baseflow.

Table 40: Volumes of Rainfall Applied, Runoff and Baseflow for A-3 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

	16-0-8 (SR) (N-P-K) Seven-day Test	
Intended intensity (in/hr)	**0.25**	**0.25**
Test Day	Day 1	Day 7
Average actual intensity (in/hr)	0.26	0.27
Flow Volumes in Liters (L)		
Applied	361.0	379.9
Baseflow Collected	86.8	55.1
Soil Moisture Content	13.5%	8.96%

The average values of total solids, alkalinity, and pH measured in both tests are presented in Table 41. Total solids were not measured on day 1, but were subsequently measured on day 7.

Alkalinity ranged from 164 to 182 mg/L as $CaCO_3$. The pH was 7.4 on day 1 and 7.3 on day 7 indicating that the soil and sod system was chemically neutral.

Table 41: Total Solids, Alkalinity, and pH for A-3 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

	16-0-8 (SR) (N-P-K)Seven-day Test	
Intensity (in/hr)	**0.25**	**0.25**
Test Day	Day 1	Day 7
Total Solids (mg/L)	--	268
Alkalinity (mg/L as $CaCO_3$)	182	164
pH	7.4	7.3

The total nitrogen applied to the test bed before testing began on day 1 was 27.2 grams as N, and no phosphorus was applied. Table 42 provides a summary of the total nitrogen and phosphorus masses and concentrations collected on each day. On day 1, 0.80 grams of total nitrogen mass were collected, and on day 7, 0.19 grams were collected. Total phosphorus mass did not change between day 1 and day 7. The reduction in nitrogen lost over the 7 days reflects the losses in baseflow that occurred on day 1, soil adsorption, sod utilization between day 1 and 7, etc. The difference between day 1 and day 7 total nitrogen losses are shown graphically in Figure 41.

Table 42: Total Nitrogen and Phosphorus Lost. For A-3 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

	16-0-8 (SR) (N-P-K) Seven-day Test			
Intensity (in/hr)	**0.25**	**0.25**	**0.25**	**0.25**
Test Day	Day 1	Day 7	Day 1	Day 7
TN Mass (g as N)			TN Concentration (mg/L)	
Total	0.80	0.19	7.1	3.5
TP Mass (g as P)			TP Concentration (mg/L)	
Total	0.003	0.003	0.04	0.06

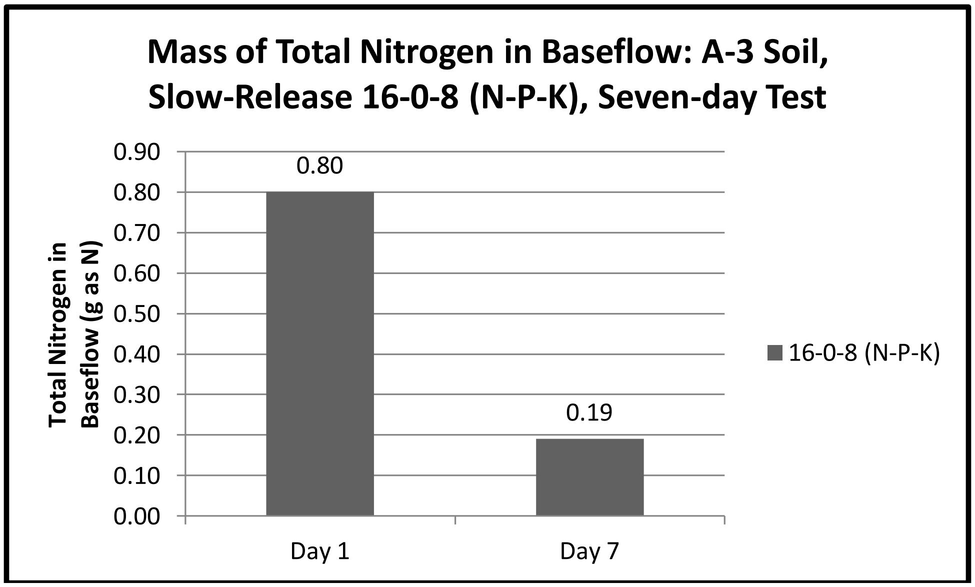


Figure 41: Mass of Total Nitrogen Collected for A-3 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

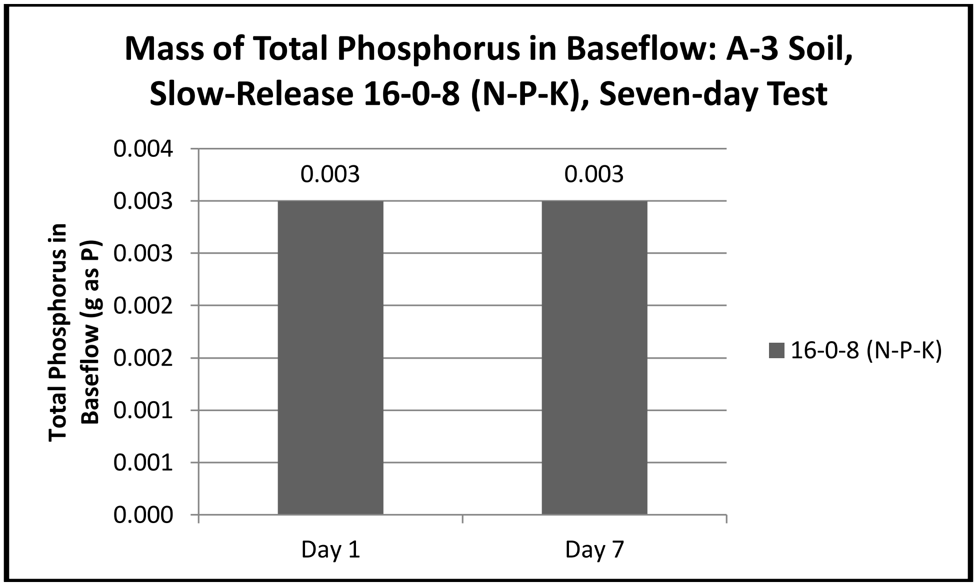


Figure 42: Mass of Total Phosphorus Collected for A-3 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

AASHTO A-3 Soil with Pensacola Bahia –Soil Analysis Results

In addition to effluent from the test bed, soil samples were collected before tests that had no fertilizer and before and after tests that had fertilizer applied. These were subsequently analyzed for total nitrogen, total phosphorus, and cation exchange capacity (CEC).

No Application of Fertilizer

Prior to 10-10-10 (N-P-K)

The average total nitrogen and total phosphorus mass in the entire test bed as well as the cation exchange capacity (CEC) of the A-3 soil prior to the addition of the 10-10-10 (N-P-K) fertilizer are presented in Table 43 for both rainfall intensities. These samples were collected before each no fertilizer test. The values of total nitrogen and total phosphorus for this soil and sod batch are higher than the values of these parameters for the A-2-4 soil tests with no fertilizer (Table 20). This suggests that this batch of A-3 soil and/or Argentine Bahia sod could have been already heavily loaded with nutrients. Furthermore, the average CEC of unfertilized A-3 soil prior to the application of the 10-10-10 (N-P-K) fertilizer was approximately 12 meq/100 g, which indicates that this is a high CEC soil (typical values of high and low CEC values of soil are summarized in Table 3).

Table 43: Total Nitrogen, Total Phosphorus, and CEC for A-3 Soil with No Fertilizer prior to 10-10-10 (N-P-K)

	No Fertilizer Prior to 10-10-10 (N-P-K)	
Intensity (in/hr)	**0.1**	**0.25**
Total Nitrogen (g)	6637	6650
Total Phosphorus (g)	2474	2279
CEC (meq/g)	0.121	0.121

<u>Prior to 16-0-8 (N-P-K)</u>

The average total nitrogen and total phosphorus mass in the entire test bed as well as the cation exchange capacity (CEC) of the A-3 soil prior to the addition of 16-0-8 (N-P-K) fertilizer are presented in Table 44 for both rainfall intensities. The values of total nitrogen and total phosphorus indicate that this batch of A-3 soil and/or Argentine Bahia sod was already heavily loaded with nutrients, at least a magnitude more than the batch of the A-2-4 soil with Pensacola Bahia and similarly to the batch of A-3 soil prior to 10-10-10 (N-P-K) fertilizer application. Furthermore, the chronological order of these tests was such that the 0.25 in/hr rainfall intensity tests were performed first, and the 0.1 in/hr rainfall intensity tests last. As such, it can be assumed that nutrients began to leach from the test bed before any fertilizer was even applied. The cation exchange capacity, 6.5 meq/ 100 g and 7.6 meq/100 g for 0.25 in/hr intensity and 0.1 in/hr intensity, respectively, is not considered high (typical values of high and low CEC values of soil are summarized in Table 3).

Table 44: Total Nitrogen, Total Phosphorus, and CEC for A-3 Soil with No Fertilizer prior to Slow-Release 16-0-8 (N-P-K)

	No Fertilizer Prior to 16-0-8 (SR) (N-P-K)	
Intensity (in/hr)	**0.1**	**0.25**
Total Nitrogen (g as N)	7668	9162
Total Phosphorus (g as P)	511	611
CEC (meq/g)	0.065	0.076

10-10-10 (N-P-K) Fertilizer

The average total nitrogen and total phosphorus mass in the entire test bed as well as the cation exchange capacity (CEC) of the A-3 soil during the 10-10-10 (N-P-K) fertilizer series are presented in Table 45 for both rainfall intensities. These samples were taken before each test (before fertilizer was applied) and after each test (after fertilizer and rainfall were applied). The values of total nitrogen are lower at both intensities after the addition of 10-10-10 (N-P-K) fertilizer compared to the values with no fertilizer added (Table 43). This may be due to the sod tiles being heavily loaded with nutrients. The decreasing value of total nitrogen indicates that the nutrients inherent to the sod tiles began to wash out after several rainfall events. In addition, the chronological sequence of these tests is such that the 0.25 in/hr rainfall intensity tests were performed prior to the 0.1 in/hr rainfall intensity tests. The increased level of nutrients at the 0.1 in/hr rainfall intensity compared to the 0.25 in/hr rainfall intensity shows that nutrients began to build-up in the test bed. This is likely due to the occurrence of tests at the 0.25 in/hr rainfall intensity before ones at the 0.1 in/hr rainfall intensity causing nutrients from fertilizer to build-up in the soil, as well as the reduced washing out potential at the lower rainfall intensity rainfall of 0.1 in/hr.

Table 45: Total Nitrogen, Total Phosphorus, and CEC for A-3 Soil with 10-10-10 (N-P-K)

	10-10-10 (N-P-K)	
Intensity (in/hr)	**0.1**	**0.25**
Total Nitrogen Before Test (g)	4857	5896
Total Nitrogen After Test (g)	6276	4388
Total Phosphorus Before Test (g)	2223	1935
Total Phosphorus After Test (g)	1909	1791
CEC Before Test(meq/g)	0.10	0.11
CEC After Test(meq/g)	0.11	0.11

16-0-8 (N-P-K) Fertilizer

The average total nitrogen and total phosphorus mass in the entire test bed as well as the cation exchange capacity (CEC) of A-3 soil during the 16-0-8 (N-P-K) fertilizer series are presented in Table 46 for both rainfall intensities. The values of total nitrogen and total phosphorus slightly decrease after tests indicating that washing out of nutrients may have occurred during a rainfall event. The cation exchange capacity (CEC) is lower than the no fertilizer tests, indicating that there may be a decline in exchangeable cations. A decrease in exchangeable cations occurs from the addition of cations in fertilizer applied to the soil.

Table 46: Total Nitrogen, Total Phosphorus, and CEC for A-3 Soil with Slow-Release 16-0-8 (N-P-K)

	16-0-8 (SR) (N-P-K)
Intensity (in/hr)	**0.25**
Total Nitrogen Before Test (g)	9966
Total Nitrogen After Test (g)	8013
Total Phosphorus Before Test (g)	799
Total Phosphorus After Test (g)	690
CEC Before Test(meq/g)	0.05
CEC After Test(meq/g)	0.05

Cation Exchange Capacity (CEC) of A-3 Soil over Time

The cation exchange capacity (CEC) of the A-3 soil with no fertilizer and 10-10-10 (N-P-K) fertilizer is presented chronologically in Figure 43. While the CEC does not show any changes with the no application of fertilizer, there is an increase in the beginning of testing with 10-10-10 (N-P-K) fertilizer, followed by a drop after a couple of tests and another increase. In general, however, there is a decreasing trend. A similar trend occurred during testing with slow-release 16-0-8 (N-P-K) fertilizer as shown in Figure 44. Similarly to the behavior in the A-2-4 soil, the decline could be due to exchange sites being utilized by cations introduced to the soil via fertilizer, or a decline in soil pH as a result of nitrification and the subsequent release of H^+ ions, which also decreases CEC.

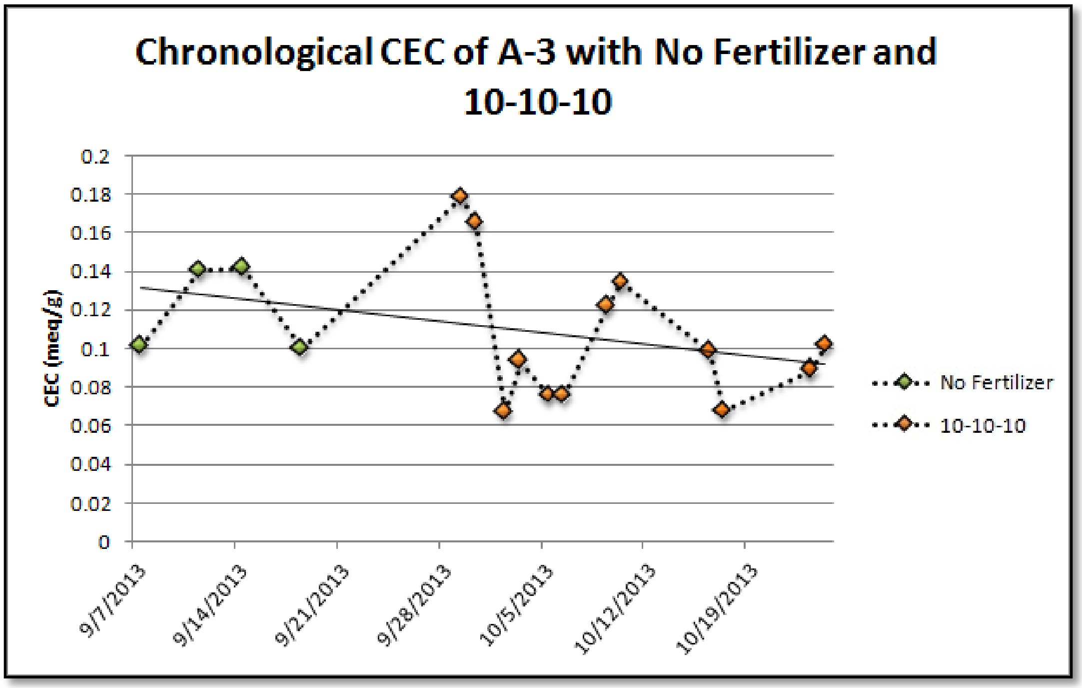


Figure 43: Chronological Sequence of CEC of A-3 Soil with No Fertilizer and 10-10-10 (N-P-K)

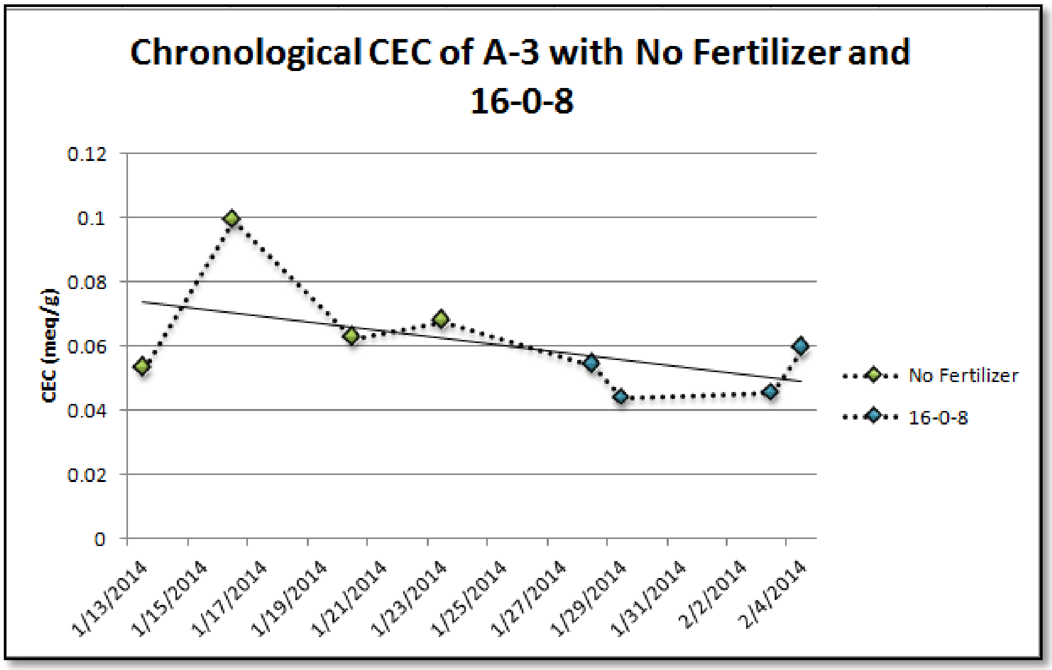


Figure 44: Chronological Sequence of CEC of A-3 Soil with No Fertilizer and Slow-Release 16-0-8 (N-P-K)

Mass Balance of Nutrients on A-3 Soil with Argentine Bahia

A-3 Soil Batch 1: No Fertilizer and 10-10-10 (N-P-K)

Table 47 shows the chronological sequence of tests performed on batch 1 of the A-3 soil. This batch underwent tests with no fertilizer and 10-10-10 (N-P-K) fertilizer. The moisture balance as well as the nitrogen and phosphorus mass balances are presented in Appendix D as Table 81, Table 82, and Table 83, respectively.

Table 47: Chronological Sequence of Tests on A-3 Batch 1

Test #	Soil Type	Bahia Sod Type	Fertilizer Type	Rainfall Intensity (in/hr.)	Date Completed
1	A-3	Argentine	None	0.25	9/7/2013
2	A-3	Argentine	None	0.25	9/11/2013
3	A-3	Argentine	None	0.1	9/14/2013
4	A-3	Argentine	None	0.1	9/18/2013
5	A-3	Argentine	10-10-10	0.25	9/29/2013
6	A-3	Argentine	10-10-10	0.25	10/2/2013
7	A-3	Argentine	10-10-10	0.1	10/5/2013
8	A-3	Argentine	10-10-10	0.1	10/9/2013
9	A-3	Argentine	10-10-10	0.25*	10/16/2013
10	A-3	Argentine	10-10-10	0.25*	10/23/2013

* indicates a seven-day test

Calculated mass balance total nitrogen and total phosphorus values are compared to measured values for batch 1 of the A-3 soil in Figure 45 and Figure 46, respectively. The vertical green line indicates the beginning of tests with applied fertilizer. The measured values of both total nitrogen and total phosphorus follow a similar trend to the calculated values; however the measured values are more variable. Calculated total nitrogen values show that TN mass is gradually released from the soil but remains stable, while calculated total phosphorus values show some accumulation in the soil, but remain stable as well. The trend of measured total phosphorus shows more variability than calculated values, with a slight decrease in the soil over time after fertilizer application. This is contrary to the measured values of total phosphorus in the A-2-4 soil which showed accumulation over time. This could be due to a decreased capacity of A-3 soil to retain phosphorus as compared to A-2-4 soil. Comparison between the calculated and measured total nitrogen and phosphorus was made using the Wilcoxon Rank Sum Test. Results from this analysis showed that there was not enough evidence to show that the calculated and measured values, for both nitrogen and phosphorus, were significantly different at a 95% confidence interval. Statistical analysis results are presented in Appendix E.

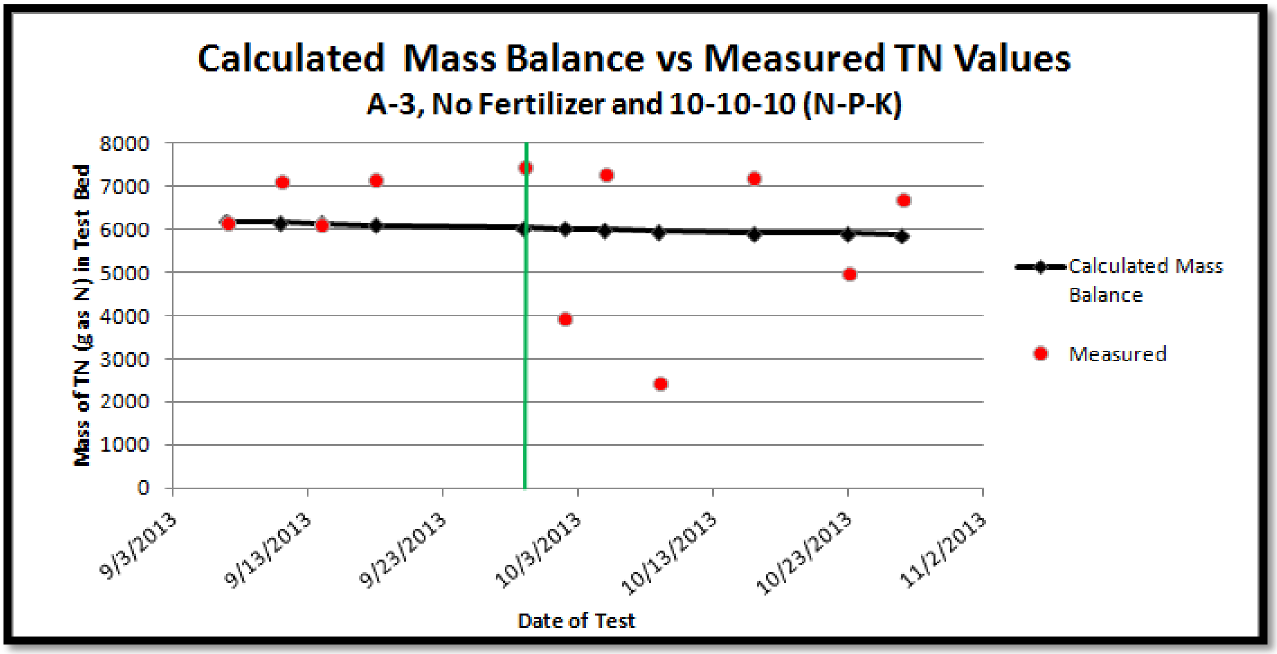


Figure 45: Model Predicted TN vs Measured Values for A-3 Soil with No Fertilizer and 10-10-10 (N-P-K)

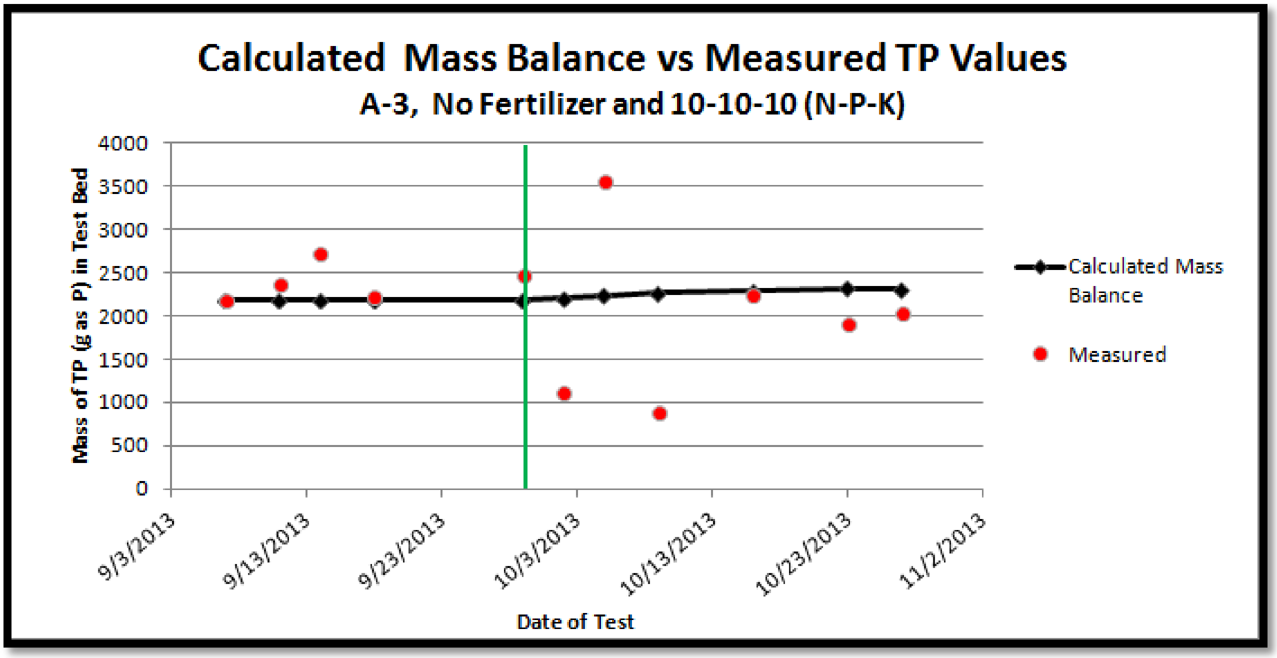


Figure 46: Model Predicted TP vs Measured Values for A-3 Soil with No Fertilizer and 10-10-10 (N-P-K)

A-3 Soil Batch 2: No Fertilizer and Slow-Release 16-0-8 (N-P-K)

Table 48 shows the chronological sequence of tests performed on batch 2 of the A-3 soil. This batch underwent tests with no fertilizer and slow-release 16-0-8 (N-P-K) fertilizer. The moisture balance as well as the nitrogen and phosphorus mass balances is presented in Appendix D as Table 84, Table 85, and Table 86, respectively.

Table 48: Chronological Sequence of Tests on A-3 soil, Batch 2

Test #	Soil Type	Bahia Sod Type	Fertilizer Type	Rainfall Intensity (in/hr.)	Date Completed
1	A-3	Argentine	None	0.25	1/13/2014
2	A-3	Argentine	None	0.25	1/16/2014
3	A-3	Argentine	None	0.1	1/20/2014
4	A-3	Argentine	None	0.1	1/23/2014
5	A-3	Argentine	16-0-8	0.25	1/28/2014
6	A-3	Argentine	16-0-8	0.25	2/3/2014
7	A-3	Argentine	16-0-8	0.25*	2/13/2014
8	A-3	Argentine	16-0-8	0.25*	2/20/2014

* indicates a seven-day test

Mass balance calculated total nitrogen and total phosphorus values are compared to measured values for batch 2 of the A-3 soil in Figure 47 and Figure 48, respectively. The vertical green line indicates the beginning of tests with applied fertilizer. Calculated total nitrogen values show that TN mass remains stable, while calculated total phosphorus values show increasing accumulation in the soil after the trials with fertilizer began, but were stable prior to these. The measured values of total nitrogen follow a similar trend to the calculated values prior to the application of fertilizer. After the application of fertilizer, however, the measured values are higher than the calculated values, which indicates that there was more accumulation of nitrogen in the soil than the model predicted. The measured values of total phosphorus appear to follow the calculated values more closely than the total nitrogen comparisons. Similarly to total nitrogen, however, the calculated and measured values of total phosphorus follow a comparable trend prior to any fertilizer addition and show slightly higher accumulation afterward when compared to the calculated values. Comparison between the calculated and measured total nitrogen and phosphorus was made using the Wilcoxon Rank Sum Test. Based on these results there was not enough evidence to show there is a significant difference between calculated and measured values of total nitrogen and phosphorus at a 95% confidence interval. Statistical analysis results are presented in Appendix E.

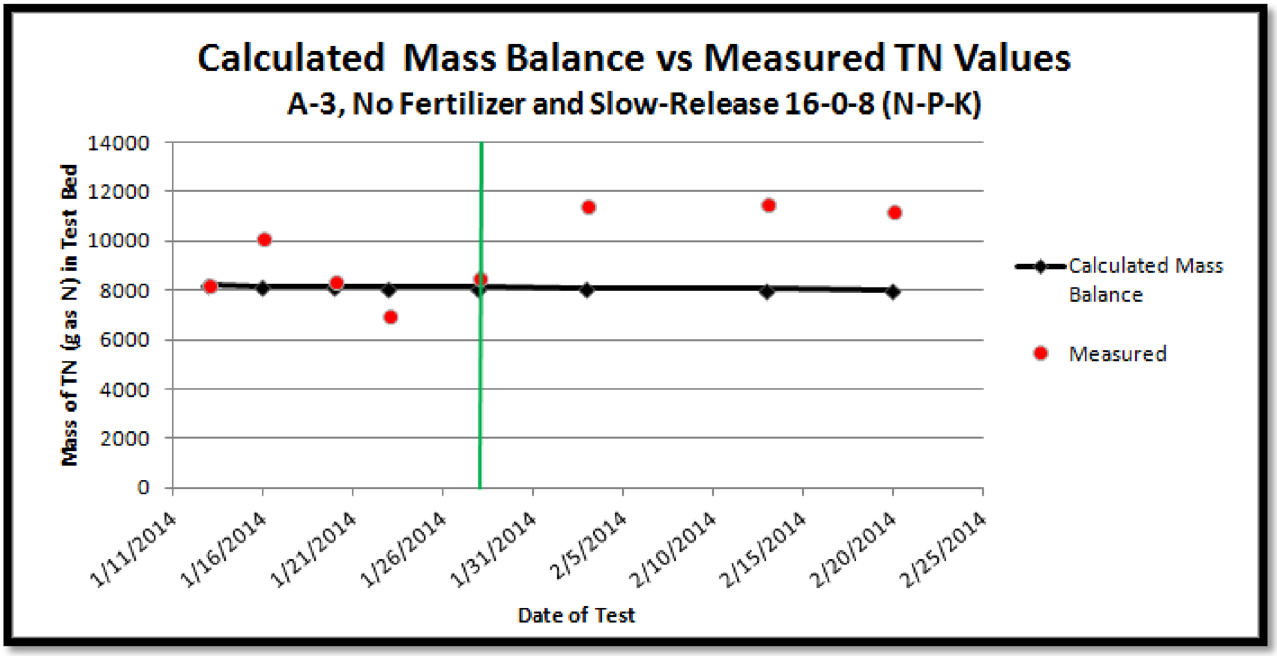


Figure 47: Model Predicted TN vs Measured Values for A-3 Soil with No Fertilizer and Slow-Realease 16-0-8 (N-P-K)

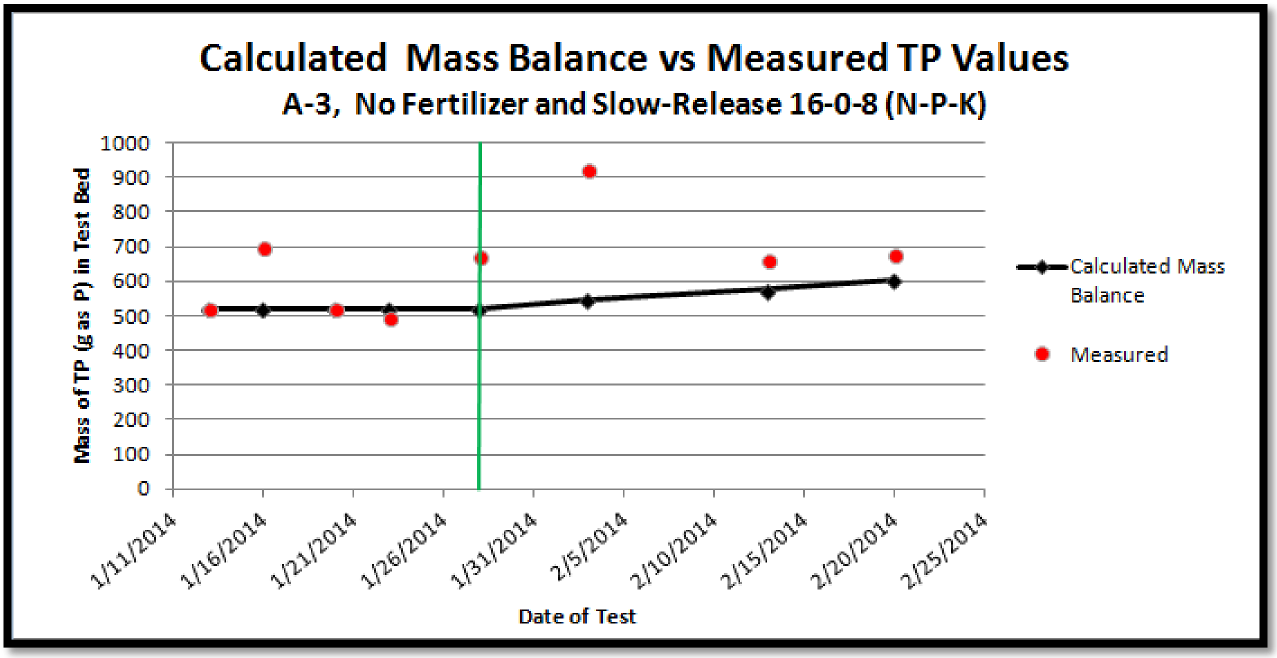


Figure 48: Model Predicted TP vs Measured Values for A-3 Soil with No Fertilizer and Slow-Release 16-0-8 (N-P-K)

<u>Comparison of Single-Day Tests with Seven-Day Tests</u>

<u>A-2-4 Soil with Pensacola Bahia Sod</u>

Table 49 shows the comparison of the 10-10-10 (N-P-K) fertilizer total nitrogen and total phosphorus losses from a single-day test to the seven-day test at the 0.25 in/hr rainfall intensity from the A-2-4 soil with Pensacola Bahia sod combination. The total nitrogen and total phosphorus lost was greatest for the single-day test. Overall, 2.15 more grams of total nitrogen and 0.61 more grams of total phosphorus were lost for the single-day test than the seven-day test. A major source of this discrepancy is the lack of runoff occurring on day 7 of the seven-day test. This resulted in overall lower nutrient losses for the seven-day test when compared to the single-day test. The likely cause of the discrepancy was variation in soil temperature and soil moisture content resulting in differences in the amount volume collected from the test bed.

Table 49: Comparison of Single-Day Test with Seven-Day Test for A-2-4 Soil with 10-10-10 (N-P-K)

	10-10-10 (N-P-K)		
Intensity (in/hr)	**0.25**	**0.25**	**0.25**
Test Type	**Single Day**	**Seven-day, Day 1**	**Seven-day, Day 7**
TN Mass (g as N)			
Baseflow	1.15	0.66	0.18
Runoff	3.87	2.04	0
Total	5.02	2.69	0.18
TP Mass (g as P)			
Baseflow	0.21	0.11	0.0006
Runoff	1.70	1.19	0
Total	1.91	1.30	0.0006

Table 50 shows the total nitrogen and total phosphorus mass losses from the slow-release 16-0-8 (N-P-K) fertilizer from a single-day test and the seven-day test at the 0.25 in/hr rainfall intensity. Total nitrogen losses were lower for the single-day test than day 1 and day 7 of the seven-day test. Overall, 10.73 more grams of total nitrogen and 0.14 more grams of total phosphorus were lost for the seven-day test than the single-day test. This discrepancy is likely because of unintended accumulation of nutrients in the soil, since the seven-day test was performed after several single-day tests. The results from the seven-day test show that nitrogen continues to leave the system a week after the initial application of fertilizer. Although overall more total phosphorus was lost from the seven-day test than the single-day test, these losses were low which is expected as 16-0-8 (N-P-K) fertilizer does not contain any phosphorus.

Table 50: Comparison of Single-Day Test with Seven-Day Test for A-2-4 Soil with Slow-Release 16-0-8 (N-P-K)

	16-0-8 (SR) (N-P-K)		
Intensity (in/hr)	**0.25**	**0.25**	**0.25**
Test Type	**Single Day**	**Seven-day, Day 1**	**Seven-day, Day 7**
TN Mass (g as N)			
Baseflow	1.89	5.6	3.09
Runoff	1.04	3.91	1.06
Total	2.93	9.51	4.15
TP Mass (g as P)			
Baseflow	0.02	0.02	0.05
Runoff	0.06	0.09	0.05
Total	0.08	0.11	0.11

A-3 Soil with Argentine Bahia Sod

Table 51 shows the 10-10-10 (N-P-K) fertilizer total nitrogen and total phosphorus losses from a single-day test compared to the seven-day test at the 0.25 in/hr rainfall intensity from the A-3 soil with Argentine Bahia sod combination. As mentioned earlier, no runoff was generated from A-3 soil. Overall, 0.2 more grams of total nitrogen and 0.007 more grams of total phosphorus were lost for the single-day test than the seven-day test. All of the values of total nitrogen and total phosphorus were low. Even though chronologically speaking the seven-day tests were performed after several single-day tests were conducted, soil tests showed that total nitrogen and total phosphorus decreased over time suggesting that the sod was heavily fertilized prior to any addition of fertilizer. Thus, with the A-3 soil being at capacity from the beginning, nutrients did not accumulate in the soil over time and gradually leached resulting in lower losses for tests occurring later on, such as the seven-day test for this batch of A-3 soil.

Table 51: Comparison of Single-Day Test with Seven-Day Test for A-3 Soil with 10-10-10 (N-P-K)

	10-10-10 (N-P-K)		
Intensity (in/hr)	**0.25**	**0.25**	**0.25**
Test Type	**Single Day**	**Seven-day, Day 1**	**Seven-day, Day 7**
TN Mass (g as N)			
Baseflow	0.71	0.24	0.27
Runoff	0	0	0
Total	0.71	0.24	0.27
TP Mass (g as P)			
Baseflow	0.02	0.005	0.003
Runoff	0	0	0
Total	0.02	0.01	0.0030

Table 52 shows the 16-0-8 (N-P-K) fertilizer total nitrogen and total phosphorus losses from a single-day test compared to the seven-day test at the same rainfall intensity from the A-3 soil with Argentine Bahia sod combination. Single-day losses were lower than losses on the first day of the seven-day test, but slightly higher than losses on the seventh day. Overall, 0.76 more grams of total nitrogen and 0.002 more grams of total phosphorus were lost for the seven-day test than the single-day test. Based on the soil tests before any fertilizer addition, this batch of A-3 soil and Argentine Bahia sod was also nutrient heavy prior to addition of fertilizer, and the testing sequence was such that the seven-day tests were conducted after the single-day tests. Thus, the reasons for higher nutrient losses on day 1 of the seven-day test than the single-day test could be that contrary to the 10-10-10 (N-P-K) fertilizer, the slow-release 16-0-8 (N-P-K) fertilizer could have accumulated in the soil and gradually released nutrients into the soil resulting in higher losses after a period of time.

Table 52: Comparison of Single-Day Test with Seven-Day Test for A-3 Soil with Slow-Release 16-0-8 (N-P-K)

	16-0-8 (SR) (N-P-K)		
Intensity (in/hr)	**0.25**	**0.25**	**0.25**
Test Type	**Single Day**	**Seven-day, Day 1**	**Seven-day, Day 7**
TN Mass (g as N)			
Baseflow	0.23	0.80	0.19
Runoff	0	0	0
Total	0.23	0.80	0.19
TP Mass (g as P)			
Baseflow	0.004	0.003	0.003
Runoff	0	0	0
Total	0.004	0.003	0.003

Comparison of 10-10-10 (N-P-K) and Slow-Release 16-0-8 (N-P-K) Fertilizers

A-2-4 Soil with Pensacola Bahia

Both the 10-10-10 (N-P-K) fertilizer and 16-0-8 (N-P-K) fertilizer were applied at a rate of 0.5 lb N/1000 ft^2. As shown in Figure 49, more nitrogen was lost from the test bed using the 16-0-8 (N-P-K) fertilizer than the 10-10-10 (N-P-K) fertilizer at the 0.1 in/hr rainfall intensity. At the 0.25 in/hr rainfall intensity, however, there was less nitrogen lost from the test bed with the 16-0-8 (N-P-K) fertilizer than the 10-10-10 (N-P-K) fertilizer. Total phosphorus losses from the 16-0-8 (N-P-K) fertilizer trial were lower than losses from 10-10-10 (N-P-K) fertilizer at the 0.25 in/hr intensity. At the 0.1 in/hr rainfall intensity, however, total phosphorus losses (Figure 51) were slightly higher from the 16-0-8 (N-P-K) fertilizer than 10-10-10 (N-P-K) fertilizer, even though there was no phosphorus added to the soil during the 16-0-8 (N-P-K) fertilizer trials. The difference could also be attributed to factors such as percentage of runoff collected to total water collected, as runoff can be, and frequently was, a major source of nutrient loss. The concentrations of TN and TP in runoff and baseflow are shown in Figure 50 and Figure 52, respectively. Based on these graphs it is evident that the highest concentration of total nitrogen, over 20 mg/L as N was found in runoff for 10-10-10 (N-P-K) fertilizer. Total phosphorus concentration was also highest in runoff for 10-10-10 (N-P-K) fertilizer, and was over 10 mg/L as P. The remaining total phosphorus concentrations were low, indicating that phosphorus has a higher tendency to be lost in runoff than baseflow.

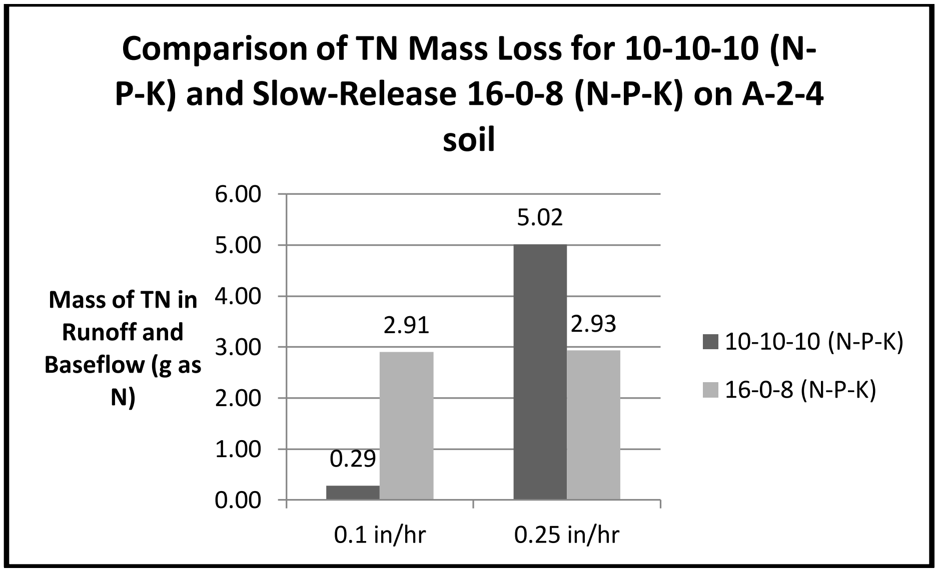


Figure 49: Comparison of Total Nitrogen Lost for A-2-4 Soil with 10-10-10 (N-P-K) vs. 16-0-8 (N-P-K)

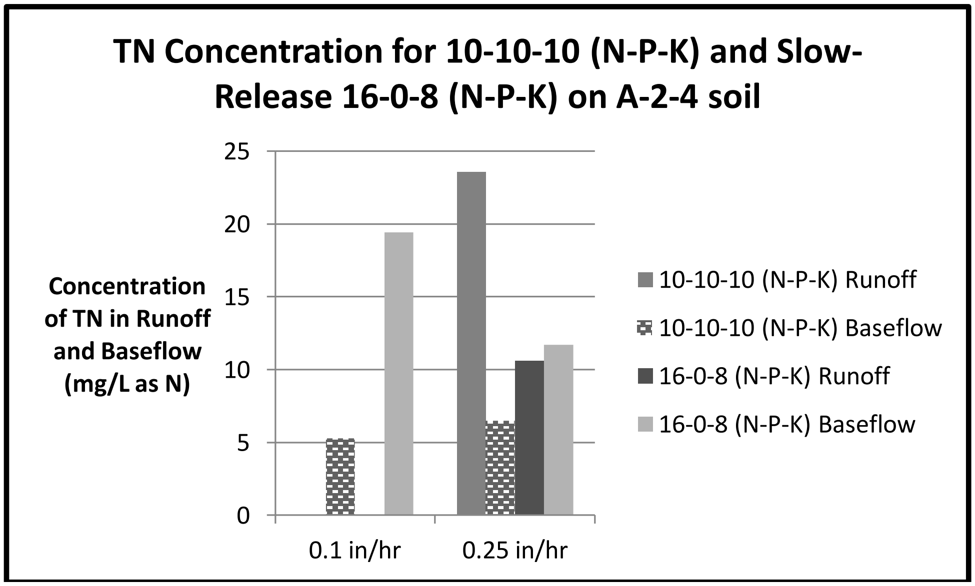


Figure 50: Concentration Comparison of Total Nitrogen Lost for A-2-4 Soil with 10-10-10 (N-P-K) vs 16-0-8 (N-P-K

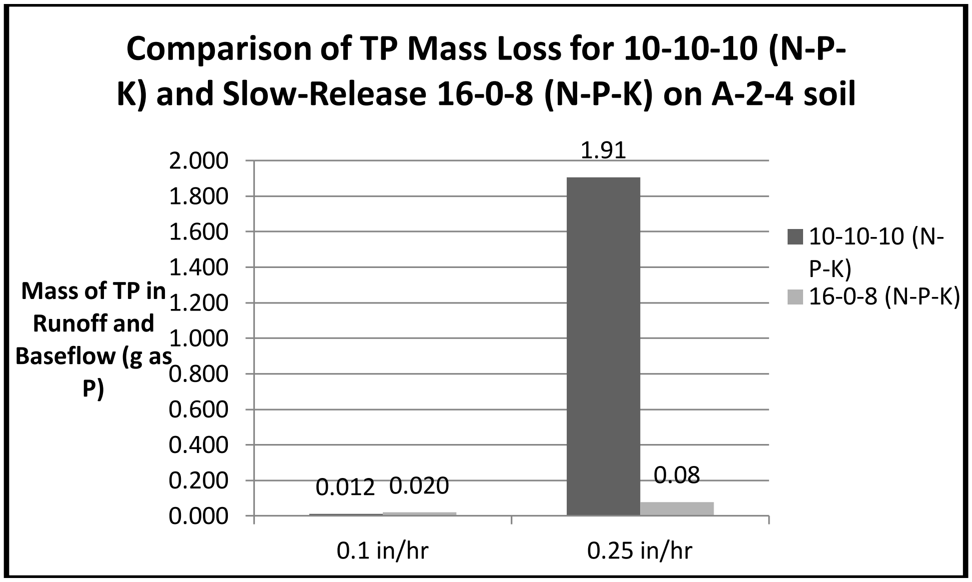


Figure 51: Comparison of Total Phosphorus Lost for A-2-4 Soil with 10-10-10 (N-P-K) vs. 16-0-8 (N-P-K)

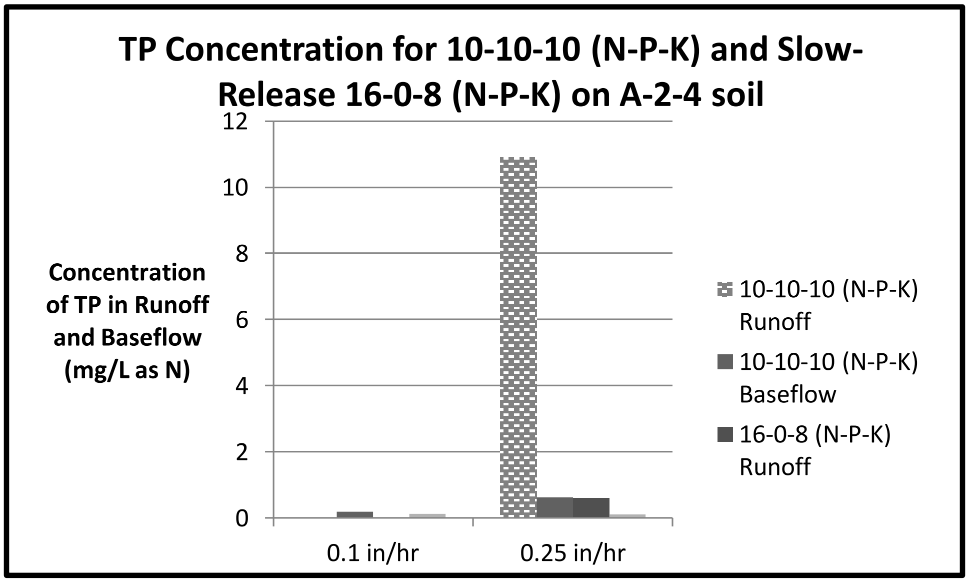


Figure 52: Concentration Comparison of Total Phosphorus Lost for A-2-4 Soil with 10-10-10 (N-P-K) vs 16-0-8 (N-P-K)

Examining the amount of runoff versus baseflow that occurred during all of these tests, runoff was not generated at the 0.1 in/hr rainfall intensity for either fertilizer type. At the 0.25 in/hr rainfall intensity, the percent of runoff collected to total volume collected was 53.6% for 10-10-10 (N-P-K) fertilizer and 39.2% for 16-0-8 (N-P-K) fertilizer. The most noteworthy difference between these tests was the amount of baseflow collected. The average moisture content of the soil prior to the 10-10-10 (N-P-K) fertilizer tests was lower than the 16-0-8 (N-P-K) fertilizer tests (Table 8, Table 14). This resulted in a longer rainfall duration required in order for the test bed to reach saturation before baseflow and/or runoff occurred. Thus, despite comparable applied volumes of rainfall, the 10-10-10 (N-P-K) fertilizer tests had less baseflow collected at the 0.1 in/hr intensity and less baseflow collected at the 0.25 in/hr intensity than the 16-0-8 (N-P-K) fertilizer tests. Because of this, more nitrogen could have leached from 16-0-8 (N-P-K) than 10-10-10 (N-P-K).

A-3 Soil with Argentine Bahia

As shown in Figure 53, more nitrogen was lost from the test bed using the 10-10-10 (N-P-K) fertilizer compared with the 16-0-8 (N-P-K) fertilizer. Total phosphorus collected, shown in Figure 55, was lower for the 16-0-8 (N-P-K) fertilizer than 10-10-10 (N-P-K) fertilizer. The reduction in nitrogen and phosphorus collected for the 16-0-8 (N-P-K) fertilizer as compared to 10-10-10 (N-P-K) fertilizer suggests there is an environmental benefit to using a 16-0-8 (N-P-K) fertilizer. In addition, more baseflow was collected during the 10-10-10 (N-P-K) fertilizer trials than 16-0-8 (N-P-K), even though slightly more rainfall volume was applied for the 16-0-8 (N-P-K) trials. This is because of the lower moisture content during the 16-0-8 (N-P-K) fertilizer trials requiring more rainfall application to the test bed in order for the soil to reach saturation before baseflow occurred. The concentration of TN and TP collected are shown in Figure 54 and Figure 56, respectively. The concentrations of both TN and TP follow the same trend as the collected masses and are low because no runoff was generated on this soil type.

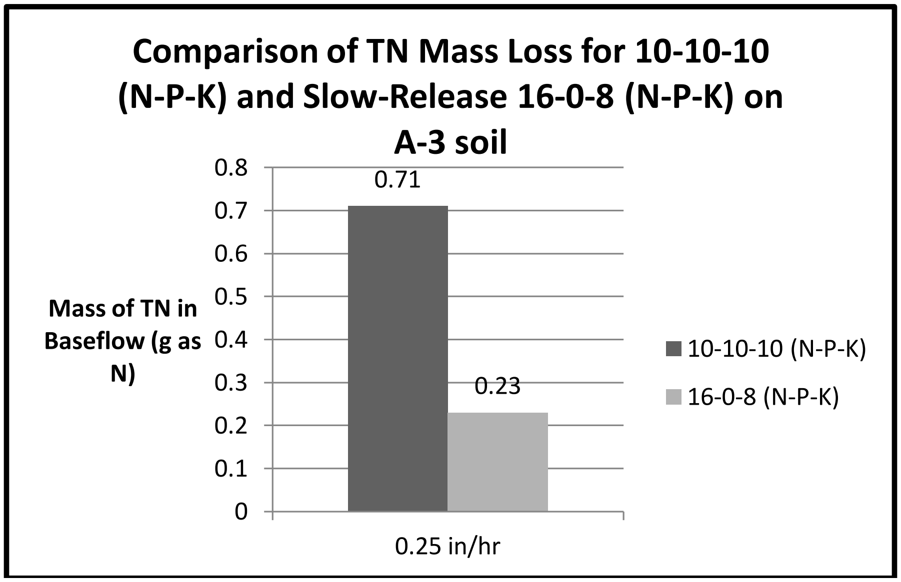


Figure 53: Comparison of Total Nitrogen Lost for A-3 Soil with 10-10-10 (N-P-K) vs. 16-0-8 (N-P-K)

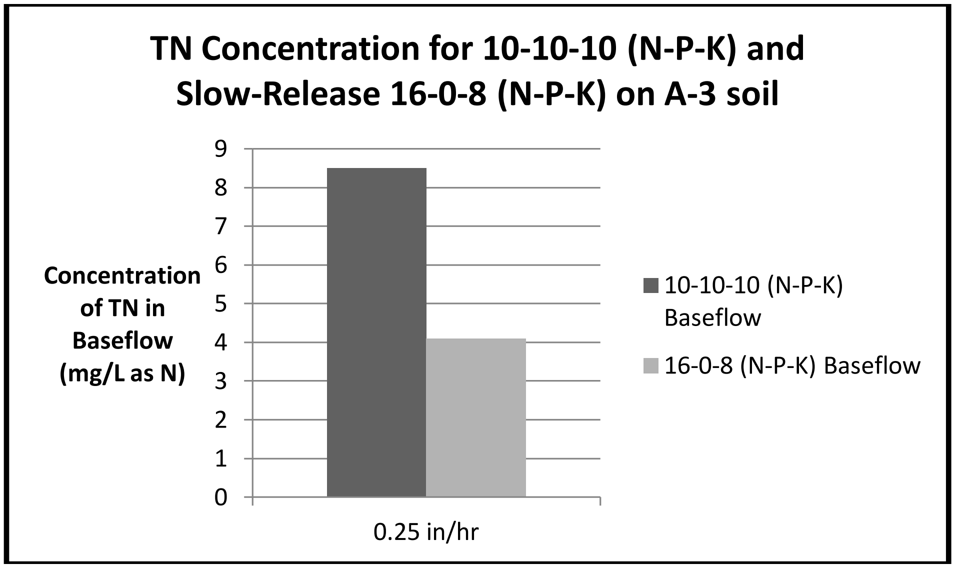


Figure 54: Concentration Comparison of Total Nitrogen Lost for A-3 Soil with 10-10-10 (N-P-K) vs. 16-0-8 (N-P-K)

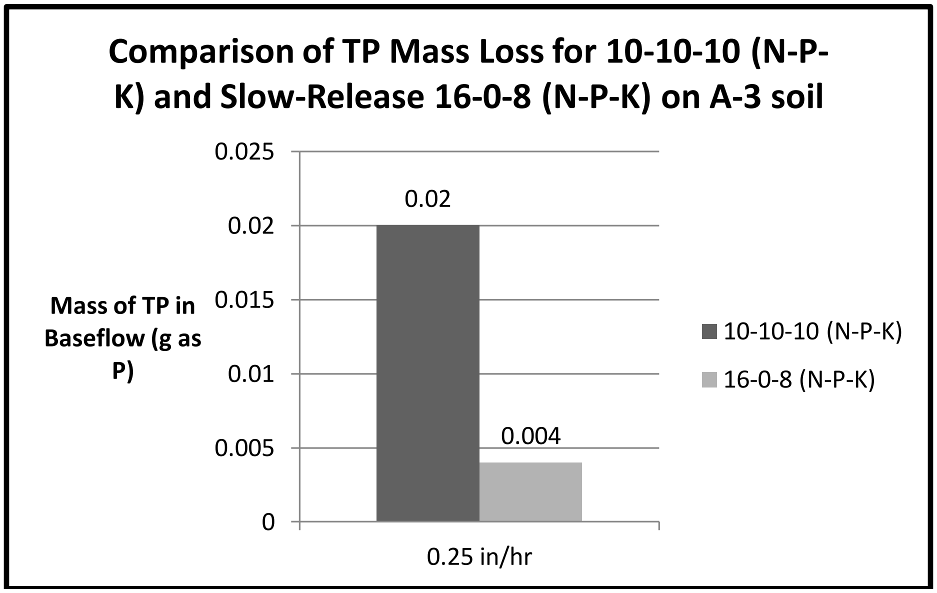


Figure 55: Comparison of Total Phosphorus Lost for A-3 Soil with 10-10-10 (N-P-K) vs. 16-0-8 (N-P-K)

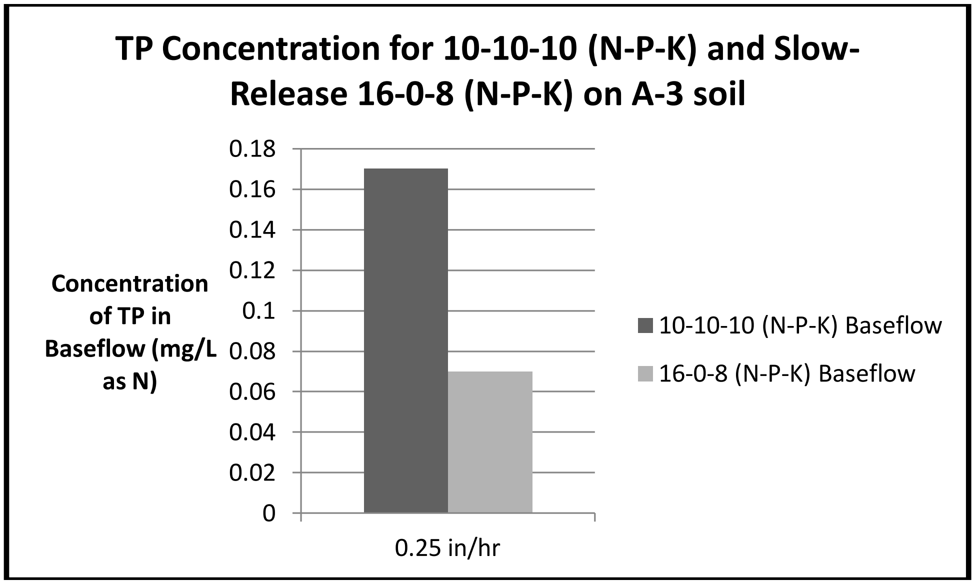


Figure 56: Concentration Comparison of Total Phosphorus Lost for A-3 Soil with 10-10-10 (N-P-K) vs. 16-0-8 (N-P-K)

A-2-4 Soil and Pensacola Bahia Sod Compared with A-3 Soil and Argentine Bahia Sod

The following analysis compares the loss of nutrients from both soil types using no fertilizer, the 10-10-10 (N-P-K) fertilizer, and the 16-0-8 (N-P-K) fertilizer.

No Fertilizer Comparison

In order to establish a baseline of nutrients present in the test bed, each soil and sod combination was tested without the addition of any fertilizer. As mentioned earlier, the A-2-4 soil and Pensacola Bahia test series had only four no fertilizer tests prior to the addition of 10-10-10 (N-P-K) fertilizer. Once the tests using the 10-10-10 (N-P-K) fertilizer were completed, the soil and sod were replaced with new soil and sod for the 16-0-8 (N-P-K) fertilizer series.

Prior to addition of the 16-0-8 (N-P-K) fertilizer to A-2-4 soil, there were no tests performed without fertilizer based on the assumption that the starting conditions would be identical to the previous batch of soil and sod. This assumption was not necessarily correct as sod is delivered with soil that is already fertilized to varying degrees, thus the starting conditions for the 16-0-8 (N-P-K) fertilizer series may not have been necessarily identical to the starting condtions for the 10-10-10 (N-P-K) fertilizer series. As a result, tests with no fertilizer were performed prior to the addition of either fertilizer (for each new batch of soil and sod) for the A-3 soil which was tested after all the A-2-4 soil and Pensacola Bahia combination tests were completed.

The assumption that the starting conditions for each batch of soil and sod are not the same appears to be valid when comparing the nutrient losses between the two A-3 soil and Argentine Bahia sod batches as shown in Figure 57 and Figure 59. There was 0.97 more grams of total nitrogen collected from the 0.1 in/hr rainfall intensity for the no fertilizer tests prior to the addition of the 10-10-10 (N-P-K) fertilizer than from the no fertilizer tests prior to the addition of 16-0-8 (N-P-K) fertilizer. Furthermore, 1.80 more grams of total nitrogen was collected at the 0.25 in/hr rainfall intensity for the no fertilizer tests prior to the addition of the 10-10-10 (N-P-K) fertilizer than from the no fertilizer tests prior to the addition of 16-0-8 (N-P-K) fertilizer. Comparing these to A-2-4 soil with Pensacola Bahia sod tests, the losses from the A-3 soil with Argentine Bahia sod prior to 16-0-8 (N-P-K) fertilizer addition were lower, and the losses from the A-3 soil prior to 10-10-10 (N-P-K) fertilizer addition were higher. The concentration of TN collected is shown in Figure 58. The highest concentration was collected in baseflow for A-3 soil prior to 10-10-10 (N-P-K) fertilizer addition.

It is important to note that no runoff was generated on the A-3 soil, and that runoff was generated for only the 0.1 in/hr rainfall intensity on the A-2-4 soil. The nitrogen collected in runoff at this intensity, however, was only 0.02 grams, or 8% of the total nitrogen lost from the test bed, thus a figure showing the total nitrogen collected for baseflow only is not shown.

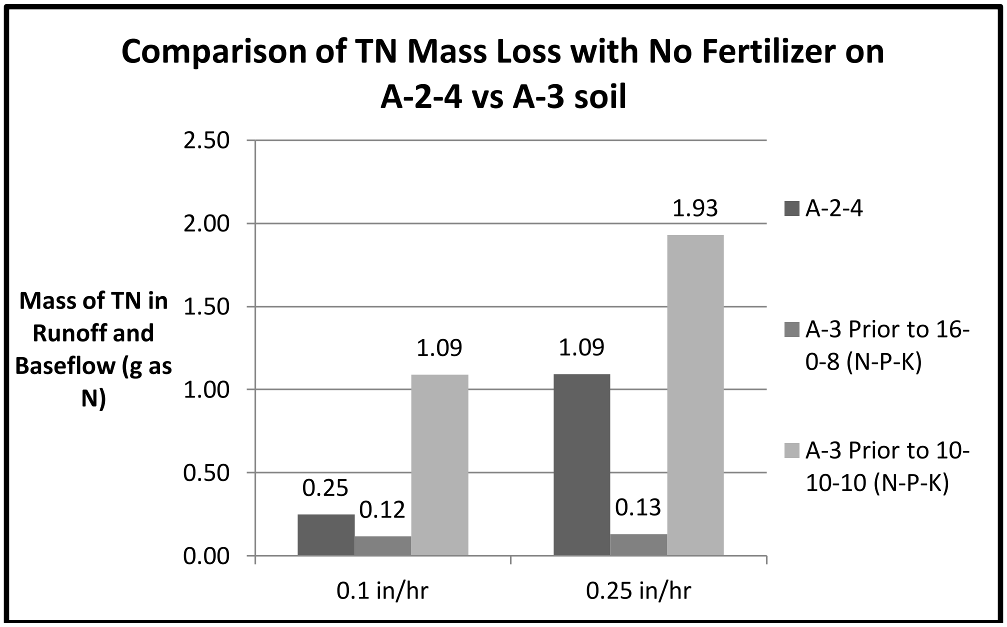


Figure 57: Comparison of Total Nitrogen Lost for A-2-4 Soil vs. A-3 Soil with No Fertilizer

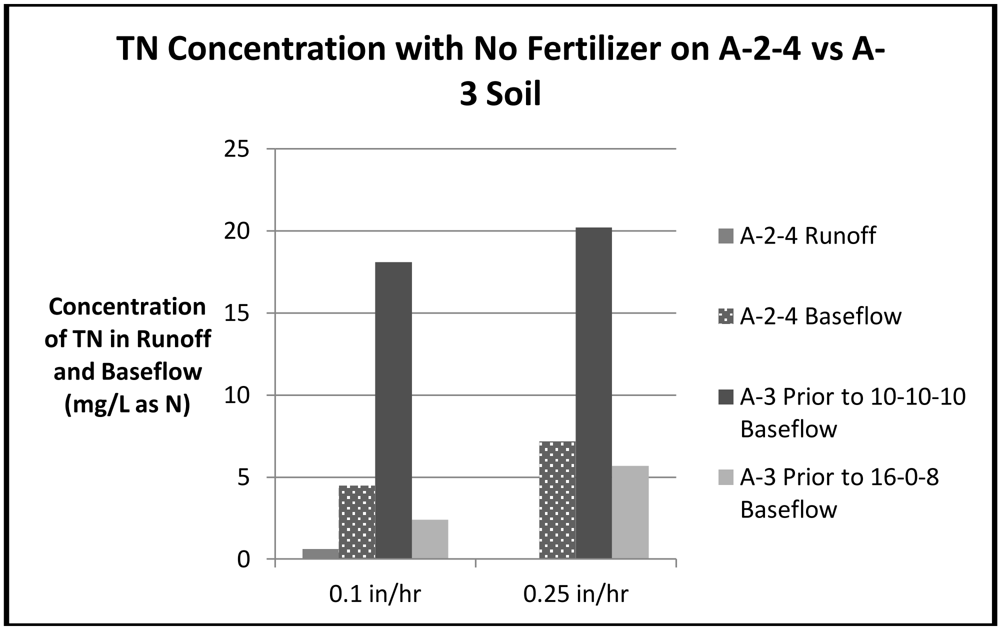


Figure 58: Concentration Comparison of Total Nitrogen Lost for A-2-4 Soil vs. A-3 Soil with No Fertilizer

Total phosphorus losses are shown in Figure 59 and phosphorus losses in baseflow only are shown in Figure 60. Total phosphorus losses were highest for the A-2-4 soil at 0.1 in/hr rainfall intensity. Much like total nitrogen, total phosphorus losses were lowest on the A-3 soil prior to 16-0-8 (N-P-K) fertilizer addition. The majority (91.7%) of phosphorus lost was from runoff on the A-2-4 soil at 0.1 in/hr rainfall intensity, which was the only series out of the three to generate runoff. Thus, baseflow losses were highest for the A-3 soil prior to 10-10-10 (N-P-K) fertilizer application. The concentration of TP collected is shown in Figure 61. The concentration of TP collected was highest in runoff for A-2-4 soil.

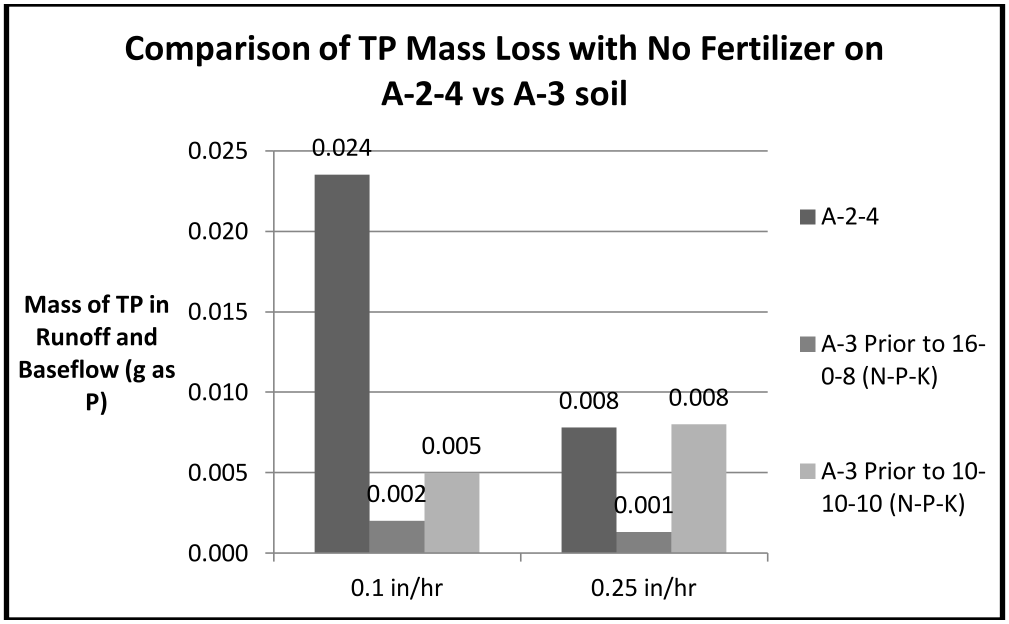


Figure 59: Comparison of Total Phosphorus Lost for A-2-4 Soil vs. A-3 Soil with No Fertilizer

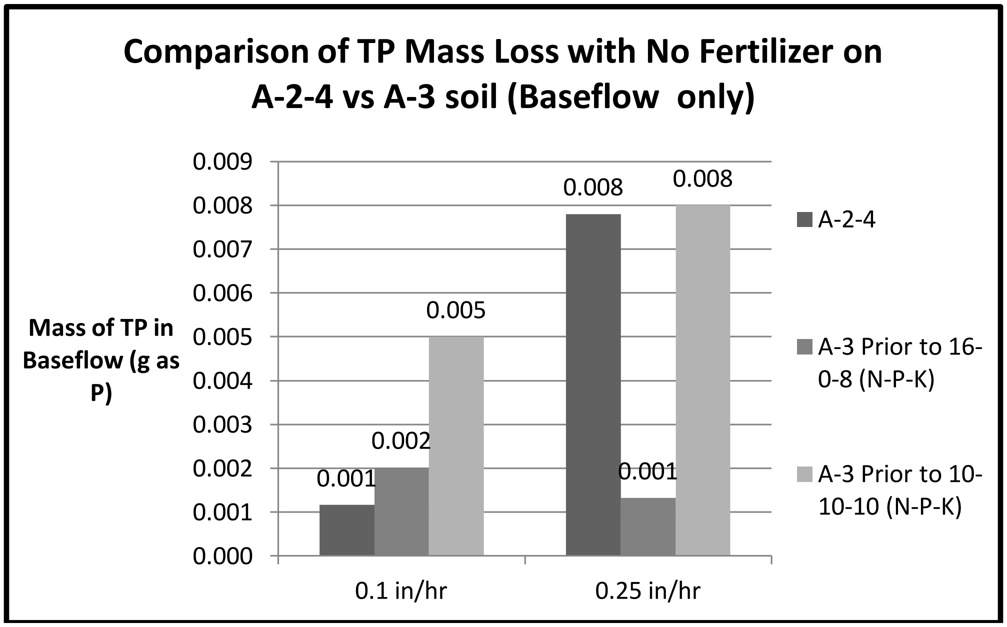


Figure 60: Comparison of Total Phosphorus Lost in Baseflow Only for A-2-4 Soil vs. A-3 Soil with No Fertilizer

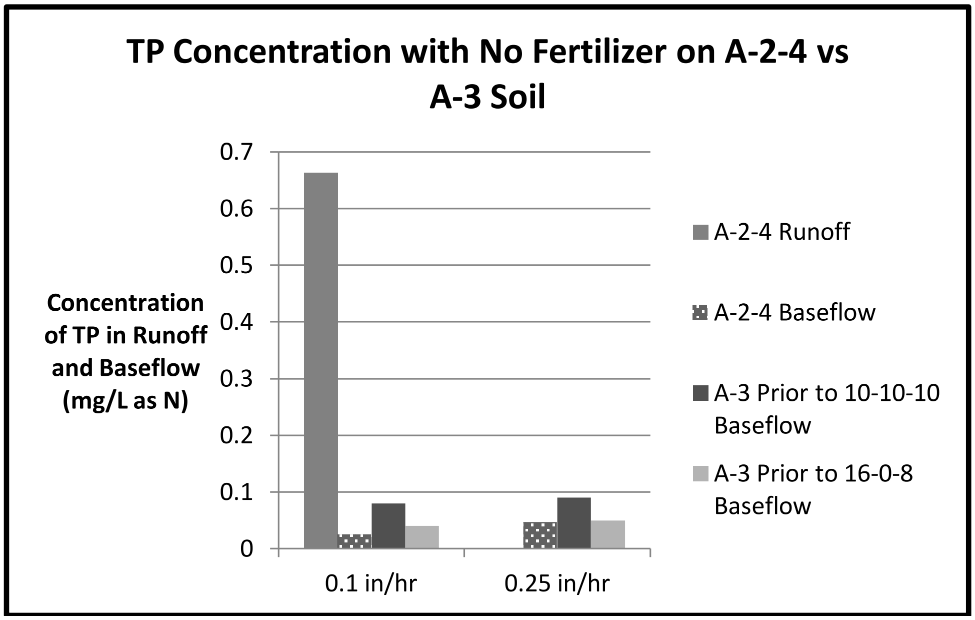


Figure 61: Concentration Comparison of Total Phosphorus Lost for A-2-4 Soil vs. A-3 Soil with No Fertilizer

<u>10-10-10 (N-P-K) Fertilizer Comparison</u>

Figure 62 shows the total nitrogen collected including runoff and baseflow, while Figure 63 shows only the baseflow. The total nitrogen collected from the 0.25 in/hr rainfall intensity on the A-2-4 soil with Pensacola Bahia sod is higher than the total nitrogen collected at any other time. This can be attributed to runoff being generated only from the 0.25 in/hr rainfall intensity on the A-2-4 soil. Runoff contributed to 77.1% of total nitrogen collected from A-2-4 at 0.25 in/hr rainfall intensity. Taking into account collected baseflow only, as shown in Figure 63, the total nitrogen losses were still highest from the A-2-4 soil at 0.25 in/hr rainfall intensity while there appears to be no difference at 0.1 in/hr rainfall intensity. The concentration of TN is shown in Figure 64. The highest concentration was collected in runoff for A-2-4 soil and was over 20 mg/L. Despite no runoff generated for A-3 soil, baseflow concentrations were between 5 mg/L and 10 mg/L.

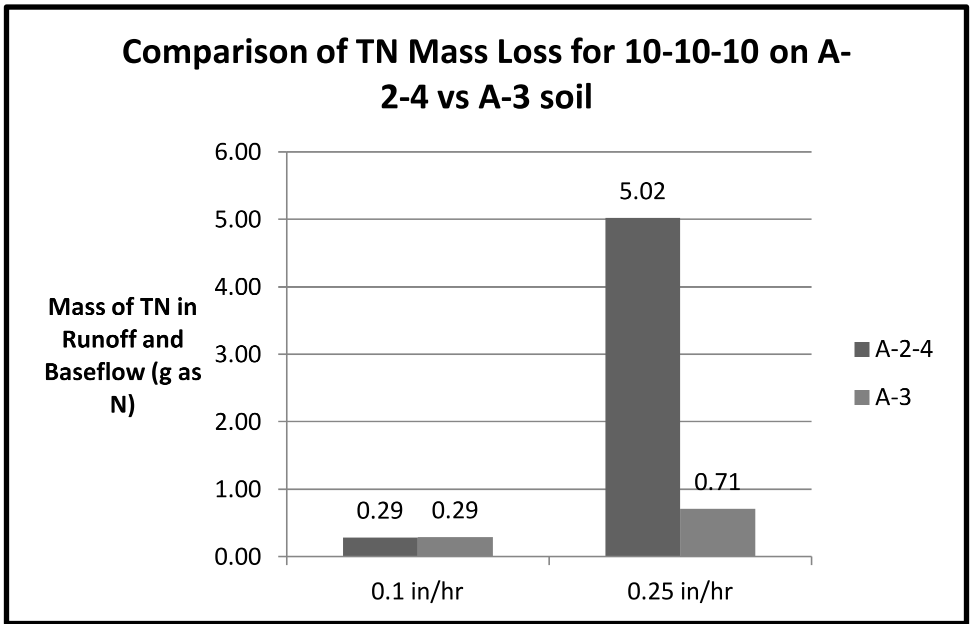


Figure 62: Comparison of Total Nitrogen Lost for A-2-4 Soil vs. A-3 Soil with 10-10-10 (N-P-K)

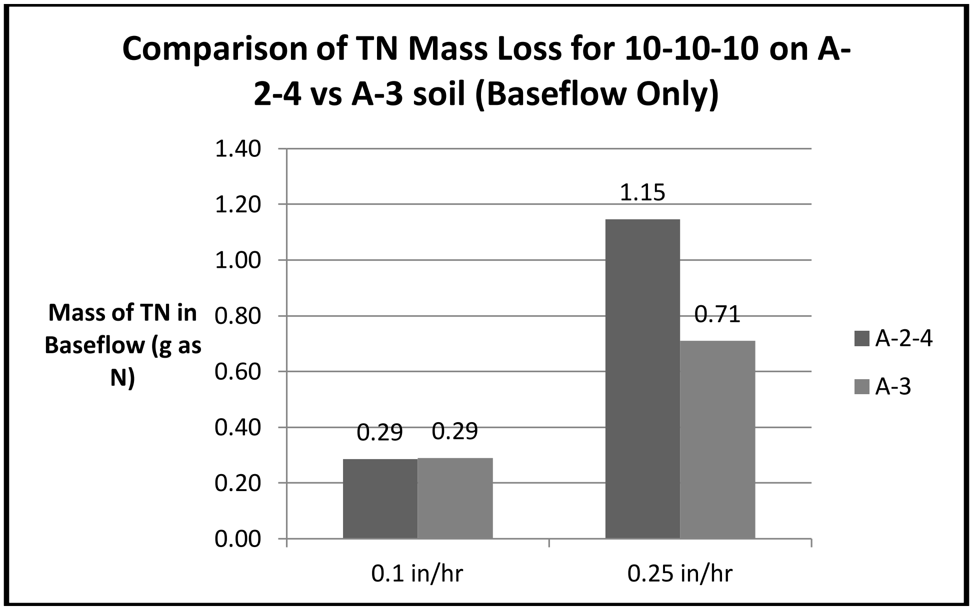


Figure 63: Comparison of Total Nitrogen Lost in Baseflow Only for A-2-4 Soil vs. A-3 Soil with 10-10-10 (N-P-K)

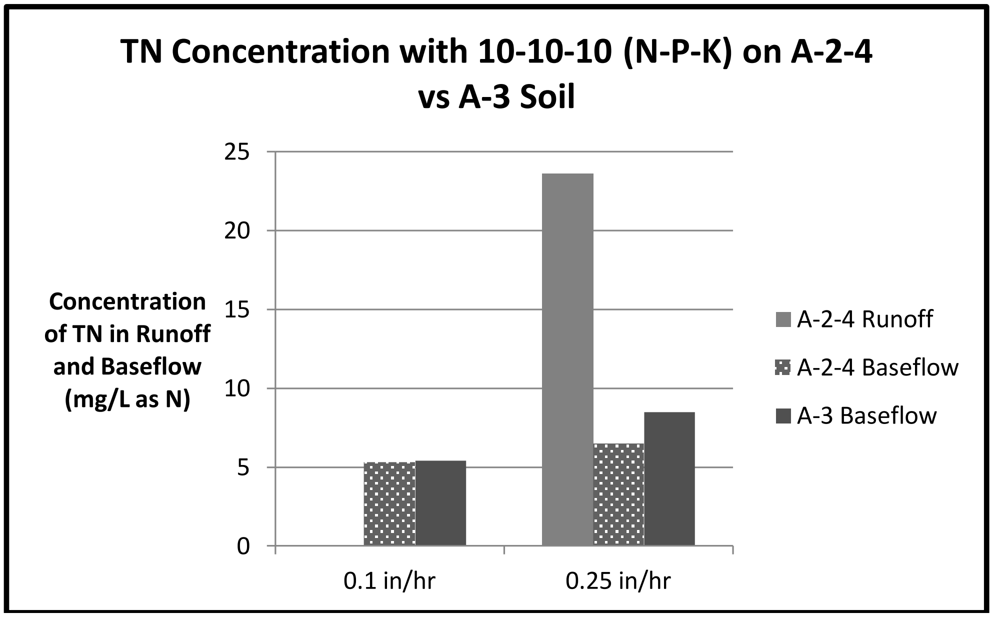


Figure 64: Concentration Comparison of Total Nitrogen Lost for A-2-4 Soil vs. A-3 Soil with 10-10-10 (N-P-K)

Total phosphorus mass lost is shown in Figure 65, and concentrations are shown in Figure 66. The variation of total phosphorus losses was similar to total nitrogen. The highest loss was from the A-2-4 soil at the 0.25 in/hr rainfall intensity, which again was the only test where runoff was generated. The concentration of total phosphorus was also highest in runoff and was over 10 mg/L. Total phosphorus lost in baseflow only from the A-2-4 soil from the 0.25 in/hr rainfall intensity was 0.21 grams, which is still higher than the A-3 soil at that intensity and both soil types at 0.1 in/hr rainfall intensity. This could be because of a number of reasons such as build-up of fertilizer in the soil, higher soil moisture content promoting leaching and larger baseflow volumes, and differences in soil physicochemical characteristics.

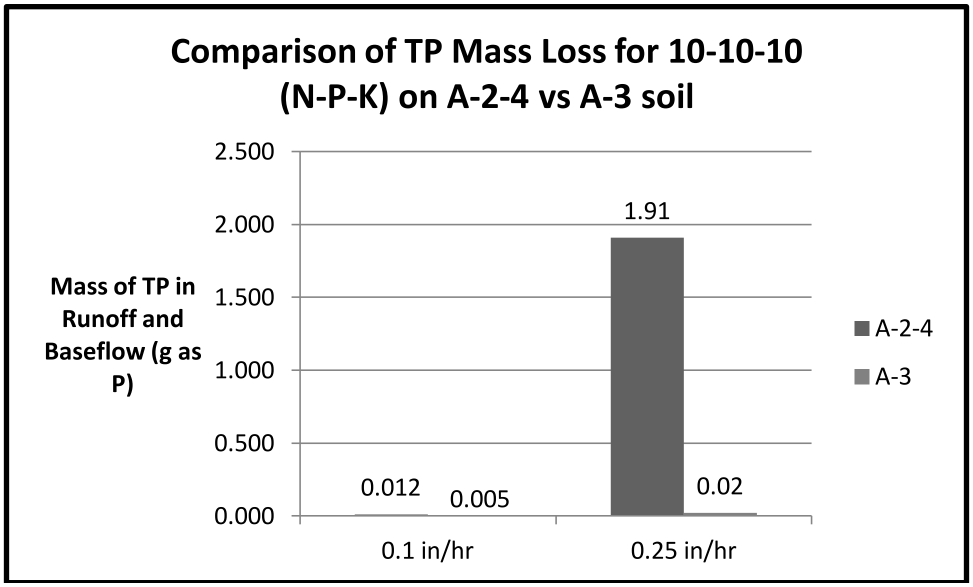


Figure 65: Comparison of Total Phosphorus Lost for A-2-4 Soil vs. A-3 Soil with 10-10-10 (N-P-K)

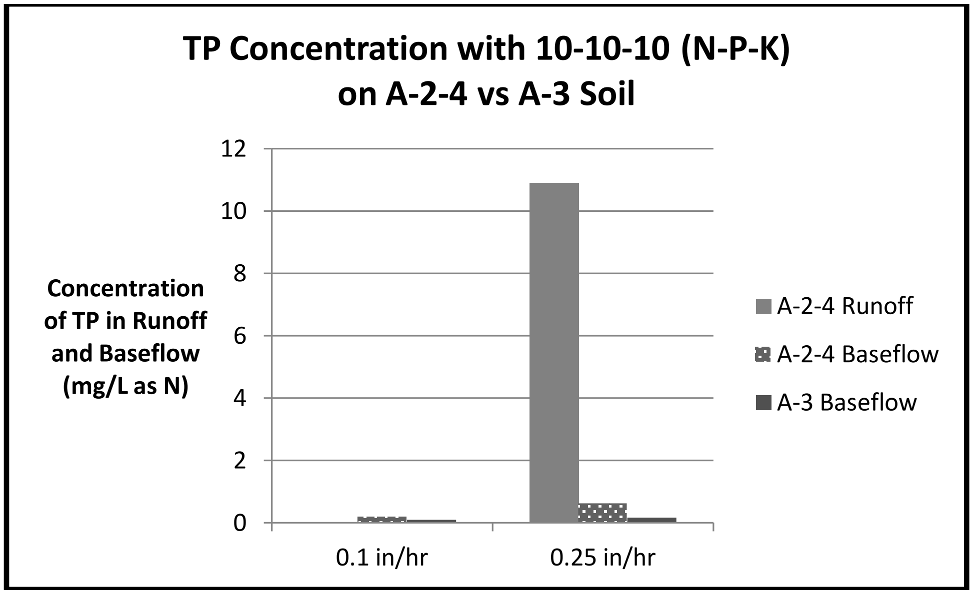


Figure 66: Concentration Comparison of Total Phosphorus Lost for A-2-4 Soil vs. A-3 Soil with 10-10-10 (N-P-K)

10-10-10 (N-P-K) Seven-day Tests

The seven-day tests for the 10-10-10 (N-P-K) fertilizer were conducted on both soil types at a rainfall intensity of 0.25 in/hr and a rate of fertilizer application of 0.5 lb N/1000 ft^2. The comparison of total nitrogen and phosphorus collected mass is shown in Figure 67 and Figure 69, respectively. Concentration graphs of TN and TP are shown in Figure 68 and Figure 70, respectively. For these tests runoff was generated only on the first day of testing on the A-2-4 soil and Pensacola Bahia sod combination, which had the highest total nitrogen losses. The concentration of TN in runoff was over 8 mg/L. No runoff was generated on the seventh day, likely because of lower soil moisture content. Runoff was not generated for either test on the A-3 soil and Argentine Bahia sod combination. Excluding runoff from the A-2-4 soil on the first day, the total nitrogen collected was 0.66 grams, which is still higher than the remaining tests.

However, the total nitrogen collected on the seventh day, was lower for the A-2-4 soil than the A-3 soil, reflecting the adsorption of nutrients in the test bed, sod utilization, and the remaining physicochemical transformations that occurred in the test bed between days 1 and 7 on that soil type. Comparing the losses between the A-2-4 soil and the A-3 soil, it is clear that the majority of losses from the A-2-4 soil occurred on the first day of testing because of the runoff generated, while losses from the A-3 soil were similar from day 1 to day 7.

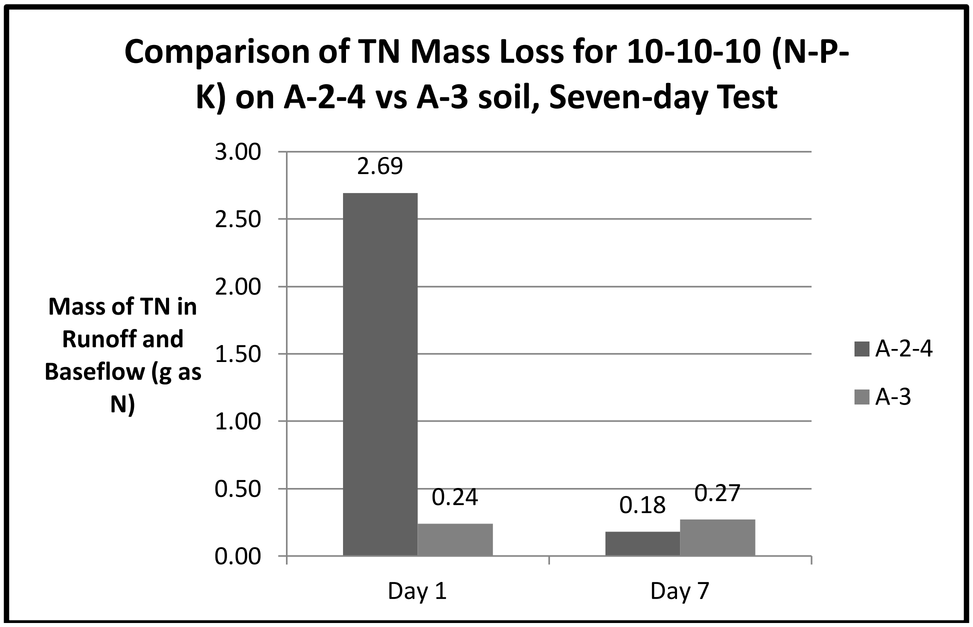


Figure 67: Comparison of Total Nitrogen Lost on A-2-4 Soil vs. A-3 Soil with 10-10-10 (N-P-K); Seven-day Test

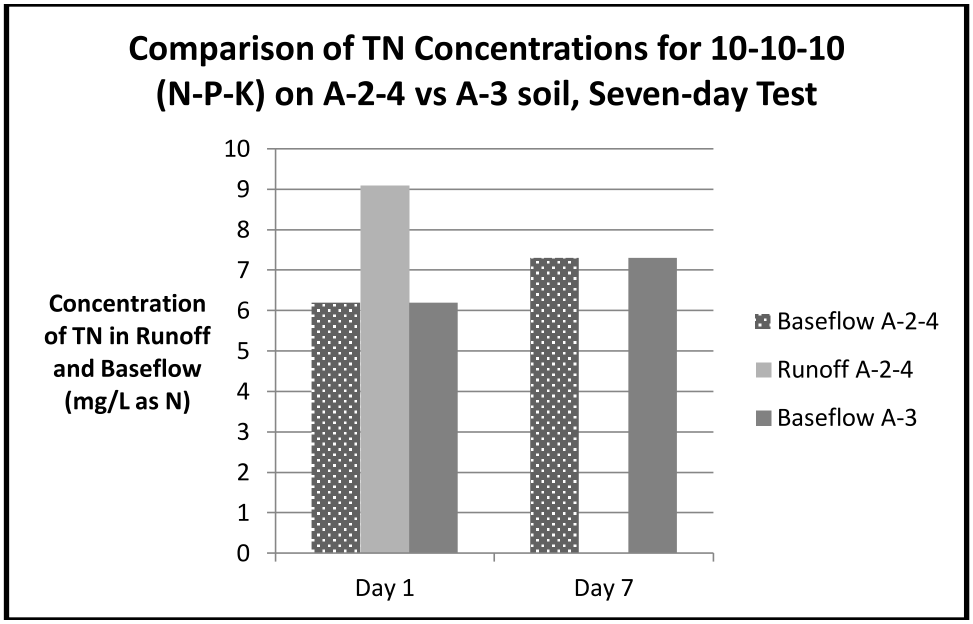


Figure 68: Concentration Comparison of Total Nitrogen Lost for A-2-4 Soil vs. A-3 Soil with 10-10-10 (N-P-K); Seven-day Test

The pattern of total phosphorus loss is similar to total nitrogen. Figure 69 shows the total phosphorus lost on day 1 and day 7 from the A-2-4 soil and the A-3 soil. The highest losses of phosphorus occurred from the A-2-4 soil at the 0.25 in/hr rainfall intensity. Again, runoff, generated only for the A-2-4 soil from the 0.25 in/hr rainfall intensity, contributed 91.5% of the total phosphorus lost from the test bed. The concentration of TP in runoff was over 5 mg/L. Excluding the runoff, total phosphorus at that intensity from the A-2-4 soil was only 0.11 grams, which is still higher than losses from the A-3 soil on both days. Day 7 losses from the A-2-4 soil, however, are substantially lower than day 1 losses indicating that the majority of 10-10-10 (N-P-K) fertilizer was lost on the first day. As mentioned earlier, the majority of this loss is via runoff, which tends to be the source of the majority of nutrient loss. However, losses from the A-3 soil are low and relatively unchanged from day 1 to day 7, as no runoff was generated on that soil type.

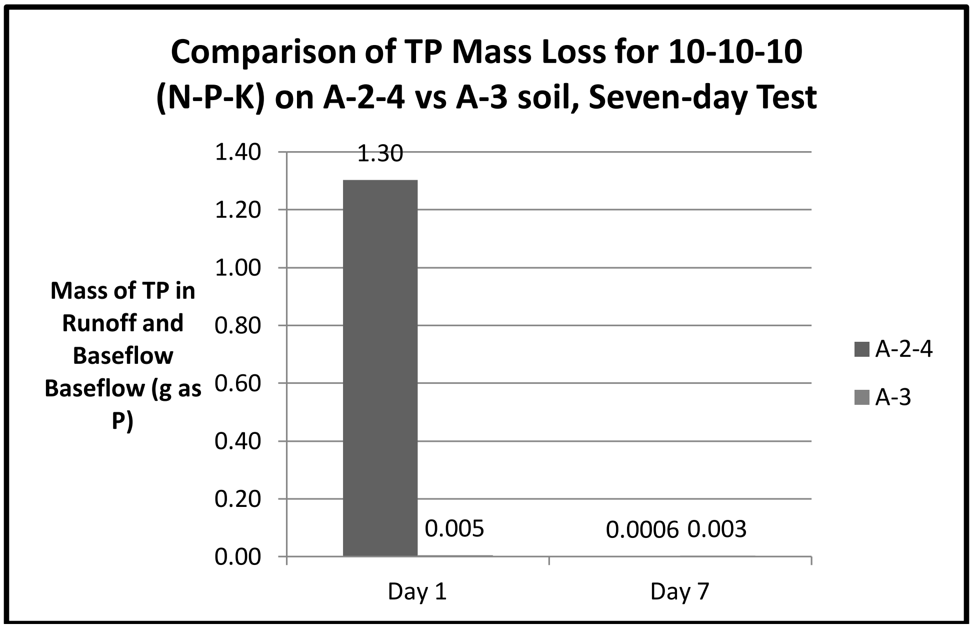


Figure 69: Comparison of Total Phosphorus Lost for A-2-4 Soil vs. A-3 Soil with 10-10-10 (N-P-K); Seven-day Test

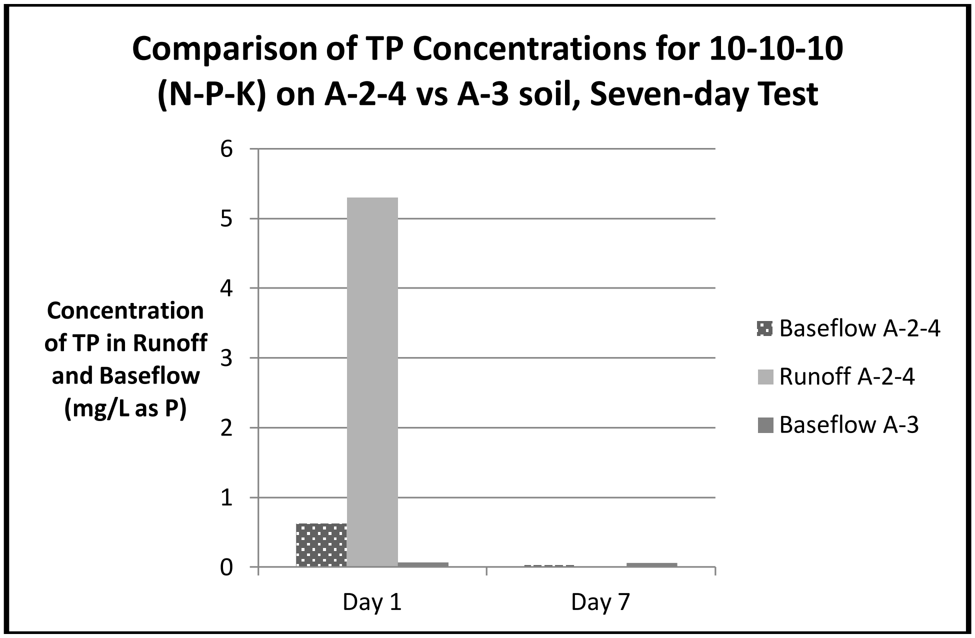


Figure 70: Concentration Comparison of Total Phosphorus Lost for A-2-4 Soil vs. A-3 Soil with 10-10-10 (N-P-K); Seven-day Test

16-0-8 (N-P-K) Fertilizer Comparison

A slow-release 16-0-8 (N-P-K) fertilizer was applied at a rate of 0.5 lb N/1000 ft^2. Figure 71 shows the total nitrogen collected from the A-2-4 soil and Pensacola Bahia combination versus the A-3 and Argentine Bahia combination at a 0.25 in/hr rainfall intensity. Figure 72 Figure 74 show the concentrations of collected TN and TP, respectively, from these soil and sod combinations. It is important to note that runoff was generated from the A-2-4 soil at this intensity, and not the A-3 soil. Approximately 35.5% of total nitrogen collected from the A-2-4 soil was from runoff. The mass of total nitrogen collected in baseflow was 1.89 grams, which is still higher than what was collected from the A-3 soil.

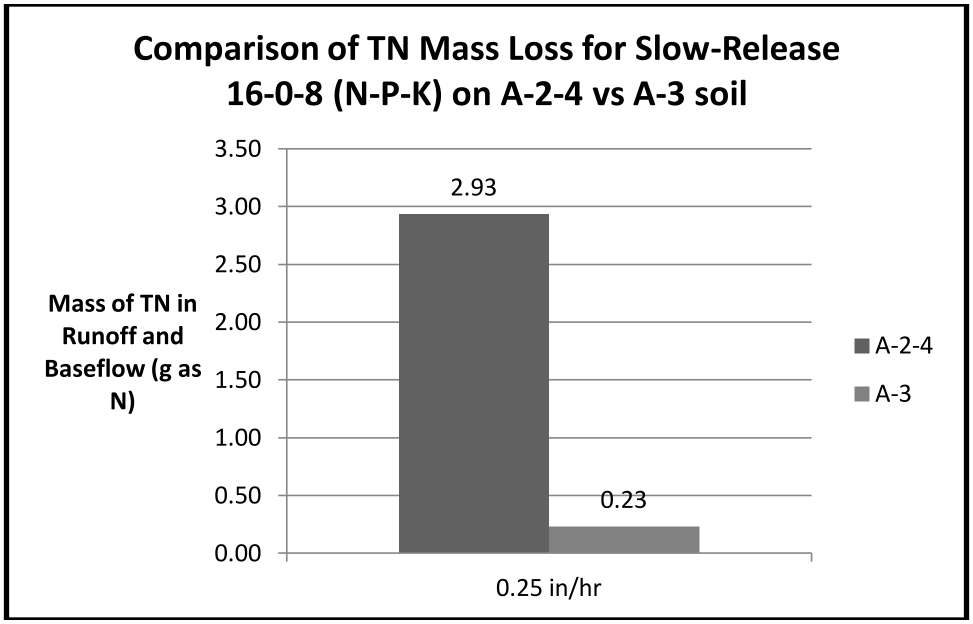


Figure 71: Comparison of Total Nitrogen Lost for A-2-4 Soil vs. A-3 Soil with Slow-Release 16-0-8 (N-P-K)

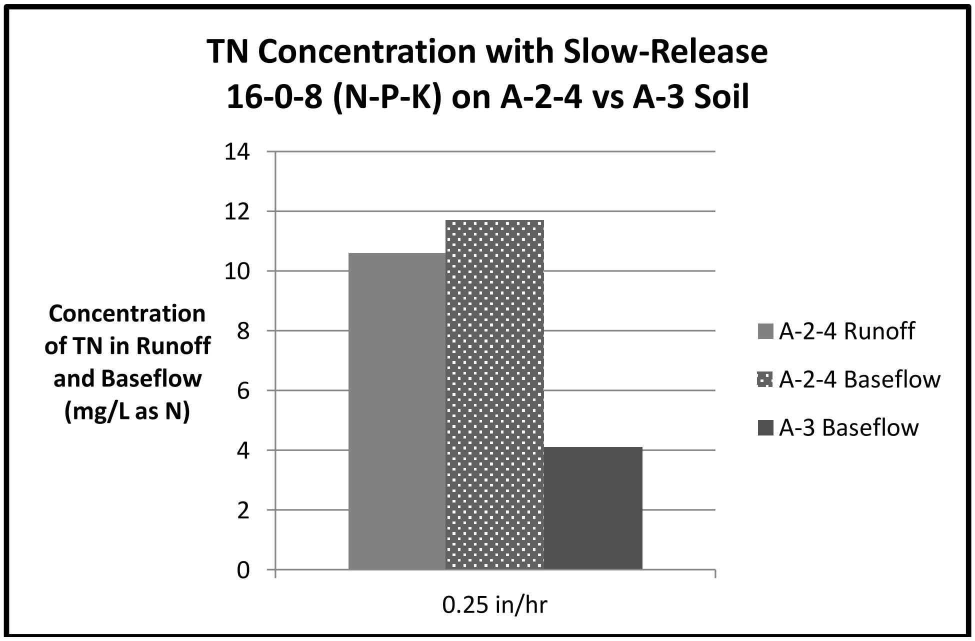


Figure 72: Concentration Comparison of Total Nitrogen Lost for A-2-4 Soil vs. A-3 Soil with Slow-Release 16-0-8 (N-P-K)

The difference between losses of total phosphorus was similar to total nitrogen, as shown in Figure 73. The highest loss was from the A-2-4 soil which again was the only test where runoff was generated. The concentration of TP in runoff was 0.6 mg/L which is low. Total phosphorus lost in baseflow from the A-2-4 soil was 0.06 grams, which is still higher than what was lost from the A-3 soil. This could be due to a number of reasons such as build-up of fertilizer in the A-2-4 soil over time, environmental conditions, and more nitrogen and phosphorus inherent to the A-2-4 soil and Pensacola Bahia combination than the A-3 soil and Argentine Bahia combination.

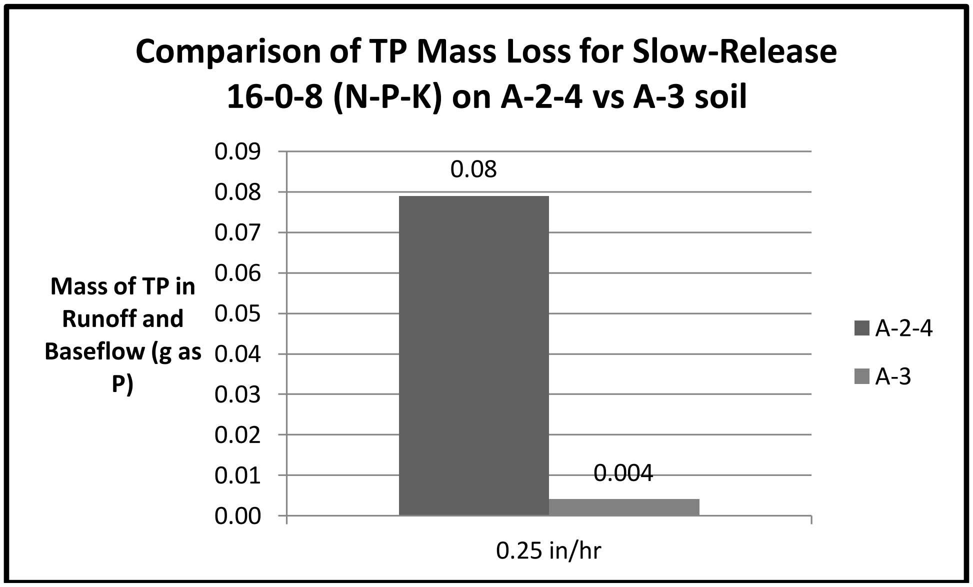


Figure 73: Comparison of Total Phosphorus Lost on A-2-4 Soil vs. A-3 Soil with Slow-Release 16-0-8 (N-P-K)

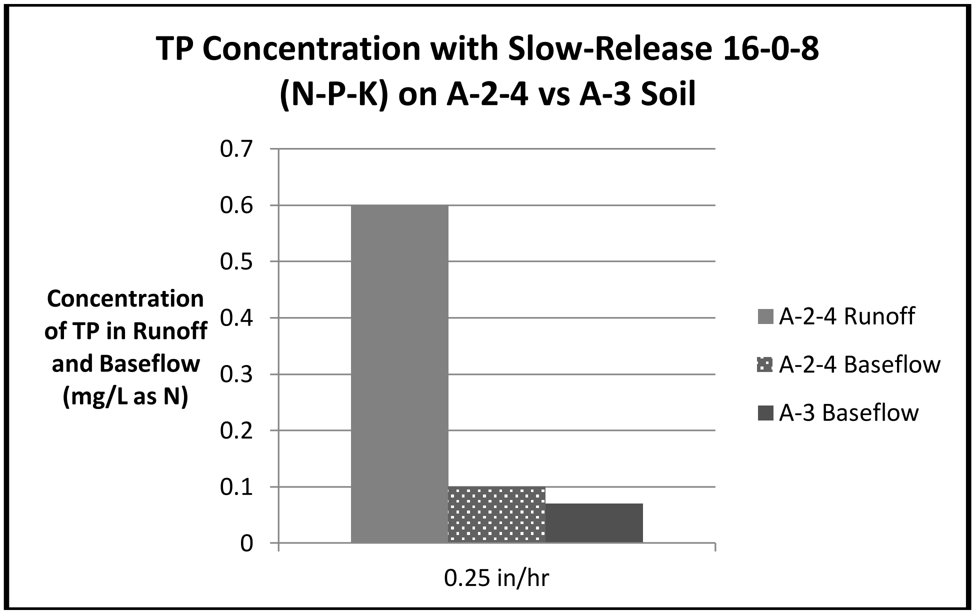


Figure 74: Concentration Comparison of Total Phosphorus Lost on A-2-4 Soil vs. A-3 Soil with Slow-Release 16-0-8 (N-P-K)

<u>16-0-8 (N-P-K) Seven-day Tests</u>

The seven-day tests for the slow-release16-0-8 (N-P-K) fertilizer were conducted on both types of soil at a rainfall intensity of 0.25 in/hr and a fertilizer application rate of 0.5 lb N/1000 ft^2. The comparison of total nitrogen and total phosphorus collected mass is shown in Figure 75 and Figure 77, respectively. The concentrations of TN and TP are shown in Figure 76 and Figure 78, respectively. Contrary to other tests, runoff was generated on day 1 as well as day 7 on the A-2-4 soil and Pensacola Bahia sod combination, which contributed to the high losses of nitrogen on both of those days. The highest concentration of both TN and TP were collected in runoff and were over 8 mg/L and over 35 mg/L, respectively. Even after omitting runoff, the A-2-4 soil nitrogen losses from baseflow contributed to 58.9% of total nitrogen collected on day 1, and 74.5% on day 7. Total nitrogen losses from the A-3 soil were lower on both days than the A-2-4 soil. This could be because the A-2-4 soil and Pensacola Bahia sod had inherently more nutrients than the A-3 soil and Argentine Bahia sod combination in addition to fertilizer build-up that could have occurred prior to the seven-day test.

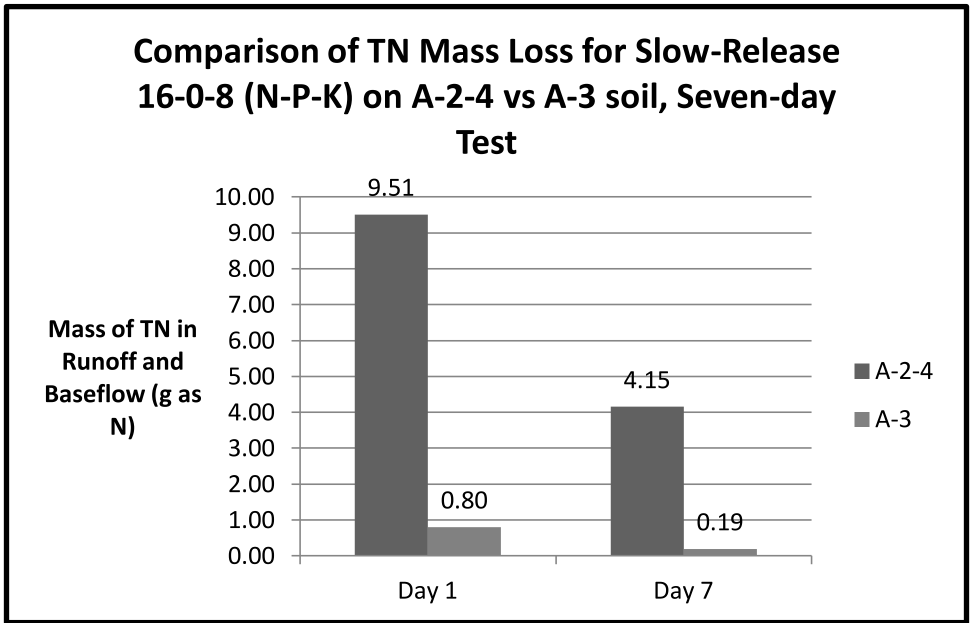


Figure 75: Comparison of Total Nitrogen Lost for A-2-4 Soil vs. A-3 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

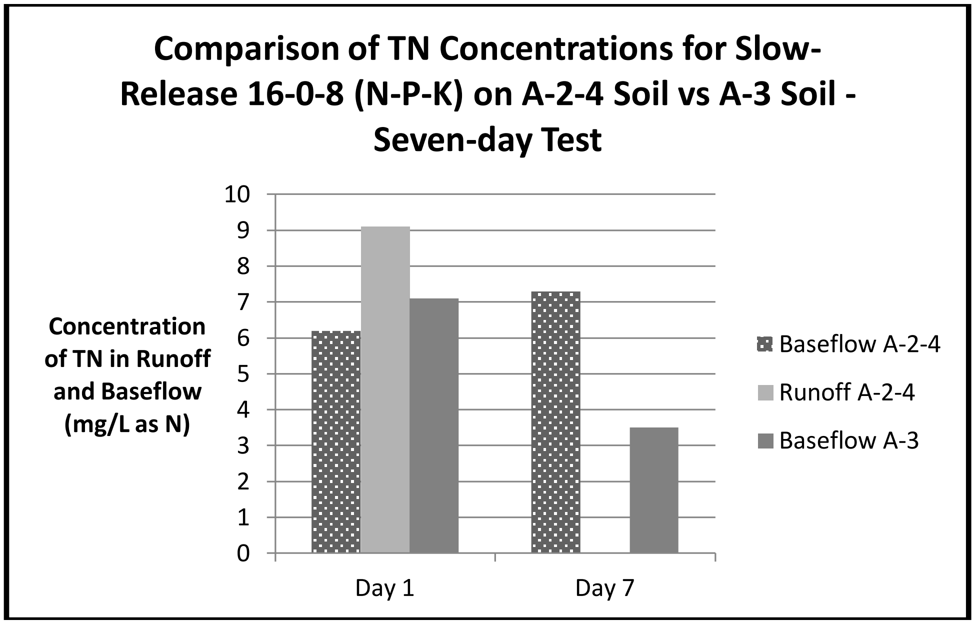


Figure 76: Concentration Comparison of Total Nitrogen Lost for A-2-4 Soil vs. A-3 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

Total phosphorus mass losses were low for both soil types, which is expected as the slow-release 16-0-8 (N-P-K) fertilizer does not contain phosphorus. The lack of added phosphorus is apparent because there is no change in phosphorus collected between day 1 and day 7 for either soil type. There is, however, a difference in concentrations between day 1 and day 7

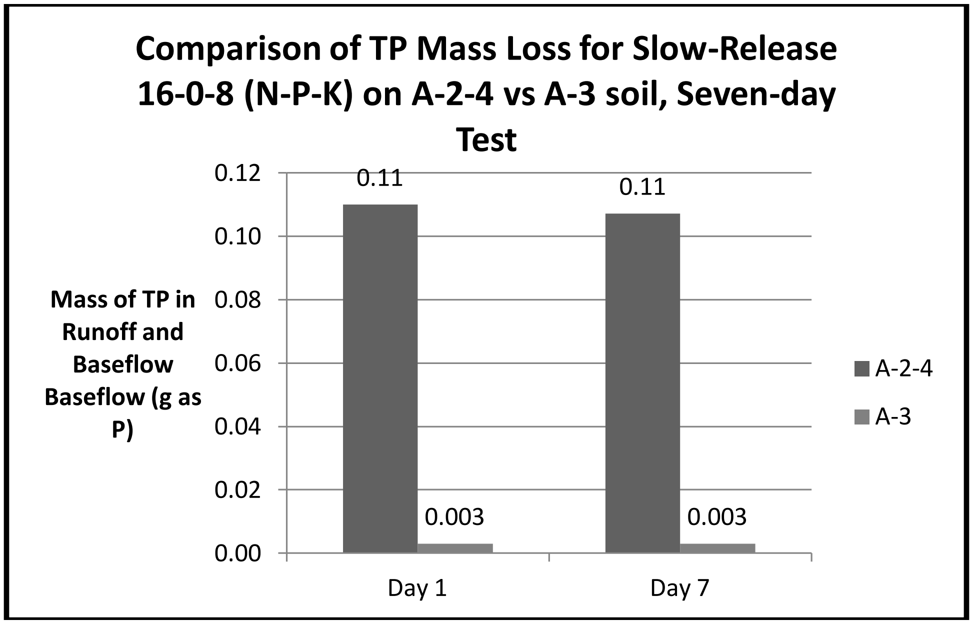


Figure 77: Comparison of Total Phosphorus Lost for A-2-4 Soil vs. A-3 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

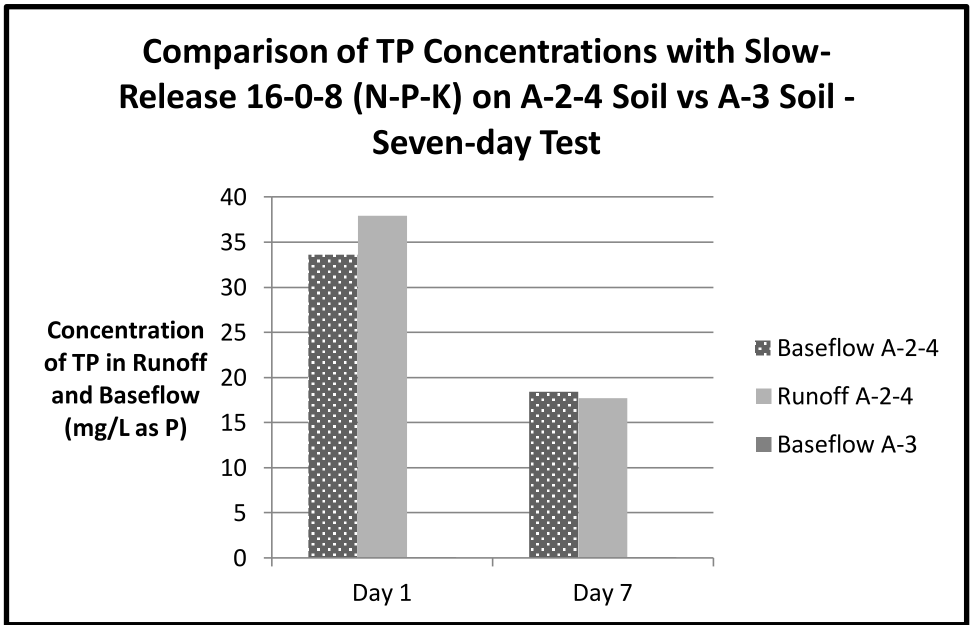


Figure 78: Concentration Comparison of Total Phosphorus Lost for A-2-4 Soil vs. A-3 Soil with Slow-Release 16-0-8 (N-P-K); Seven-day Test

Comparison of Total Nitrogen, Total Phosphorus, and CEC of A-2-4 and A-3

A comparison of average total nitrogen, total phosphorus, and cation exchange capacity for all tests with no fertilizer is shown in Table 53, followed by the 10-10-10 (N-P-K) fertilizer tests shown in Table 54, and the slow-release 16-0-8 (N-P-K) fertilizer tests in Table 55. The results from tests with no fertilizer are the baseline conditions for all of the soil and sod combinations examined. Of these, the highest CEC was found in the A-2-4 soil, which is expected due to its high silt content. The CEC of the A-3 soil prior to the application of the 10-10-10 (N-P-K) fertilizer is lower than that of the A-2-4 soil. The lowest CEC, less than 10 meq/100 g, was found in the A-3 soil prior to 16-0-8 (N-P-K). The discrepancy of CEC values between A-3 batches can be attributed to varying levels of humus (organic matter) inherent to the soil and differences in soil pH.

Table 53: Comparison of Total Nitrogen, Total Phosphorus, and CEC for A-2-4 Soil vs. A-3 Soil with No Fertilizer

	A-2-4, No Fertilizer		**A-3, No Fertilizer Prior to 10-10-10 (N-P-K)**		**A-3, No Fertilizer Prior to 16-0-8 (SR) (N-P-K)**	
Intensity (in/hr)	**0.1**	**0.25**	**0.1**	**0.25**	**0.1**	**0.25**
Total Nitrogen (g)	216.8	305.5	6637	6650	7668	9162
Total Phosphorus (g)	328.4	277.3	2474	2279	511	611
CEC (meq/g)	0.63	0.64	0.12	0.12	0.065	0.076

For tests involving no fertilizer application, shown in Table 53, the A-3 soil had inherently as much as thirty times more total nitrogen and ten times more total phosphorus than the A-2-4 soil. Based on these values, the capacity for nutrient storage in the A-2-4 soil is much greater than the A-3 soil, as the maximum total nitrogen increase in the A-2-4 soil was approximately 88%, and the maximum total phosphorus increase was approximately 75%. The A-3 soil, however, showed an overall reduction in total nitrogen and total phosphorus after fertilizer application indicating that its potential for nutrient storage was at capacity. In addition, the values of total nitrogen and total phosphorus prior to fertilizer application indicate that the sod applied to the A-3 soil was already heavily fertilized, more so than the sod applied to the A-2-4 soil.

The tests performed with the 10-10-10 (N-P-K) fertilizer were performed initially at the 0.25 in/hr rainfall intensity on the A-3 soil with Argentine Bahia sod as well as the A-2-4 soil with Pensacola Bahia sod. Once the tests at the 0.25 in/hr rainfall intensity were completed, tests at the 0.1 in/hr rainfall intensity were performed afterward. As a result, when comparing the results between intensities for each soil/fertilizer type, most often the values of total nitrogen and total phosphorus are higher at the 0.1 in/hr rainfall intensity than the 0.25 in/hr rainfall intensity. This is likely because of a slight build-up of nutrients in the test bed, as well as the reduced potential for nutrient leaching at a low intensity rainfall such as 0.1 in/hr.

Table 54: Comparison of Total Nitrogen, Total Phosphorus, and CEC for A-2-4 Soil vs. A-3 Soil with 10-10-10 (N-P-K)

	A-2-4, 10-10-10 (N-P-K)		**A-3, 10-10-10 (N-P-K)**	
Intensity (in/hr)	**0.1**	**0.25**	**0.1**	**0.25**
Total Nitrogen Before Test (g)	1333	821	4857	5896
Total Nitrogen After Test (g)	1337	1847	6276	4388
Total Phosphorus Before Test (g)	1131	575	2223	1935
Total Phosphorus After Test (g)	950	758	1909	1791
CEC Before Test(meq/g)	0.377	0.611	0.099	0.108
CEC After Test(meq/g)	0.427	0.657	0.105	0.107

Similar to the 10-10-10 (N-P-K) fertilizer series, the tests performed with the slow-release 16-0-8 (N-P-K) fertilizer were performed initially at the 0.25 in/hr rainfall intensity on the A-3 soil with Argentine Bahia sod as well as on the A-2-4 soil with Pensacola Bahia sod. Once the tests at the 0.25 in/hr rainfall intensity were completed, tests at the 0.1 in/hr rainfall intensity were performed afterward. As mentioned earlier, 0.1 in/hr rainfall intensity tests were not performed for 16-0-8 (N-P-K) fertilizer. As shown in Table 55, total nitrogen before and after fertilizer application is higher in the A-3 soil than the A-2-4 soil. Total phosphorus values are similar for both soil types and intensities. CEC values of the A-3 soil are lower than the CEC of the A-2-4 soil, which suggests that the A-2-4 soil has a higher nutrient retaining capacity than the A-3 soil. This is also evident in the amount of total nitrogen present in the A-3 soil prior to fertilizer addition and its decline in subsequent tests after the addition of fertilizer.

Table 55: Comparison of Total Nitrogen, Total Phosphorus, and CEC for A-2-4 Soil vs. A-3 Soil with Slow-Release 16-0-8 (N-P-K)

	A-2-4, 16-0-8 (SR) (NPK)		**A-3, 16-0-8 (SR) (NPK)**
Intensity (in/hr)	**0.1**	**0.25**	**0.25**
Total Nitrogen Before Test (g)	2168.148	1046.017	9965.839
Total Nitrogen After Test (g)	486.0391	490.7509	8013.258
Total Phosphorus Before Test (g)	792.3054	568.3142	798.8168
Total Phosphorus After Test (g)	551.6417	508.5108	690.3401
CEC Before Test(meq/g)	0.4891	0.5232	0.049775
CEC After Test(meq/g)	0.4325	0.49705	0.051625

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The objective of this research was to evaluate the environmental benefit of switching to a slow-release 16-0-8 (N-P-K) fertilizer from an all-purpose 10-10-10 (N-P-K) fertilizer by the Florida Department of Transportation. This was done by simulating a typical highway cross section, soil and sod, as well as typical rainfall intensities found in Florida. The rate of fertilizer application was 0.5 lb N per 1000 ft^2. Comparing the tests performed at a rainfall intensity of 0.25 in/hr on the A-2-4 soil with Pensacola Bahia sod, it was found that there was 2.09 grams less total nitrogen (TN) collected and 1.83 grams less total phosphorus (TP) collected because of the fertilizer switch. Comparison of the A-3 soil with Argentine Bahia sod at a rainfall intensity of 0.25 in/hr showed a similar trend: 0.48 grams less total nitrogen (TN) and 0.02 grams less of total phosphorus (TP) was collected.

Results at a rainfall intensity of 0.1 in/hr, available only for the A-2-4 soil with Pensacola Bahia sod combination, show that at this rainfall intensity there was no apparent benefit to the switch in fertilizers, In fact, the slow-release 16-0-8 (N-P-K) showed greater losses than the 10-10-10 (N-P-K) fertilizer. This may be attributed to more nutrients inherent to the soil and sod used for the slow-release 16-0-8 (N-P-K) fertilizer trials in addition to higher average temperatures occurring during testing at the 0.1 in/hr rainfall intensity. Higher average temperatures increase the rate of biological and chemical transformations taking place in the soil thereby creating more easily leachable forms of nitrogen.

A secondary objective of this study was to examine the effect of soil and sod types on nutrient losses from fertilized highway slopes. The combination of A-3 soil and Argentine Bahia sod with 10-10-10 (N-P-K) fertilizer resulted in 4.31 grams less TN lost and 1.89 grams less TP lost at a rainfall intensity of 0.25 in/hr compared to the combination of A-2-4 soil and Pensacola Bahia sod. Runoff, generated only for the A-2-4 soil with Pensacola Bahia sod, was a major source of these losses. At the 0.1 in/hr rainfall intensity, there did not appear to be a difference in TN lost. However, less TP was lost from the A-3 soil with Argentine Bahia sod combination than the A-2-4 soil with Pensacola Bahia sod combination, although losses from both soil and sod combinations were low. The combination of A-3 soil and Argentine Bahia with slow-release 16-0-8 (N-P-K) fertilizer showed that 2.70 grams less TN was lost and 0.08 grams less TP was lost from the A-3 soil with Argentine Bahia sod combination compared to the A-2-4 soil with Pensacola Bahia sod combination. This difference can be attributed to the higher infiltration capacity of the A-3 soil compared with the A-2-4 soil as well as possible higher nutrient uptake capacity of Argentine Bahia compared with Pensacola Bahia. A higher infiltration capacity resulted in no runoff being generated for any tests with the A-3 soil.

While the masses leaving the system were low, the concentrations coming off the test bed are still elevated when comparing to typical stormwater concentrations (see discussion on page 16). High concentrations are of particular concern when the fertilized area is extensive and can have a large environmental impact on surface water bodies as well as springsheds. Although runoff was found to be a major source of nutrient loss when it occurred, baseflow losses of total nitrogen were also considerable. Total phosphorus losses in baseflow were observed to be lower than total nitrogen. This suggests that nitrogen tends to be lost from soil easily via both runoff and baseflow, while phosphorus has a lower tendency to leach through the soil column but readily runs off from the soil surface. Nitrogen, particularly nitrate, tends to be highly mobile in soil and moves with the soil water. Phosphorus does not leach as easily from soil as nitrogen, however once the capacity of the soil to absorb phosphorus is exceeded, the excess will move freely through the soil column. However, phosphorus does readily adsorb to soil particles which increases its potential for being lost via runoff.

This study differed from Chopra (2011) in that soil sampling was performed to analyze total nitrogen and total phosphorus present in the soil as well as the CEC for all tests. The results from these tests provided valuable information as to the nutrients inherent to each batch of soil before and after fertilization as well as the cation exchange capacity of the soil. Total nitrogen and total phosphorus tended to increase over time in the A-2-4 soil with Pensacola Bahia sod indicating that an unintentional accumulation of nutrients could have occurred. For the A-3 soil with Argentine Bahia sod combination, the total nitrogen and total phosphorus tended to decrease over time, indicating that the sod placed on the test bed was already heavily fertilized.

The cation exchange capacity tended to decrease over time with the application of fertilizer likely due to exchange sites being utilized by cations introduced to the soil via fertilizer. In addition, fertilizer application can also cause a decline in soil pH as a result of nitrification and the subsequent release of H^+ ions, which also decreases CEC. This too indicates that an unintended accumulation of nutrients could have occurred.

The final objective of this study was to compare mass balance results based on literature models adopted from Chopra (2011) to actual soil nutrient analyses. The results of these comparisons show that while prior to the addition to fertilizer the predicted values followed actual measured values closely, the values of predicted total nitrogen and total phosphorus were less correlated as tests with fertilizer addition commenced. While this difference was not statistically significant ($\alpha = 0.05$), this variability suggests that the models may not account for the full extent of nutrient build-up in the soil. The mass balance models, adopted from Chopra (2011), were performed on only one foot of soil. Thus, because this study was performed on three feet of soil, more nutrients may have been retained in the test bed than the model could accurately predict.

Recommendations

The experimental findings of this study suggest that there is an environmental benefit to applying slow-release fertilizers with no phosphorus. This finding was more evident at the 0.25 in/hr rainfall intensity than the 0.1 in/hr rainfall intensity suggesting that the physicochemical processes occurring in the soil are more complex at low rainfall intensities. Thus, the magnitude of nutrient losses depends more on these physicochemical processes than rainfall intensities due to the low erosive force occurring at low intensity rainfall. In addition, the nature of the A-2-4 soil with Pensacola Bahia sod combination results in runoff even at the relatively low rainfall intensity of 0.25 in/hr, whereas the A-3 soil with Argentine Bahia combination did not generate any runoff at the same rainfall intensity. This reduction in runoff potential can result in the loss of fewer nutrients as more nutrients are lost to the environment via runoff than baseflow. As a result, it is suggested that A-3 soil gets preferential use in highway construction, if possible. Furthermore, it was observed that new sod could come already heavily fertilized from the sod farm. If the sod was recently fertilized prior to harvesting, applications of fertilizer could be reduced or avoided entirely after sod placement and applied later on, as needed.

The mass balance models adopted for this study are based on limited results from literature. In order to more closely approximate actual field conditions, extensive laboratory and modeling studies should be performed on these soil and sod types. In addition, because of the limited amount of measured soil data, taking more soil samples in the field, especially at various depths, could improve correlation between predicted and measured values.

APPENDIX A: SOIL CHARACTERISTICS

Table 56: Sieve Analysis of A-2-4

Sieve No.	Sieve opening (*mm*)	Mass of soil retained on each sieve, W_n (*g*)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
10	2.000	0.80	0.2	0.2	99.84
20	0.850	9.18	1.8	2.0	98.00
40	0.425	73.14	14.6	16.6	83.38
60	0.250	175.78	35.2	51.8	48.22
100	0.150	167.53	33.5	85.3	14.71
140	0.106	49.08	9.8	95.1	4.90
200	0.075	12.74	2.5	97.7	2.35
Pan	--	9.20	1.8		
		$W_1 = \sum$	**497.5**	g	

Table 57: Washed Sieve Analysis of A-2-4

Item	**Test No.**		
	1	**2**	**3**
Can No.	SW9	SW10	SW29
Mass of can, W_1 (g)	60.79	60.41	60.96
Mass of can + dry soil, W_3 (g)	110.59	112.59	119.83
Mass of can + Washed and Dried Soil (g)	100.03	101.67	107.71
Mass of dry soil, W_3 - W_1 (g)	**49.79**	**52.18**	**58.87**
Mass of washed & dried soil, W_4 (g)	**39.23**	**41.26**	**46.75**
Passing Sieve 200 (%)	**21.2**	**20.9**	**20.6**
Average	**20.91**		

Table 58: Sieve Analysis of A-3

Sieve No.	**Sieve opening (*mm*)**	**Mass of soil retained on each sieve, W_n (*g*)**	**Percent of mass retained on each sieve, R_n**	**Cumulative percent retained, $\sum R_n$**	**Percent finer, 100 - $\sum R_n$**
10	2.000	4.98	1.0	1.0	99.00
20	0.850	3.40	0.7	1.7	98.33
40	0.425	26.67	5.3	7.0	93.00
60	0.250	108.19	21.6	28.6	71.37
100	0.150	259.16	51.8	80.4	19.58
140	0.106	75.61	15.1	95.5	4.47
200	0.075	11.97	2.4	97.9	2.08
Pan	--	10.09	2.0		

		$W_1 = \sum$	**500.1**	g	

Table 59: Maximum Dry Unit Weight for A-2-4

					Moisture Content Determination			
Trial No.	Mass of Moist Specimen + Mold, M_t (*kg*)	Mass of Mold, M_{md} (*kg*)	Mass of Moist Specimen (*kg*)	Moist Density of Compacted Specimen, ρ_m (Mg/m^3)	Theoretical Moisture Content, *w* (%)	Mass of Wet Soil + Can, M_{cws} (*g*)	Mass of Dry Soil + Can, M_{cs} (*g*)	Mass of Water, M_w (*g*)
1	6.06	4.28	1.78	1.88	13.60	89.13	84.87	4.26
2	6.19	4.28	1.91	2.03	15.00	85.69	80.89	4.80
3	6.26	4.28	1.98	2.10	16.00	83.15	77.93	5.22
4	6.28	4.28	2.00	2.12	17.00	100.06	92.03	8.03
5	6.22	4.28	1.94	2.06	18.00	87.06	79.90	7.16
	Moisture Content Determination				Unit Weight			
Trial No.	Mass of Can, M_c (*g*)	Mass of Dry Soil, M_s (*g*)	Moisture Content, *w* (%)	Dry Density of Compacted Specimen ρ_d (Mg/m^3)	Dry Unit Weight, γ_d (lb/ft^3)	Moist Density of Compacted Specimen ρ_m (Mg/m^3)	Moist Unit Weight, γ_m (lb/ft^3)	zero-air-void Unit Weight, γ_m (lb/ft^3)
1	37.78	47.09	9.04	1.72	107.68	1.88	117.41	119.92
2	37.48	43.41	11.06	1.82	113.88	2.03	126.47	116.78
3	37.59	40.33	12.95	1.86	115.95	2.10	130.97	114.63
4	37.83	54.19	14.82	1.85	115.22	2.12	132.29	112.56
5	37.72	42.18	16.97	1.76	109.71	2.06	128.33	110.57

Table 60: Maximum Dry Unit Weight for A-3

					Moisture Content Determination			
Trial No.	Mass of Moist Specimen + Mold, M_t (*kg*)	Mass of Mold, M_{md} (*kg*)	Mass of Moist Specimen (*kg*)	Moist Density of Compacted Specimen, ρ_m (Mg/m^3)	Theoretical Moisture Content, *w* (%)	Mass of Wet Soil + Can, M_{cws} (*g*)	Mass of Dry Soil + Can, M_{cs} (*g*)	Mass of Water, M_w (*g*)
1	6.02	4.32	1.70	1.80	8.00	151.46	143.39	8.06
2	6.05	4.32	1.73	1.83	10.00	166.75	155.99	10.76
3	6.08	4.32	1.76	1.86	11.00	212.90	196.99	15.91
4	6.08	4.32	1.76	1.86	13.00	196.78	180.55	16.23
5	6.04	4.32	1.72	1.82	16.00	209.67	189.77	19.90
	Moisture Content Determination				Unit Weight			
Trial No.	Mass of Can, M_c (*g*)	Mass of Dry Soil, M_s (*g*)	Moisture Content, *w* (%)	Dry Density of Compacted Specimen ρ_d (Mg/m^3)	Dry Unit Weight, γ_d (lb/ft^3)	Moist Density of Compacted Specimen ρ_m (Mg/m^3)	Moist Unit Weight, γ_m (lb/ft^3)	zero-air-void Unit Weight, γ_m (lb/ft^3)
1	49.65	93.74	8.60	1.66	103.54	1.80	112.45	134.37
2	50.54	105.45	10.20	1.66	103.84	1.83	114.44	128.82
3	49.71	147.27	10.81	1.68	105.07	1.86	116.42	126.22
4	50.23	130.32	12.45	1.66	103.53	1.86	116.42	121.31
5	50.02	139.75	14.24	1.60	99.59	1.82	113.77	114.63

Table 61: Specific Gravity Test of A-2-4

Item	Test No.		
	1	2	3
Volumetric flask No.	1	2	3
Mass of flask + water filled to mark, W_1 (g)	702.58	703.19	705.08
Mass of flask + soil +water filled to mark, W_2 (g)	763.00	758.89	757.35
Mass of dry soil, W_S (g)	100.00	100.00	100.00
Mass of equal volume of water as the soil solids, W_W (g) = $(W_1 + W_S) - W_2$	39.58	44.30	47.73
$G_{S(T1°C)} = W_S / W_W$	2.53	2.26	2.10
$G_{S(20°C)} = G_{S(T1°C)} \times A$	2.52	2.25	2.09
Average G_S	2.29		

Table 62: Specific Gravity Test of A-3

Item	Test No.		
	1	2	3
Volumetric flask No.	1	2	3
Mass of flask + water filled to mark, W_1 (g)	681.53	681.68	681.63
Mass of flask + soil +water filled to mark, W_2 (g)	712.9	743.98	737.12
Mass of dry soil, W_S (g)	50.37	101.44	89.89
Mass of equal volume of water as the soil solids, W_W (g) = $(W_1 + W_S) - W_2$	19.00	39.14	34.40
$G_{S(T1°C)} = W_S / W_W$	2.65	2.59	2.61
$G_{S(20°C)} = G_{S(T1°C)} \times A$	2.65	2.59	2.61
Average G_S	2.62		

Table 63: Nuclear Density Testing Data for Batch 1 of A-2-4

Soil Density Testing by Nuclear Gauge (Data Sheet)

Company:	Stormwater Management Academy and Reseach Testing Laboratory		
Project:	Fertilizer Testing - After Soil Placement		
Tested by:	Ikiensinma Gogo-Abite		
Date:	Friday, November 16, 2012	*Time:*	8.50 am
Test Duration:	60 seconds	*Location:*	"East" Rainfall Bed

Standard Count

Trials	*Density*	*Variation*	*Moisture*	*Variation*
#1	2553	**-8.80**	3760	**-24.80**
#2	2574	**12.20**	3813	**28.20**
#3	2568	**6.20**	3818	**33.20**
#4	2598	**36.20**	3805	**20.20**
#5	2516	**-45.80**	3728	**-56.80**
Average	**2561.8**	***C.V.***	**3784.8**	***C.V.***
Std. Dev.	**30.30**	**0.0118**	**39.20**	**0.0104**

Transmission at 2 inches

Test Point Location	***Gauge Reading***		***Ratio, R***		***Density (pcf)***		***Water***	
	Density	***Moisture***	***Density***	***Moisture***	***Moist, γ_m***	***Dry, γ_d***	***Density, M (pcf)***	***MC, %***
Front-Side	5386	1204	**2.102**	**0.318**	**103.9**	**91.6**	**12.3**	10.55
Middle	5428	1172	**2.119**	**0.310**	**103.4**	**91.5**	**11.9**	11.81
Back-Side	5706	1490	**2.227**	**0.394**	**100.2**	**84.3**	**15.9**	11.32
Average values =					**102.50**	**89.1**	**13.4**	**11.2**

Transmission at 8 inches

Test Point Location	***Gauge Reading***		***Ratio, R***		***Density (pcf)***		***Water***	
	Density	***Moisture***	***Density***	***Moisture***	***Moist, γ_m***	***Dry, γ_d***	***Density, M (pcf)***	***MC, %***
Front-Side	2241	1240	**0.875**	**0.328**	**106.06**	**93.27**	**12.79**	10.55
Middle	2266	1234	**0.884**	**0.326**	**105.60**	**92.88**	**12.72**	11.81
Back-Side	2428	1317	**0.948**	**0.348**	**102.64**	**88.89**	**13.75**	11.32
Average values =					**104.77**	**91.68**	**13.09**	**11.23**

Overall average dry density: 90 (pcf)

Table 64: Sand Cone Testing Data for Batch 2 of A-2-4

Item	Quantity
Calibration of Unit of Ottawa Sand	
1. Weight of Proctor mold, W_1	9.4
2. Weight of Proctor mold + sand, W_2	12.67
3. Volume of mold, V_1 (ft^3)	0.033333
4. Dry unit Weight, $\gamma_{d(sand)}=(W_2-W_1)/V_1$	**98.1**
Calibration Cone	
5. Weight of bottle + cone + sand (before use), W_3	8.15
6. Weight of bottle + cone + sand (after use), W_4	4.15
7. Weight of sand to fill the cone, $W_c = W_4 - W_3$	**4**
Results from Field Tests	
8. Weight of bottle + cone + sand (before use), W_6	8.67
9. Weight of bottle + cone + sand (after use), W_8	3.9
10. Volume of hole, $V_2 = (W_6 - W_8 - W_c)/\gamma_{d(sand)}$	**0.007849**
Can Number	**1**
11. Weight of moisture can, W_5	0.137485
12. Weight of moisture can + moist soil, W_7	0.45
13. Weight of moisture can + dry soil, W_9	0.42067
14. Moist unit weight of soil in field, $\gamma = (W_7 - W_5)/V_2$	**39.81522**
15. Moisture content in the field, $w(\%)=((W_7 - W_9)/(W_9 - W_5))*100$	**10.35719**
16. Dry unit weight in the field, $\gamma_{d(sand)}/((1)+(w(\%)/100))$	**88.89317**

Table 65: Sand Cone Testing Data for Batch 1 of A-3

Item	Quantity
Calibration of Unit of Ottawa Sand	
1. Weight of Proctor mold, W_1 (lb)	9.40
2. Weight of Proctor mold + sand, W_2 (lb)	12.65
3. Volume of mold, V_1 (ft^3)	0.03
4. Dry unit Weight, $\gamma_{d(sand)}=(W_2-W_1)/V_1$ (lb/ft^3)	97.50
Calibration Cone	
5. Weight of bottle + cone + sand (before use), W_3 (lb)	17.97
6. Weight of bottle + cone + sand (after use), W_4 (lb)	9.15
7. Weight of sand to fill the cone, $W_c = W_4 - W_3$ (lb)	8.82
Results from Field Tests	
8. Weight of bottle + cone + sand (before use), W_6 (lb)	11.90
9. Weight of bottle + cone + sand (after use), W_8 (lb)	7.35
10. Volume of hole, $V_2 = (W_6 - W_8 - W_c)/\gamma_{d(sand)}$ (lb/ft^3)	0.04
Can Number	1
11. Weight of moisture can, W_5 (lb)	0.13
12. Weight of moisture can + moist soil, W_7 (lb)	0.46
13. Weight of moisture can + dry soil, W_9 (lb)	0.44
14. Moist unit weight of soil in field, $\gamma = (W_7 - W_5)/V_2$ (lb/ft^3)	7.55
15. Moisture content in the field, $w(\%)=((W_7 - W_9)/(W_9 - W_5))*100$ (lb/ft^3)	7.56
16. Dry unit weight in the field, $\gamma_{d(sand)}/((1)+(w(\%)/100))$ (lb/ft^3)	90.65

Table 66: Sand Cone Testing Data for Batch 2 of A-3

Item	Quantity
Calibration of Unit of Ottawa Sand	
1. Weight of Proctor mold, W_1 (lb)	9.4
2. Weight of Proctor mold + sand, W_2 (lb)	12.65
3. Volume of mold, V_1 (ft3)	0.033333333
4. Dry unit Weight, $\gamma d(sand)=(W_2-W_1)/V_1$ (lb/ft^3)	97.5
Calibration Cone	
5. Weight of bottle + cone + sand (before use), W_3 (lb)	17.9676744
6. Weight of bottle + cone + sand (after use), W_4 (lb)	9.149184
7. Weight of sand to fill the cone, $Wc = W_4 - W_3$ (lb)	8.8184904
Results from Field Tests	
8. Weight of bottle + cone + sand (before use), W_6 (lb)	14.28595
9. Weight of bottle + cone + sand (after use), W_8 (lb)	12.08133
10. Volume of hole, $V_2 = (W_6 - W_8 - Wc)/\gamma d(sand)$ (lb/ft^3)	0.067834568
Can Number	
11. Weight of moisture can, W_5 (lb)	0.136445916
12. Weight of moisture can + moist soil, W_7 (lb)	0.514205569
13. Weight of moisture can + dry soil, W_9 (lb)	0.4850164
14. Moist unit weight of soil in field, $\gamma = (W_7 - W_5)/V_2$ (lb/ft^3)	5.568836993
15. Moisture content in the field, $w(\%)=((W_7 - W_9)/(W_9 - W_5))*100$ (lb/ft^3)	8.37396456
16. Dry unit weight in the field, $\gamma d(sand)/((1)+(w(\%)/100))$ (lb/ft^3)	90.21625748

APPENDIX B: WATER QUALITY ANALYSIS

Table 67: Water Quality Results for A-2-4 Batch 1

DATE	SITE	Alk. (mg/l)	Total N (µg/l)	Total P (µg /l)	Total Solids (mg/l)	pH (s.u.)
2/20/13	1	42.2	2,079	51	99	--
	2	134	14,344	40	321	--
2/23/13	1	45.8	1,331	55	127	--
	2	114	11,009	41	176	--
2/27/13	1	28.6	569	42	83	--
	2	106	9,090	32	278	--
	3	145	379	648	206	--
3/3/13	1	40.8	592	33	257	--
	2	95.8	8,256	29	240	--
	3	153	224	512	209	--
3/6/13	1	40.8	1,804	29	99	--
	2	91.4	7,944	24	249	--
	3	162	618	664	257	--
3/13/13	1	--	--	--	--	--
	2	104	6,378	20	197	--
3/16/13	1	37.6	3,871	1,209	104	--
	2	104	7,565	24	270	--
	3	194	8,258	6,300	272	--
3/27/13	1	33.2	5,656	1,229	153	--
	2	96.8	6,756	33	248	--
	3	179	9,047	5,292	307	--
4/3/13	1F	23	5,553	72	109	--
	2	99.2	7,251	26	221	--
	3F	177	456	547	224	--
4/6/13	1	53.2	14,287	2,887	185	--
	2	130	10,656	52	318	--
	3	216	38,894	15,428	346	--
	1F	23.6	10,872	141	158	--
	3F	173	807	1,042	249	--
4/10/13	1	45.4	3,392	354	153	--
	2	120	4,627	28	222	--
	1F	20.8	8,737	92	180	--
	3F	168	1,854	1,159	234	--
5/11/13	1F	25.8	5,624	69	179	6.88
	2	173	9,706	39	303	6.85
	3F	166	950	927	236	7.77

Table 68: Water Quality Results for A-2-4 Batch 2

DATE	SITE	Alk. (mg/l)	Total N (µg/l)	Total P (µg/l)	Total Solids (mg/l)	pH (s.u.)
6/12/13	1	126	7,912	58	249	7.37
	2	138	8,936	25	307	6.71
	3	48	8,133	76	196	6.49
6/14/13	2F	81	2,417	58	167	6.57
	3F	143	785	28	218	7.86
6/15/13	1	89.4	21,989	63	286	6.69
	1F	122	1,787	22	305	6.91
	2	171	7,866	15	328	7.47
	3	123	13,074	73	255	6.89
	3F	142	854	27	207	7.63
6/19/13	1	87.4	27,041	44	284	6.57
	1F	118	3,481	21	217	6.89
	2	149	9,268	10	284	7.01
	3F	152	1,447	24	199	7.74
6/22/13	1	76.4	31,314	39	369	6.51
	1F	115	4,128	25	216	6.92
	2	167	9,943	5	332	7.02
	3F	144	1,917	13	164	7.81
6/26/13	1	35.8	44,957	54	449	5.82
	2	176	22,177	9	296	6.99
	3	64.2	37,928	119	372	6.24
7/3/13	1	76	27,653	128	442	6.67
	2	201	9,051	10	368	6.89
	3	122	17,729	130	374	7.14

Table 69: Water Quality Results for A-3 Batch 1

DATE	SITE	Alk. (mg/l)	Total N (µg/l)	Total P (µg/l)	Total Solids (mg/l)	pH (s.u.)
9/7/13	1	398	22,863	70	837	7.44
	2	264	18,837	115	582	7.22
9/11/13	1	370	26,897	65	1,028	7.31
	2	286	12,283	104	598	7.14
9/14/13	1	380	34,136	56	995	7.51
	2	281	6,095	105	377	7.01
9/18/13	1	324	28,529	59	1,035	7.49
	1F	298	5,265	97	536	7.24
	2	329	3,639	97	476	7.19
	3F	105	1,104	581	197	7.2
9/29/13	1	310	6,570	375	625	7.23
	1F	270	5,032	85	531	7.14
	2	260	12,018	109	542	6.97
	3F	105	3,290	807	215	7.18
10/2/13	1	292	5,868	57	614	7.44
	2	278	9,406	122	470	7.14
	1F	243	2,612	95	403	7.34
	3F	133	1,379	1090	227	7.49
10/5/13	1	278	5,451	70	648	7.31
	2	224	5,855	55	384	7.92
	1F	249	3,164	75	425	7.1
	3F	134	3,441	780	207	7.51
10/9/13	1	296	2,400	90	538	7.51
	2	250	7,774	169	436	7.37
	1 F	262	2,827	130	422	7.26
	3 F	145	1,307	770	202	7.76
10/16/13	1	282	2,603	46	531	7.34
	2	254	3,857	95	414	7.17
10/23/13	1	260	1,953	41	541	7.19
	2	270	7,041	76	422	7.01
	1F	253	2,733	56	433	6.98
	3F	142	1,050	401	231	7.29

Table 70: Water Quality Results for A-3 Batch 2

DATE	SITE	Alk. (mg/l)	Total N (µg/l)	Total P (µg/l)	Total Solids (mg/l)	pH (s.u.)
1/13/14	1	243	5,941	64	374	7.67
	1F	244	4,851	64	412	7.54
	3F	109	779	52	185	7.26
1/16/14	1	241	5,445	43	425	7.81
	1F	270	4,764	39	420	7.84
	3F	115	506	56	183	7.46
1/20/14	1	244	2,177	40	385	7.49
	1F	185	1,709	56	353	7.65
	3F	117	227	49	219	7.37
1/23/14	1	196	2,635	42	248	7.46
	1F	175	1,289	61	197	175
	3F	128	194	69	140	128
1/28/14	1	188	1,214	51	252	7.35
	1F	185	997	63	261	7.46
	2	175	9,306	101	290	7.43
	3F	126	632	62	172	7.41
2/3/14	1	176	2,061	54	176	7.22
	1F	194	1,032	47	194	7.71
	2	176	3,761	65	176	7.46
	3F	131	617	56	131	7.92
2/13/14	1	189	10,193	34	189	7.29
	2	174	4,056	45	174	7.43
2/20/14	1	150	1,989	52	275	7.3
	1F	199	5,678	46	356	7.39
	2	178	4,932	74	261	7.26
	3F	141	445	72	147	7.52

APPENDIX C: SOIL ANALYSIS

Table 71: Soil Analysis Results for A-2-4 Batch 1

DATE	SITE	TOTAL NITROGEN (μg/g dry weight)	TOTAL PHOSPHORUS (μg/g dry weight)	CEC (meq/g)
2/20/13	1	18.8	12.9	0.5763
	2	33.2	33.1	0.6984
2/23/13	1	17.8	15.7	0.6174
	2	14.5	14.8	0.6739
2/27/13	1	22.6	16.6	0.556
	2	32.9	22.6	0.7118
3/3/13	1	11.5	20.7	0.5436
	2	13.8	22	0.6199
3/6/13	1	13	18.8	0.5963
	2	15.8	22.5	0.6848
3/13/13	1	10.6	21.1	0.5102
	2	16.5	22	0.7384
3/16/13	1	22.8	29.4	0.5359
	2	6.2	16.9	0.5935
	1 F	137	53.4	0.6212
	2 F	102	54.4	0.6409
3/27/13	1	97.5	44	0.6198
	1 A	109	60.6	0.6186
	2	120	49.4	0.6472
	2 A	105	36.7	0.7355
4/3/13	1	85.9	38.7	0.5285
	1 F	93.4	41.2	0.6038
	2	151	61.5	0.6178
	2 F	109	39.1	0.7264
4/6/13	1	109	66.3	0.6149
	1 A	147	46.6	0.6037
	2	84.3	39.4	0.7003
	2 A	89.2	39.2	0.7612
4/10/13	1	134	142.2	0.4266
	1 A	107.6	93.3	0.6325
	2	129	51.9	0.3923
	2 A	207	90	0.3125
5/11/13	1	74.3	67.7	0.225
	1 A	19.6	33.5	0.4625
	2	30.6	50.3	0.2805
	2 A	34.7	45.4	0.4819

Table 72: Soil Analysis Results for A-2-4 Batch 2

DATE	SITE	TOTAL NITROGEN (μg/g dry weight)	TOTAL PHOSPHORUS (μg/g dry weight)	CEC (meq/g)
6/12/13	1	199	61	0.5026
	1 A	45.1	36.6	0.5209
	2	15.3	28.5	0.4808
	2 A	43.6	36.8	0.5691
6/15/13	1	15	33.4	0.5115
	1 A	27.5	33.9	0.3873
	2	59.3	33.9	0.5979
	2 A	19.2	33	0.5109
6/19/13	1	14.1	34.6	0.5586
	1 A	14.7	41.2	0.3778
	2	163	51.1	0.5414
	2 A	9	30	0.503
6/22/13	1	73.1	39.4	0.4689
	1 A	76.3	40.4	0.4313
	2	348	93.5	0.3875
	2 A	34.1	33.4	0.4179
6/26/13	1	18.2	31.2	0.4545
	1 A	19.6	28.9	0.4626
	2	11.4	27.9	0.361
	2 A	20.8	28.4	0.4388
7/3/13	1	48.1	37.7	0.4418
	1 A	34.7	35.9	1.0049
	2	99.5	55.6	0.3947
	2 A	21	38	1.3392

Table 73: Soil Analysis Results for A-3 Batch 1

DATE	SITE	TOTAL NITROGEN (µg/g dry weight)	TOTAL PHOSPHORUS (µg/g dry weight)	CEC (meq/g)
9/7/13	1	388.8	116.5	0.1223
	2	446.7	179.4	0.0802
9/11/13	1	462	131.5	0.1204
	2	504.7	190.3	0.1611
9/14/13	1	545.1	210.4	0.1612
	2	284.9	159.6	0.1223
9/18/13	1	525	164.4	0.0802
	2	443.7	136.2	0.1204
9/29/13	1	500.5	159.3	0.1776
	2	509.6	175.7	0.1793
	1A	215.7	72.7	0.1939
	2A	334.8	295.2	0.1364
10/2/13	1	154.4	51.4	0.0183
	2	383.2	99.8	0.1162
	1A	193.5	60.2	0.1205
	2A	399.2	155.4	0.0667
10/5/13	1	618.9	350.7	0.0988
	2	368.7	131.2	0.053
	1A	275.2	67.2	0.0956
	2A	651.3	241.7	0.0564
10/9/13	1	156.5	64.2	0.086
	2	172.3	56.4	0.1584
	1A	429.8	120.3	0.1009
	2A	344.7	88.2	0.1681
10/16/13	1	542.7	178.9	0.1475
	2	431.6	125.2	0.0496
	1A	474.3	143	0.0552
	2A	212.9	88	0.0805
10/23/13	1	478.9	135.1	0.0663
	2	194.8	123.5	0.1119
	1A	210.9	54.5	0.1234
	2A	337.3	101.9	0.0805

Table 74: Soil Analysis Results for A-3 Batch 2

DATE	SITE	TOTAL NITROGEN (μg/g dry weight)	TOTAL PHOSPHORUS (μg/g dry weight)	CEC (meq/g)
1/13/14	1	484.3	33.9	0.042
	2	629	36.9	0.0642
1/16/14	1	524	30.6	0.0771
	2	845.8	64.1	0.1211
1/20/14	1	601.8	36.9	0.0507
	2	529.3	34.1	0.0744
1/23/14	1	528.9	37.9	0.0964
	2	418.2	29.6	0.0393
1/28/14	1	448.9	33	0.0358
	2	703.4	58.3	0.0725
	1F	370.4	32.9	0.0312
	2F	640.8	52.3	0.0565
2/3/14	1	737.2	59.7	0.049
	2	811.5	65.5	0.0418
	1F	453.2	56	0.2184
	2F	707.4	45.9	0.0594
2/13/2014	1	706	38	0.0491
	2	850	52	0.0418
	1A	843	53	0.2184
	2A	814	54	0.0594
2/20/2014	1	765	45	0.0336
	2	752	47	0.0689
	1F	594	46	0.0357
	2F	506	29	0.0201

APPENDIX D: MASS BALANCE RESULTS

Table 75: Moisture Balance of A-2-4 Batch 1

Date	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Natural Rainfall, in	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapo transpi ration (mm per day)	Bed Evapo transpi ration (L)	Rainfall Applied [L]	Collected Runoff and Baseflow [L]	Seepage + Final Storage [L]
2/20/2013	14.15%	2051.44	0.4675	0	0	0	68	11.3333	1.1875	13.2474	631.438	161.534	2508.1
2/21/2013					0	0	70	11.3667	1.22917	13.7122			
2/22/2013					0	0	73	11.3833	1.27552	14.2293			
2/23/2013	14.97%	2170.32	0.43664	296.585	0	0	79	11.4167	1.3776	15.3681	572.447	166.063	2561.34
2/24/2013					0.2	112.796	71	11.45	1.29531	14.4501			
2/25/2013					0.33	186.114	75	11.4833	1.3776	15.3681			
2/26/2013					0.15	84.5972	71	11.5	1.32813	14.8161			
2/27/2013	13.55%	1964.45	0.49008	920.39	0	0	67	11.5333	1.28333	14.3165	422.374	170.592	2201.92
2/28/2013					0	0	61	11.05	1.01719	11.3474			
3/1/2013					0	0	58	11.5833	1.14583	12.7826			
3/2/2013					0	0	53	11.6167	1.05781	11.8006			
3/3/2013	12.03%	1744.09	0.54728	407.586	0	0	47	11.6333	0.94063	10.4933	528.558	80.0121	2182.14
3/4/2013					0	0	48	11.6667	0.95833	10.6909			
3/5/2013					0	0	59	11.7	1.19688	13.352			
3/6/2013	13.55%	1964.45	0.49008	183.149	0	0	60	11.7167	1.22396	13.6541	323.27	78.9707	2195.1
3/7/2013					0	0	55	11.75	1.11719	12.463			
3/8/2013					0	0	59	11.7667	1.21563	13.5611			
3/9/2013					0	0	63	11.8	1.325	14.7813			

Date	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Natural Rainfall, in	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapo transpi ration (mm per day)	Bed Evapo transpi ration (L)	Rainfall Applied [L]	Collected Runoff and Baseflow [L]	Seepage + Final Storage [L]
3/10/2013					0	0	67	11.8333	1.44271	16.0944			
3/11/2013					0	0	67	11.85	1.45156	16.1932			
3/12/2013					0.2	112.796	65	11.8833	1.41406	15.7748			
3/13/2013	13.01%	1886.17	0.5104	319.207	0.01	5.63982	64	11.9167	1.40104	15.6296	328.326	28.3062	2176.2
3/14/2013					0	0	57	11.95	1.20781	13.474			
3/15/2013					0	0	57	11.9833	1.2151	13.5553			
3/16/2013	12.55%	1819.48	0.52771	319.701	0	0	61	12	1.34375	14.9904	3166.63	228.108	4743
3/17/2013					0	0	62	12.0333	1.3875	15.4785			
3/18/2013					0.02	11.2796	70	12.05	1.65625	18.4766			
3/19/2013					0	0	77	12.0833	1.91406	21.3527			
3/20/2013					0.75	422.986	69	12.1	1.65313	18.4417			
3/21/2013					0.15	84.5972	62	12.15	1.43125	15.9666			
3/22/2013					0	0	64	12.1833	1.51771	16.9311			
3/23/2013					0.16	90.2371	75	12.2	1.9375	21.6141			
3/24/2013					0.6	338.389	75	12.2333	1.96354	21.9046			
3/25/2013					0	0	65	12.25	1.58594	17.6922			
3/26/2013					0	0	55	12.2833	1.20052	13.3926			
3/27/2013	13.46%	1951.41	0.49346	3542.85	0	0	52	12.3167	1.08229	12.0737	601.706	337	2204.04
3/28/2013					0	0	56	12.35	1.25313	13.9795			
3/29/2013					0	0	61	12.3667	1.46979	16.3965			
3/30/2013					0	0	63	12.4	1.56875	17.5005			

Date	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Natural Rainfall, in	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapo transpi ration (mm per day)	Bed Evapo transpi ration (L)	Rainfall Applied [L]	Collected Runoff and Baseflow [L]	Seepage + Final Storage [L]
3/31/2013					0	0	71	12.4333	1.94063	21.649			
4/1/2013					0	0	73	12.45	2.04219	22.782			
4/2/2013					0	0	74	12.4833	2.1125	23.5664			
4/3/2013	10.31%	1494.72	0.61201	581.366	0.19	107.157	73	12.5167	2.0901	23.3165	3211.46	24.9094	4765.11
4/4/2013					0.08	45.1185	70	12.55	1.96875	21.9627			
4/5/2013					0.15	84.5972	68	12.5667	1.88125	20.9866			
4/6/2013	16.50%	2392.14	0.37906	2543.58	0.01	5.63982	67	12.6	1.85	20.638	3155.77	298.929	5233.98
4/7/2013					0	0	71	12.6167	2.06094	22.9912			
4/8/2013					0	0	72	12.65	2.13438	23.8104			
4/9/2013					0	0	73	12.6833	2.2099	24.6529			
4/10/2013	12.21%	1770.18	0.5405	3377.35	0	0	74	12.7	2.275	25.3792	2947.18	30.1932	4661.79
4/11/2013					0	0	81	12.7333	2.67917	29.8879			
4/12/2013					0	0	80	12.75	2.64063	29.458			
4/13/2013					0	0	79	12.8	2.63125	29.3534			
4/14/2013					3.37	1900.62	79	12.8167	2.64635	29.5219			
4/15/2013					0	0	78	12.85	2.61875	29.2139			
4/16/2013					0	0	79	12.8667	2.69167	30.0274			
4/17/2013					0	0	76	12.9	2.54375	28.3773			
4/18/2013					0	0	77	12.9333	2.63125	29.3534			
4/19/2013					0	0	82	12.95	2.95	32.9093			
4/20/2013					0.15	84.5972	68	12.9833	2.11563	23.6012			

Date	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Natural Rainfall, in	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapo transpi ration (mm per day)	Bed Evapo transpi ration (L)	Rainfall Applied [L]	Collected Runoff and Baseflow [L]	Seepage + Final Storage [L]
4/21/2013					2.03	1144.88	71	13	2.3125	25.7975			
4/22/2013					0.22	124.076	73	13.0333	2.46146	27.4592			
4/23/2013					0	0	73	13.05	2.47344	27.5929			
4/24/2013					0	0	72	13.0833	2.43229	27.1339			
4/25/2013					0	0	74	13.1167	2.5875	28.8653			
4/26/2013					0	0	76	13.1167	2.71979	30.3411			
4/27/2013					0	0	76	13.15	2.74688	30.6433			
4/28/2013					0.01	5.63982	74	13.1667	2.625	29.2837			
4/29/2013					1.62	913.65	75	13.2	2.71875	30.3295			
4/30/2013					0.51	287.631	77	13.2333	2.88438	32.1772			
5/1/2013					0.41	231.232	74	13.25	2.6875	29.9809			
5/2/2013					1.49	840.333	73	13.2667	2.62917	29.3301			
5/3/2013					1.26	710.617	75	13.2833	2.78385	31.0558			
5/4/2013					0.06	33.8389	77	13.3	2.94063	32.8047			
5/5/2013					0	0	71	13.3333	2.53125	28.2378			
5/6/2013					0	0	70	13.3667	2.47917	27.6568			
5/7/2013					0	0	69	13.3833	2.4151	26.9421			
5/8/2013					0	0	71	13.4	2.575	28.7259			
5/9/2013					0	0	72	13.4167	2.66146	29.6904			
5/10/2013					0.04	22.5593	77	13.45	3.06719	34.2166			
5/11/2013	9.48%	1374.39	0.64324	8681.73	0.04	22.5593	79	13.4667	3.23542	36.0933	344.034	23.3998	1681.49

Table 76: Mass Balance of Total Nitrogen for A-2-4 Batch 1

	BEFORE Fert. Application				AFTER Fert. Application								
Date of Test	Total N - mass (g) in test bed	Ammo niacal N in test bed (g)	Nitrate N in test bed (g)	Applied (Ammo niacal N) (g)	Ammo niacal N in test bed (g)	Nitrate N in test bed (g)	Temp°F	Avg pH	Volu metric Air Content	Total Day Light Hours	Ammonia Volati lization per day k_{volati}	Nitrifi cation per day k_{nitri}	Denitri fication per day $k_{denitri}$
2/20/2013	376.9	37.7	339.2	0.0	37.7	339.2	68	6.80	0.202	11.33	0.0012	0.13	0.001
2/23/2013	373.7	22.3	351.4	0.0	22.3	351.4	79	6.80	0.155	11.42	0.0019	0.12	0.001
2/27/2013	368.5	11.6	356.9	0.0	11.6	356.9	67	6.80	0.235	11.53	0.0011	0.15	0.001
3/3/2013	362.0	4.8	357.2	0.0	4.8	357.2	47	6.80	0.321	11.63	0.0000	0.17	0.001
3/6/2013	358.2	2.4	355.8	0.0	2.4	355.8	60	6.80	0.235	11.72	0.0006	0.15	0.001
3/13/2013	352.9	0.0	352.9	0.0	0.0	352.9	64	6.80	0.266	11.92	0.0009	0.15	0.001
3/16/2013	348.5	0.0	348.5	27.2	27.2	348.5	61	6.70	0.292	12.00	0.0005	0.16	0.001
3/27/2013	364.2	0.0	364.2	27.2	27.2	364.2	52	6.70	0.240	12.32	0.0001	0.15	0.001
4/3/2013	363.0	0.0	363.0	0.0	0.0	363.0	73	6.70	0.418	12.52	0.0011	0.19	0.001
4/6/2013	354.9	0.0	354.9	27.2	27.2	354.9	67	6.80	0.069	12.60	0.0011	0.08	0.002
4/10/2013	334.2	18.5	315.7	27.2	45.7	315.7	74	6.70	0.311	12.70	0.0012	0.17	0.001
5/11/2013	293.1	0.0	293.1	27.2	27.2	293.1	79	7.17	0.465	13.47	0.0040	0.20	0.001

Date of Test	Grass uptake grams per (day*Test bed)	No. of days to next test	Ammonia volati lization loss up to next test	Conver sion to Nitrate up to next test	Denitri fication loss up to next test	Grass uptake up to next test	Seepage Since Previous Test (L)	Avg. Conc. of TN (mg/L)	TN lost in seepage since previous test (g)	TN lost in test (irr.+ rain+ flush) (g)	TN lost in test (RAIN only) (g)	% loss in sim rain w.r.to TN after fert. Application

2/20/2013	0.09	3.0	0.13	15.25	1.35	0.274725	0	8.21	0.00	1.41	1.41	0.37
2/23/2013	0.12	4.0	0.17	10.54	2.07	0.4662	279.5	6.17	1.72	0.78	0.78	0.21
2/27/2013	0.15	4.0	0.05	6.75	1.70	0.5883	662.4	4.83	3.20	1.00	1.00	0.27
3/3/2013	0.17	3.0	0.00	2.45	0.99	0.524475	439.3	4.42	1.94	0.33	0.33	0.09
3/6/2013	0.20	7.0	0.01	2.34	2.93	1.3986	151.4	4.87	0.74	0.26	0.26	0.07
3/13/2013	0.26	3.0	0.00	0.00	1.14	0.7659	353.0	6.38	2.25	0.18	0.18	0.05
3/16/2013	0.28	11.0	0.16	27.06	4.14	3.0525	318.0	5.72	1.82	2.36	1.47	0.39
3/27/2013	0.37	7.0	0.02	27.20	3.17	2.5641	3543.0	6.26	22.18	0.50	0.50	0.13
4/3/2013	0.42	3.0	0.00	0.00	0.74	1.2654	581.4	7.25	4.22	1.87	0.18	0.05
4/6/2013	0.44	4.0	0.12	8.57	2.52	1.776	2543.6	12.47	31.72	11.80	8.57	2.24
4/10/2013	0.47	31.0	1.67	44.04	10.59	14.62425	3377.3	4.01	13.54	27.83	0.24	0.07
5/11/2013	0.68	0.0	0.00	0.00	0.00	0	8681.7	9.71	84.30	0.23	0.23	0.07

Table 77: Mass Balance of Total Phosphorus for A-2-4 Batch 1

Date of Test	Total P - mass (g) in test bed	Extra-ctable P (g) **X**	Non-extra-ctable P (g) **Y**	P_{Buffer} (g)	Applied P (g)	Partition co-efficient R	Extra-ctable P (g) **X**	Non-extra-ctable P (g) **Y**	**P_{Buffer}** (g)	Total Day Light Hrs	X to Y K_1	Y to X K_2	X to P_{buffer} K_3	P_{buffer} to X K_4
2/20/2013	333.5	333.5	0.0	0.000	0.0	0.65	333.5	0.0	0.000	11.33	0.0079	0.0014	0.0004	0.0003
2/23/2013	333.4	330.6	2.6	0.149	0.0	0.99	330.6	2.6	0.149	11.42	0.0079	0.0014	0.0004	0.0003
2/27/2013	333.3	327.8	5.3	0.297	0.0	0.98	327.8	5.3	0.297	11.53	0.0079	0.0014	0.0004	0.0003
3/3/2013	333.0	324.7	7.9	0.443	0.0	0.98	324.7	7.9	0.443	11.63	0.0079	0.0014	0.0004	0.0003
3/6/2013	332.8	321.8	10.4	0.588	0.0	0.97	321.8	10.4	0.588	11.72	0.0079	0.0014	0.0004	0.0003
3/13/2013	332.5	318.8	13.0	0.732	0.0	0.96	318.8	13.0	0.732	11.92	0.0079	0.0014	0.0004	0.0003
3/16/2013	332.3	316.0	15.5	0.874	27.2	0.95	341.9	16.8	0.874	12.00	0.0079	0.0014	0.0004	0.0003
3/27/2013	356.2	335.7	19.5	1.027	27.2	0.95	361.4	21.0	1.027	12.32	0.0079	0.0014	0.0004	0.0003
4/3/2013	373.8	348.8	23.8	1.188	0.0	0.94	348.8	23.8	1.188	12.52	0.0079	0.0014	0.0004	0.0003
4/6/2013	372.3	344.4	26.5	1.344	27.2	0.93	369.7	28.5	1.344	12.60	0.0079	0.0014	0.0004	0.0003
4/10/2013	391.5	358.7	31.4	1.509	27.2	0.92	383.7	33.6	1.509	12.70	0.0079	0.0014	0.0004	0.0003
5/11/2013	414.7	376.4	36.6	1.680	27.2	0.91	401.2	39.0	1.680	13.47	0.0079	0.0014	0.0004	0.0003

Date of Test	X to Y	Y to X	X to P_{buffer}	P_{buffer} to X	Grass uptake grams per (day*Test bed)	No. of days to next test	Grass uptake up to next test	Seepage Since Previous Test (L)	Avg. Conc. of TP (mg/L)	TP lost in seepage since previous test (g)	TP lost in test (irr.+ rain+ flush)	TP lost in test (RAIN only)	% loss in sim rain w.r.to TP after fert. Application
2/20/2013	2.650	0.000	0.149	0.000	0.02	3.0	0.055	0	0.046	0.00	0.01	0.01	0.00002
2/23/2013	2.627	0.004	0.148	0.000	0.02	4.0	0.093	279.5	0.048	0.01	0.01	0.01	0.003
2/27/2013	2.604	0.008	0.146	0.000	0.03	4.0	0.118	662.4	0.241	0.16	0.01	0.01	0.002
3/3/2013	2.580	0.011	0.145	0.000	0.03	3.0	0.105	439.3	0.191	0.08	0.00	0.00	0.001
3/6/2013	2.557	0.015	0.144	0.000	0.04	7.0	0.280	151.4	0.239	0.04	0.02	0.02	0.007
3/13/2013	2.533	0.018	0.142	0.000	0.05	3.0	0.153	353.0	0.020	0.01	0.00	0.00	0.000
3/16/2013	2.717	0.024	0.153	0.000	0.06	11.0	0.611	318.0	2.511	0.80	1.98	0.78	0.228
3/27/2013	2.872	0.030	0.161	0.000	0.07	7.0	0.513	3543.0	2.190	7.76	1.30	1.30	0.359
4/3/2013	2.772	0.034	0.156	0.000	0.08	3.0	0.253	581.4	0.026	0.01512	1.24	0.0007	0.0002
4/6/2013	2.937	0.041	0.165	0.000	0.09	4.0	0.355	2543.6	1.47	3.73909	3.89	3.04	0.819
4/10/2013	3.048	0.048	0.171	0.000	0.09	31.0	2.925	3377.3	0.191	0.64506	0.489	0.382	0.099

5/11/2013	3.188	0.056	0.179	0.000	0.14	0	0	8681.7	0.039	0.33859	0.0009	0.0009	0.0002

Table 78: Moisture Balance of A-2-4 Batch 2

Date	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Natural Rainfall, in	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapo transpi ration (mm per day)	Bed Evapo transpi ration (L)	Rainfall Applied [L]	Collected Runoff and Base flow [L]	Seepage + Final Storage [L]
6/12/2013	16.49%	2390.69	0.37944	0	0.01	5.63982	83	13.9333	4.025	44.9016	3617.63	269.742	5699.32
6/13/2013					0	0	83	13.9167	4.00781	44.7099			
6/14/2013					0	0	83	13.9167	4.00781	44.7099			
6/15/2013	15.69%	2274.71	0.40954	3295.93	0	0	84	13.9	4.08125	45.5291	3785.64	240.177	5774.64
6/16/2013					1.38	778.295	84	13.9	4.08125	45.5291			
6/17/2013					0.57	321.47	82	13.9	3.9	43.5072			
6/18/2013					0.31	174.834	83	13.8833	3.97344	44.3264			
6/19/2013	15.27%	2213.82	0.42535	4656.53	0	0	83	13.8833	3.97344	44.3264	3136.03	155.495	5150.02
6/20/2013					0.14	78.9574	84	13.8833	4.06354	45.3316			
6/21/2013					0.3	169.194	81	13.8667	3.77708	42.1359			
6/22/2013	14.90%	2160.17	0.43927	3106.21	0.01	5.63982	82	13.85	3.85	42.9494	3350.68	104.921	5368.62
6/23/2013					0.01	5.63982	82	13.85	3.85	42.9494			
6/24/2013					0	0	82	13.85	3.85	42.9494			
6/25/2013					0	0	83	13.8333	3.92188	43.7512			
6/26/2013	14.68%	2128.28	0.44755	3079.02	0	0	83	13.8333	3.92188	43.7512	634.741	254.044	2465.22
6/27/2013					0	0	82	13.8333	3.83333	42.7634			
6/28/2013					0.24	135.356	83	13.8167	3.90469	43.5594			
6/29/2013					0	0	82	13.8	3.8	42.3916			

Date	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Natural Rainfall, in	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapo transpi ration (mm per day)	Bed Evapo transpi ration (L)	Rainfall Applied [L]	Collected Runoff and Base flow [L]	Seepage + Final Storage [L]
6/30/2013					0.41	231.232	82	13.8	3.8	42.3916			
7/1/2013					0.27	152.275	79	13.8	3.5375	39.4632			
7/2/2013					0.64	360.948	78	13.7833	3.43542	38.3244			
7/3/2013	13.62%	1974.6	0.48744	1077.79	0.06	33.8389	82	13.7833	3.78333	42.2057	436.532	209.594	2193.17

Table 79: Mass Balance of Total Nitrogen for A-2-4 Batch 2

	BEFORE Fert. Application				AFTER Fert. Application								
Date of Test	Total N - mass (g) in test bed	Ammo niacal N in test bed (g)	Nitrate N in test bed (g)	Applied (Ammo niacal N) (g)	Ammo niacal N in test bed (g)	Nitrate N in test bed (g)	Temp°F	Avg pH	Volu metric Air Content	Total Day Light Hours	Ammonia Volati lization per day k_{volati}	Nitrifi cation per day k_{nitri}	Denitri fication per day $k_{denitri}$
6/12/2013	1553.4	155.3	1398.1	27.2	182.5	1398.1	83	6.86	0.379	13.933	0.002441	0.184689	0.000771
6/15/2013	1566.5	80.1	1486.5	27.2	107.3	1486.5	84	7.02	0.41	13.9	0.003537	0.192094	0.000696
6/19/2013	1530.6	23.3	1507.3	27.2	50.5	1507.3	83	6.79	0.425	13.883	0.00206	0.195576	0.000661
6/22/2013	1459.1	20.6	1438.5	27.2	47.8	1438.5	82	6.77	0.439	13.85	0.001897	0.198771	0.000629
6/26/2013	1406.4	9.4	1397.0	27.2	36.6	1397.0	83	6.35	0.448	13.833	0.000404	0.200798	0.000609
7/3/2013	1304.6	0.0	1304.6	0	0.0	1304.6	82	6.9	0.487	13.783	0.002592	0.209356	0.000526

Date of Test	Grass uptake grams per (day*Test bed)	No. of days to next test	Ammonia volati lization loss up to next test	Conver sion to Nitrate up to next test	Denitri fication loss up to next test	Grass uptake up to next test	Seepage Since Previous Test (L)	Avg. Conc. of TN (mg/L)	TN lost in seepage since previous test (g)	TN lost in test (irr.+ rain+ flush) (g)	TN lost in test (RAIN only) (g)	% loss in sim rain w.r.to TN after fert. Application
6/12/2013	0.81	3.0	1.34	101.14	3.47	2.441723	0	8.327	0.00	4.635887	2.216688	0.14
6/15/2013	0.80	4.0	1.52	82.42	4.37	3.219	3295.9	14.3	47.13	6.86	3.65	0.23
6/19/2013	0.80	3.0	0.31	29.65	3.05	2.400098	4656.5	18.16	84.56	8.43	3.8	0.24
6/22/2013	0.79	4.0	0.36	37.98	3.72	3.1635	3106.2	20.62	64.05	8.58	2.01	0.14
6/26/2013	0.79	7.0	0.10	36.52	6.12	5.503103	3079	35.02	107.83	9.51	9.51	0.66
7/3/2013	0.77	0	0	0	0	0	1077.8	18.14	19.55	4.15	4.15	0.32

Table 80: Mass Balance of Total Phosphorus for A-2-4 Batch 2

Date of Test	Total P - mass (g) in test bed	Extra-ctable P (g) **X**	Non-extra-ctable P (g) **Y**	P_{Buffer} (g)	Applied P (g)	Partition co-efficient R	Extra-ctable P (g) **X**	Non-extra-ctable P (g) **Y**	$\mathbf{P_{Buffer}}$ (g)	Total Day Light Hrs	X to Y K_1	Y to X K_2	X to P_{buffer} K_3	P_{buffer} to X K_4
6/12/2013	648.8	648.8	0.0	0.000	27.2	1.00	676.0	0.0	0.000	13.933	0.0079	0.0014	0.0004	0.0003
6/15/2013	674.7	669.0	5.4	0.302	27.2	0.99	696.0	5.6	0.302	13.9	0.0079	0.0014	0.0004	0.0003
6/19/2013	699.8	688.0	11.1	0.613	27.2	0.98	714.8	11.5	0.613	13.883	0.0079	0.0014	0.0004	0.0003
6/22/2013	725.3	707.1	17.2	0.932	27.2	0.98	733.7	17.9	0.932	13.85	0.0079	0.0014	0.0004	0.0003
6/26/2013	750.5	725.6	23.7	1.260	27.2	0.97	751.9	24.5	1.260	13.833	0.0079	0.0014	0.0004	0.0003
7/3/2013	775.4	743.3	30.5	1.595	0	0.96	743.3	30.5	1.595	13.783	0.0079	0.0014	0.0004	0.0003

Date of Test	X to Y	Y to X	X to P_{buffer}	P_{buffer} to X	Grass uptake grams per (day*Test bed)	No. of days to next test	Grass uptake up to next test	Seepage Since Previous Test (L)	Avg. Conc. of TP (mg/L)	TP lost in seepage since previous test (g)	TP lost in test (irr.+ rain+ flush)	TP lost in test (RAIN only)	% loss in sim rain w.r.to TP after fert. Application
6/12/2013	5.371	0.000	0.302	0.000	0.16	3.0	0.488	0	0.307	0	0.773	0.096	0.014
6/15/2013	5.530	0.008	0.311	0.000	0.16	4.0	0.644	3295.9	0.233	0.76794	0.735	0.062	0.009
6/19/2013	5.679	0.016	0.319	0.000	0.16	3.0	0.480	4656.5	0.115	0.5355	0.67	0.025	0.003
6/22/2013	5.829	0.025	0.328	0.000	0.16	4.0	0.633	3106.2	0.1455	0.45195	0.9	0.014	0.002
6/26/2013	5.974	0.035	0.336	0.000	0.16	7.0	1.101	3079	0.364	1.12076	0.109	0.109	0.014
7/3/2013	5.906	0.043	0.332	0.000	0.15	0.0	0.000	1077.8	0.298	0.32118	0.107	0.107	0.014

Table 81: Moisture Balance of A-3 Batch 1

Date	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Natural Rainfall, in	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapo transpi ration (mm per day)	Bed Evapo transpi ration (L)	Rainfall Applied [L]	Collected Runoff and Base flow [L]	Seepage + Final Storage [L]
6/12/2013	16.49%	2390.69	0.37944	0	0.01	5.63982	83	13.9333	4.025	44.9016	3617.63	269.742	5699.32
6/13/2013					0	0	83	13.9167	4.00781	44.7099			
6/14/2013					0	0	83	13.9167	4.00781	44.7099			
6/15/2013	15.69%	2274.71	0.40954	3295.93	0	0	84	13.9	4.08125	45.5291	3785.64	240.177	5774.64
6/16/2013					1.38	778.295	84	13.9	4.08125	45.5291			
6/17/2013					0.57	321.47	82	13.9	3.9	43.5072			
6/18/2013					0.31	174.834	83	13.8833	3.97344	44.3264			
6/19/2013	15.27%	2213.82	0.42535	4656.53	0	0	83	13.8833	3.97344	44.3264	3136.03	155.495	5150.02
6/20/2013					0.14	78.9574	84	13.8833	4.06354	45.3316			
6/21/2013					0.3	169.194	81	13.8667	3.77708	42.1359			
6/22/2013	14.90%	2160.17	0.43927	3106.21	0.01	5.63982	82	13.85	3.85	42.9494	3350.68	104.921	5368.62
6/23/2013					0.01	5.63982	82	13.85	3.85	42.9494			
6/24/2013					0	0	82	13.85	3.85	42.9494			
6/25/2013					0	0	83	13.8333	3.92188	43.7512			
6/26/2013	14.68%	2128.28	0.44755	3079.02	0	0	83	13.8333	3.92188	43.7512	634.741	254.044	2465.22
6/27/2013					0	0	82	13.8333	3.83333	42.7634			
6/28/2013					0.24	135.356	83	13.8167	3.90469	43.5594			
6/29/2013					0	0	82	13.8	3.8	42.3916			
6/30/2013					0.41	231.232	82	13.8	3.8	42.3916			
7/1/2013					0.27	152.275	79	13.8	3.5375	39.4632			

Date	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Natural Rainfall, in	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapo transpi ration (mm per day)	Bed Evapo transpi ration (L)	Rainfall Applied [L]	Collected Runoff and Base flow [L]	Seepage + Final Storage [L]
7/2/2013					0.64	360.948	78	13.7833	3.43542	38.3244			
7/3/2013	13.62%	1974.6	0.48744	1077.79	0.06	33.8389	82	13.7833	3.78333	42.2057	436.532	209.594	2193.17

Table 82: Mass Balance of Total Nitrogen for A-3 Batch 1

	BEFORE Fert. Application				AFTER Fert. Application								
Date of Test	Total N - mass (g) in test bed	Ammoniacal N in test bed (g)	Nitrate N in test bed (g)	Applied (Ammoniacal N) (g)	Ammoniacal N in test bed (g)	Nitrate N in test bed (g)	Temp°F	Avg pH	Volumetric Air Content	Total Day Light Hours	Ammonia Volatilization per day k_{volati}	Nitrification per day k_{nitri}	Denitrification per day $k_{denitri}$
9/7/2013	6165.5	616.5464	5548.917	0	616.5464	5548.9	81	7.33	0.721	12.56667	0.005484	0.254735	0.000156
9/11/2013	6144.7	614.473	5530.257	0	614.473	5530.3	84	7.23	0.715	12.45	0.005144	0.253673	0.000162
9/14/2013	6124.4	612.4402	5511.961	0	612.4402	5512.0	84	7.26	0.64	12.36667	0.005398	0.24	0.000259
9/18/2013	6097.6	609.7587	5487.828	0	609.7587	5487.8	80	7.34	0.612	12.25	0.005387	0.234691	0.000301
9/29/2013	6028.0	602.8027	5425.225	27.2	630.0027	5425.2	80	7.1	0.708	11.96667	0.00363	0.252428	0.000171
10/2/2013	6010.6	601.059	5409.531	27.2	628.259	5409.5	88	7.29	0.67	11.86667	0.006324	0.245561	0.000218
10/5/2013	5992.2	599.2164	5392.947	27.2	626.4164	5392.9	90	7.62	0.692	11.8	0.010498	0.24956	0.00019
10/9/2013	5955.7	595.5716	5360.145	27.2	622.7716	5360.1	83	7.44	0.723	11.68333	0.006843	0.255088	0.000153
10/16/2013	5914.0	591.3967	5322.57	27.2	618.5967	5322.6	87	7.26	0.685	11.48333	0.005874	0.248294	0.000198
10/23/2013	5895.9	589.5865	5306.279	0	589.5865	5306.3	83	7.1	0.729	11.01667	0.003993	0.256144	0.000147
10/27/2013	5869.8	586.9843	5282.859	27.2	614.1843	5282.9	80	7.04	0.698	11.01667	0.003245	0.250639	0.000182

Date of Test	Grass uptake grams per (day*Test bed)	No. of days to next test	Ammonia volatilization loss up to next test	Conversion to Nitrate up to next test	Denitrification loss up to next test	Grass uptake up to next test	Seepage Since Previous Test (L)	Avg. Conc. of TN (mg/L)	TN lost in seepage since previous test (g)	TN lost in test (irr.+ rain+ flush) (g)	TN lost in test (RAIN only) (g)	% loss in sim rain w.r.to TN after fert. Application
9/7/2013	0.43	4.0	13.52	603.02	3.83	1.739	0	20.85	0	1.64	1.64	0.0266
9/11/2013	0.40	3.0	9.48	467.63	2.92	1.207125	224.4	19.59	4.395996	2.32	2.32	0.037756
9/14/2013	0.38	4.0	13.22	587.94	6.32	1.517	219.9	20.1	4.41999	1.33	1.33	0.021716
9/18/2013	0.35	11.0	36.13	573.63	20.08	3.815625	137.9	16.08	2.217432	7.32	0.843	0.013825
9/29/2013	0.27	3.0	6.86	477.09	3.02	0.80475	2262.9	9.29	21.02234	12.93	1.08	0.017836

10/2/2013	0.24	3.0	11.92	462.83	3.84	0.7215	2651.1	7.34	19.45907	9.69	0.789	0.013068
10/5/2013	0.22	4.0	26.30	600.11	4.55	0.888	3548.3	5.65	20.0479	11.86	0.442	0.007343
10/9/2013	0.19	7.0	29.83	592.94	6.39	1.327375	4407.9	5.09	22.43621	8.96	0.129	0.002156
10/16/2013	0.13	7.0	25.44	593.16	8.22	0.938875	3239.9	3.23	10.46488	0.244	0.244	0.004107
10/23/2013	0.00	4.0	9.42	580.17	3.46	0.0185	959.6	4.5	4.3182	8.81	2.67	0.045286
10/27/2013	0	0	0	0	0	0	3326.2	3.12	10.37774	2.18	2.18	0.036968

Table 83: Mass Balance of Total Phosphorus for A-3 Batch 1

Date of Test	Total P - mass (g) in test bed	Extra-ctable P (g) **X**	Non-extra-ctable P (g) **Y**	P_{Buffer} (g)	Applied P (g)	Partition co-efficient R	Extra-ctable P (g) **X**	Non-extra-ctable P (g) **Y**	**P_{Buffer}** (g)	Total Day Light Hrs	X to Y K_1	Y to X K_2	X to P_{buffer} K_3	P_{buffer} to X K_4
9/7/2013	2183.56	2183.56	0	0	0	1	2183.56	0	0	12.57	0.0079	0.0014	0.0004	0.0003
9/11/2013	2183.20	2164.88	17.35	0.98	0	0.99	2164.88	17.35	0.98	12.45	0.0079	0.0014	0.0004	0.0003
9/14/2013	2182.93	2146.47	34.52	1.94	0	0.98	2146.47	34.52	1.94	12.37	0.0079	0.0014	0.0004	0.0003
9/18/2013	2182.60	2128.17	51.53	2.90	0	0.98	2128.17	51.53	2.90	12.25	0.0079	0.0014	0.0004	0.0003
9/29/2013	2181.66	2109.44	68.36	3.85	27.2	0.97	2135.79	69.22	3.85	11.97	0.0079	0.0014	0.0004	0.0003
10/2/2013	2207.67	2116.77	86.09	4.80	27.2	0.96	2142.91	87.15	4.80	11.87	0.0079	0.0014	0.0004	0.0003
10/5/2013	2233.69	2123.87	104.05	5.76	27.2	0.95	2149.80	105.32	5.76	11.80	0.0079	0.0014	0.0004	0.0003
10/9/2013	2259.97	2131.00	122.25	6.72	27.2	0.95	2156.72	123.73	6.72	11.68	0.0079	0.0014	0.0004	0.0003
10/16/2013	2285.60	2137.23	140.69	7.68	27.2	0.94	2162.75	142.37	7.68	11.48	0.0079	0.0014	0.0004	0.0003
10/23/2013	2312.38	2144.38	159.35	8.65	0	0.93	2144.38	159.35	8.65	11.02	0.0079	0.0014	0.0004	0.0003
10/27/2013	2311.99	2126.22	176.16	9.61	27.2	0.92	2151.34	178.24	9.61	11.02	0.0079	0.0014	0.0004	0.0003

Date of Test	X to Y	Y to X	X to P_{buffer}	P_{buffer} to X	Grass uptake grams per (day*Test bed)	No. of days to next test	Grass uptake up to next test	Seepage Since Previous Test (L)	Avg. Conc. of TP (mg/L)	TP lost in seepage since previous test (g)	TP lost in test (irr.+ rain+ flush)	TP lost in test (RAIN only)	% loss in sim rain w.r.to TP after fert. Application
9/7/2013	17.35	0	0.975	0	0.08695	4	0.348	0	0.0925	0	0.008	0.008	0.00037
9/11/2013	17.20	0.025	0.967	0	0.08048	3	0.241	224.4	0.0845	0.0189618	0.008	0.008	0.00037
9/14/2013	17.05	0.049	0.959	0	0.07585	4	0.303	219.9	0.0805	0.017702	0.006	0.006	0.00028
9/18/2013	16.91	0.073	0.950	0	0.06938	11	0.763	137.9	0.078	0.0107562	0.174	0.005	0.00023
9/29/2013	16.97	0.099	0.954	0	0.05365	3	0.161	2262.9	0.242	0.5476218	0.482	0.035	0.00164
10/2/2013	17.03	0.124	0.957	0	0.04810	3	0.144	2651.1	0.0895	0.2372735	0.794	0.009	0.00042
10/5/2013	17.08	0.150	0.960	0	0.04440	4	0.178	3548.3	0.0625	0.2217688	0.519	0.006	0.00028

10/9/2013	17.14	0.176	0.963	0	0.03793	7	0.265	4407.9	0.1295	0.5708231	0.735	0.005	0.00023
10/16/2013	17.18	0.203	0.966	0	0.02683	7	0.188	3239.9	0.0705	0.228413	0.005	0.005	0.00023
10/23/2013	17.04	0.227	0.958	0	0.00093	4	0.004	959.6	0.0585	0.0561366	0.329	0.329	0.01528
10/27/2013	17.09	0.254	0.961	0	0.00093	0	0	3326.2	1.07	3.559034	0.866	0.866	0.04007

Table 84: Moisture Balance of A-3 Batch 2

Date	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Natural Rainfall, in	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapo transpi ration (mm per day)	Bed Evapo transpi ration (L)	Rainfall Applied [L]	Collected Runoff and Base flow [L]	Seepage + Final Storage [L]
1/13/2014	0.09183	1355.26	0.64821	0	0	0	65	10.5	0.76563	8.54107	2343.11	33.2126	3656.62
1/14/2014					0.04	22.5593	68	10.5167	0.72813	8.12273			
1/15/2014					0	0	59	10.5333	0.86875	9.6915			
1/16/2014	0.09528	1406.19	0.63499	2246.64	0.09	50.7583	49	10.55	1.01406	11.3126	2354.91	12.0773	3788.47
1/17/2014					0	0	50	10.5667	1	11.1557			
1/18/2014					0	0	47	10.5833	1.03906	11.5914			
1/19/2014					0	0	50	10.6	1	11.1557			
1/20/2014	0.09183	1355.26	0.64821	2438.75	0	0	56	10.6167	0.92813	10.3539	2140.19	56.6123	3428.48
1/21/2014					0	0	64	10.6333	0.83958	9.36612			
1/22/2014					0	0	49	10.6667	1.01042	11.2719			
1/23/2014	0.08313	1226.82	0.68155	2170.67	0	0	50	10.6667	1	11.1557	2055.24	42.2705	3228.64
1/24/2014					0	0	51	10.6833	0.9901	11.0453			
1/25/2014					0.01	5.63982	58	10.7167	0.92917	10.3655			
1/26/2014					0	0	58	10.7333	0.93333	10.412			
1/27/2014					0.44	248.152	68	10.7667	0.86875	9.6915			
1/28/2014	0.09367	1382.51	0.64114	2047.25	0	0	67	10.7833	0.8849	9.87161	3624.39	93.599	4903.43
1/29/2014					0.61	344.029	57	10.7833	0.9526	10.6269			
1/30/2014					0.3	169.194	49	10.8167	1.00573	11.2196			
1/31/2014					0.44	248.152	58	10.8333	0.95833	10.6909			
2/1/2014					0.01	5.63982	69	10.8667	0.92083	10.2725			

Date	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Natural Rainfall, in	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapo transpi ration (mm per day)	Bed Evapo transpi ration (L)	Rainfall Applied [L]	Collected Runoff and Base flow [L]	Seepage + Final Storage [L]
2/2/2014					0	0	74	10.8833	0.9125	10.1796			
2/3/2014	0.09292	1371.33	0.64404	4236.26	0	0	74	10.9	0.925	10.319	3846.2	40.006	5167.21
2/4/2014					0.1	56.3982	74	10.9333	0.95	10.5979			
2/5/2014					0	0	76	10.95	0.95937	10.7025			
2/6/2014					0.01	5.63982	62	10.9833	0.99375	11.086			
2/7/2014					0.12	67.6778	56	11.0167	1.00313	11.1905			
2/8/2014					0.51	287.631	58	11.0167	1.00417	11.2022			
2/9/2014					0	0	61	11.05	1.01719	11.3474			
2/10/2014					0	0	63	11.0833	1.03385	11.5333			
2/11/2014					0	0	66	11.1	1.05	11.7135			
2/12/2014					0.71	400.427	66	11.1167	1.05833	11.8064			
2/13/2014	0.13497	1991.95	0.48294	3881.53	0	0	57	11.15	1.03281	11.5217	436.532	86.8056	2330.16
2/14/2014					0	0	55	11.1667	1.02604	11.4462			
2/15/2014					0	0	60	11.2167	1.06771	11.911			
2/16/2014					0	0	59	11.2167	1.06094	11.8355			
2/17/2014					0	0	62	11.25	1.09375	12.2015			
2/18/2014					0	0	67	11.2833	1.15052	12.8348			
2/19/2014					0	0	70	11.3	1.1875	13.2474			
2/20/2014	0.09	1328.29	0.65521	916.874	0	0	72	11.3333	1.22917	13.7122	436.532	209.594	1541.51

Table 85: Mass Balance of Total Nitrogen for A-3 Batch 2

	BEFORE Fert. Application				AFTER Fert. Application								
Date of Test	Total N - mass (g) in test bed	Ammoniacal N in test bed (g)	Nitrate N in test bed (g)	Applied (Ammoniacal N) (g)	Ammoniacal N in test bed (g)	Nitrate N in test bed (g)	Temp°F	Avg pH	Volumetric Air Content	Total Day Light Hours	Ammonia Volatilization per day k_{volati}	Nitrification per day k_{nitri}	Denitrification per day $k_{denitri}$
1/13/2014	8215.5	821.5453	7393.907	0	821.5453	7393.9	65	7.67	0.648	10.5	0.004183	0.241495	0.000248
1/16/2014	8188.7	818.8693	7369.824	0	818.8693	7369.8	49	7.81	0.635	10.55	0	0.239061	0.000266
1/20/2014	8156.8	815.681	7341.129	0	815.681	7341.1	56	7.49	0.648	10.61667	0.001332	0.241495	0.000248
1/23/2014	8138.9	813.8917	7325.025	0	813.8917	7325.0	50	7.46	0.6825	10.66667	0	0.247841	0.000202
1/28/2014	8122.7	812.2682	7310.413	27.2	839.4682	7310.4	67	7.39	0.641	10.78333	0.003285	0.240187	0.000258
2/3/2014	8106.2	810.6241	7295.617	27.2	837.8241	7295.6	74	7.34	0.644	10.9	0.004309	0.240749	0.000253
2/13/2014	8061.2	806.1223	7255.101	27.2	833.3223	7255.1	57	7.36	0.483	11.15	0.001295	0.208495	0.000535
2/20/2014	8021.9	802.1868	7219.681	0	802.1868	7219.7	72	7.28	0.655	11.33333	0.003604	0.242796	0.000238

Date of Test	Grass uptake grams per (day*Test bed)	No. of days to next test	Ammonia volatilization loss up to next test	Conversion to Nitrate up to next test	Denitrification loss up to next test	Grass uptake up to next test	Seepage Since Previous Test (L)	Avg. Conc. of TN (mg/L)	TN lost in seepage since previous test (g)	TN lost in test (irr.+ rain+ flush) (g)	TN lost in test (RAIN only) (g)	% loss in sim rain w.r.to TN after fert. Application
1/13/2014	0.00	3.0	10.31	595.20	5.94	0	0	5.94	0	10.51	0.197	0.002398
1/16/2014	0.00	4.0	0.00	783.04	8.69	0	2246.6	5.45	12.24397	10.95	0.066	0.000806
1/20/2014	0.00	3.0	3.26	590.95	5.90	0	2438.7	2.18	5.316366	3.42	0.123	0.001508
1/23/2014	0.00	5.0	0.00	813.89	8.20	0	2170.7	2.64	5.730648	2.3	0.111	0.001364

1/28/2014	0.00	6.0	16.54	822.92	12.58	0	2047.2	5.26	10.76827	3.75	0.352	0.004319
2/3/2014	0.00	10.0	36.11	801.72	20.52	0	4236.256	2.91	12.32751	3.26	0.102	0.001254
2/13/2014	0.04	7.0	7.55	825.77	30.24	0.291375	3881.528	7.13	27.67529	0.797	0.797	0.009854
2/20/2014	0.09	0	0	0	0	0	916.8742	3.46	3.172385	0.185	0.185	0.002306

Table 86: Mass Balance of Total Phosphorus for A-3 Batch 2

Date of Test	Total P - mass (g) in test bed	Extractable P (g) **X**	Non-extractable P (g) **Y**	P_{Buffer} (g)	Applied P (g)	Partition co-efficient R	Extractable P (g) **X**	Non-extractable P (g) **Y**	**P_{Buffer}** (g)	Total Day Light Hrs	X to Y K_1	Y to X K_2	X to P_{buffer} K_3	P_{buffer} to X K_4
1/13/2014	522.46	522.46	0	0	0	1	522.46	0	0	10.50	0.0079	0.0014	0.0004	0.0003
1/16/2014	522.32	517.93	4.15	0.23	0	0.99	517.93	4.15	0.23	10.55	0.0079	0.0014	0.0004	0.0003
1/20/2014	522.12	513.40	8.26	0.46	0	0.98	513.40	8.26	0.46	10.62	0.0079	0.0014	0.0004	0.0003
1/23/2014	521.91	508.89	12.33	0.69	0	0.98	508.89	12.33	0.69	10.67	0.0079	0.0014	0.0004	0.0003
1/28/2014	521.70	504.43	16.35	0.92	27.2	0.97	530.77	17.21	0.92	10.78	0.0079	0.0014	0.0004	0.0003
2/3/2014	548.52	525.96	21.40	1.16	27.2	0.96	552.10	22.46	1.16	10.90	0.0079	0.0014	0.0004	0.0003
2/13/2014	575.31	547.09	26.82	1.40	27.2	0.95	573.02	28.09	1.40	11.15	0.0079	0.0014	0.0004	0.0003
2/20/2014	602.29	568.03	32.60	1.66	0	0.95	568.03	32.60	1.66	11.33	0.0079	0.0014	0.0004	0.0003

Date of Test	X to Y	Y to X	X to P_{buffer}	P_{buffer} to X	Grass uptake grams per (day*Test bed)	No. of days to next test	Grass uptake up to next test	Seepage Since Previous Test (L)	Avg. Conc. of TP (mg/L)	TP lost in seepage since previous test (g)	TP lost in test (irr.+ rain+ flush)	TP lost in test (RAIN only)	% loss in sim rain w.r.to TP after fert. Application
1/13/2014	4.15	0	0.23	0	0	3	0	0	0.019	0	0.144	0.002	0.00038
1/16/2014	4.12	0.01	0.23	0	0	4	0	2246.60	0.043	0.097	0.098	0.0005	0.00010
1/20/2014	4.08	0.01	0.23	0	0	3	0	2438.70	0.040	0.098	0.115	0.002	0.00039
1/23/2014	4.04	0.02	0.23	0	0	5	0	2170.70	0.042	0.091	0.116	0.002	0.00039
1/28/2014	4.22	0.02	0.24	0	0	6	0	2047.20	0.076	0.156	0.228	0.006	0.00113
2/3/2014	4.39	0.03	0.25	0	0	10	0	4236.26	0.060	0.254	0.154	0.002	0.00036
2/13/2014	4.55	0.04	0.26	0	0.008	7	0.058	3881.53	0.040	0.155	0.003	0.003	0.00052
2/20/2014	4.51	0.05	0.25	0	0.019	0	0	916.87	0.063	0.058	0.003	0.003	0.00053

APPENDIX E: STATISTICAL ANALYSES

Table 87: Wilcoxon Rank Sum Test: Statistical Difference Between Predicted and Measured Values on Batch 1 of A-2-4

Parameter	N	p-Value	Median	Significance (α = .05)
Total Nitrogen	12	0.29	-464.3	Not Significant
Total Phosphorus	12	0.126	-168.4	Not Significant

Table 88: Wilcoxon Rank Sum Test: Statistical Difference Between Predicted and Measured Values on Batch 2 of A-2-4

Parameter	N	p-Value	Median	Significance (α = .05)
Total Nitrogen	6	0.59	240.7	Not Significant
Total Phosphorus	6	0.418	88.79	Not Significant

Table 89: Wilcoxon Rank Sum Test: Statistical Difference Between Predicted and Measured Values on Batch 1 of A-3

Parameter	N	p-Value	Median	Significance (α = .05)
Total Nitrogen	11	0.61	-334.1	Not Significant
Total Phosphorus	11	0.838	22.28	Not Significant

Table 90: Wilcoxon Rank Sum Test: Statistical Difference Between Predicted and Measured Values on Batch 1 of A-3

Parameter	N	p-Value	Median	Significance (α = .05)
Total Nitrogen	7	0.076	-1624	Not Significant
Total Phosphorus	7	0.052	-85.5	Not Significant

REFERENCES

Al-Kanani, T., et al. (1991). "Soil water and ammonia volatilization relationships with surface-applied nitrogen fertilizer solutions." Soil science Society of America Journal **55**(6): 1761-1766.

Ansari, A. A. (2010). Eutrophication: Causes, Consequences, and Control. Dordrecht, Springer.

Avnimelech, Y. and M. Laher (1977). "Ammonia Volatilization from Soils: Equilibrium Considerations." Soil science Society of America Journal **41**: 1080-1084.

Badruzzaman, M., et al. (2012). "Sources of Nutrient Impacting Surface Waters in Florida: A Review." Journal of Environmental Management **109**: 80-92.

Baird, J. V. (1990). Nitrogen Management and Water Quality. North Carolina, North Carolina Cooperative Extension Service.

Barton, L. and T. D. Colmer (2006). "Irrigation and fertiliser strategies for minimising nitrogen leaching from turfgrass." Agricultural Water Management **80**: 160-175.

Barton, L., et al. (2006). "Turfgrass (*Cynodon dactylon* L.) sod production on sandy soils: II. Effects of irrigation and fertiliser regimes on N leaching." Plant and Soil **284**(1-2): 147-164.

Bowman, D. C., et al. (2002). "Fate and Transport of Nitrogen Applied to Six Warm-Season Turfgrasses." 37.

Brown, K. W., et al. (1982). "Nitrogen Source Effect on Nitrate and Ammonium Leaching and Runoff Losses from Greens." Agronomy Journal **74**(6): 947-950.

Buchholz, D. D. (1983). Soil Test Interpretation and Recommendations Handbook. U. o. M.-C. o. Agriculture.

Cao, W. and J. Wang (2007). "Assessing nitrate leaching with the GLEAMS model in an agricultural catchment in southeast China." Methodology in Hydrology **311**.

Capel, P. D., et al. (2004). Studies by the U.S. Geological Survey on Sources, Transport, and Fate of Agricultural Chemicals.

Carpenter, S. R., et al. (1998). Nonpoint Pollution of Surface Waters with Phosphorus and Nitrogen. Issues in Ecology. **8:** 559-568.

Chopra, M., Wanielista, M., Kakuturu, S., Hardin, M., Stuart, E. (2011). Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions. Florida Department of Transportation Final Report.

Cloern, J. (2001). "Our Evolving Conceptual Model of the Coastal Eutrophication Problem." Marine Ecology Press Series **210**: 223-253.

Domagalski, J. L. and H. Johnson (2012). Phosphorus and Groundwater: Establishing Links Between Agricultural Use and Transport to Streams. U.S. Geological Survey Fact Sheet 2012-3004**:** 4.

Easton, Z. M. and A. M. Petrovic (2004). "Fertilizer Source Effect on Ground and Surface Water Quality and Drainage from Turfgrass." Journal of Environmental Quality **33**(2): 645-655.

EPA (2012). "What is Nonpoint Source Pollution?". from http://water.epa.gov/polwaste/nps/whatis.cfm.

Erickson, J. E., et al. (2005). "Phosphorus and potassium leaching under contrasting residential landscape models established on a sandy soil." Crop Science **45**(2): 546-552.

Erickson, J. E., et al. (2001). "Comparing nitrogen runoff and leaching between newly St. Augustinegrass turf and an alternative residential landscape." Crop Science **41**(6): 1889-1895.

Erickson, J. E., et al. (2010). "Effects of Sod Type, Irrigation, and Fertilization on Nitrate-Nitrogen and Orthophosphate-Phosphorus Leaching from Newly Established St. Augustine Sod." Crop Science **50**(3): 1030-1036.

Erickson, J. E., et al. (1999). "A Facility for Documenting the Effect of Urban Landscape Type on Fertilizer Nitrogen Runoff " Proceedings of the Florida State Horticultural Society **112**: 266-269.

Fan, X. H., et al. (2011). "Effects of Temperature and Soil Type on Ammonia Volatilization from Slow-Release Nitrogen Fertilizers." Communications in Soil Science and Plant Analysis **42**: 1111-1122.

FDEP and Water Management Districs (2010). Stormwater Quality Permitting Requirements. Environmental Resouce Permit: Stormwater Quality Applicant's Handbook: Design Requirements for Stormwater Treatment Systems in Florida.

Ferrell, J., et al. (2012). A Guide for Roadside Vegetation Management. FDOT.

Florida Climate Center (2014). Florida State University Center for Ocean-Atmospheric Prediction Studies.

Florida Department of Transportation (2009). Plans Preparation Manual Volume 2: Plans Preparation and Assembly. Tallahassee, Florida.

Florida Lakewatch (2000). A Beginner's Guide to Water Management - Nutrients. D. o. F. a. A. Sciences. Florida, University of Florida Institute of Food and Agricultural Sciences.

Follett, R. (2008). Chapter 2. Transformation and Transport Processes of Nitrogen in Agricultural Systems, USDA-ARS/UNL Faculty.

Greenwood, D. J., et al. (2001). "Dynamic Model for the Effects of Soil P and Fertilizer P on Crop Growth, P Uptake and Soil P in Arable Cropping: Model Design." Annals of Botany **88**: 279-291.

Greenwood, D. J., et al. (2001b). "Dynamic Model for the E€ ects of Soil P and Fertilizer P on Crop Growth, P Uptake and Soil P in Arable Cropping: Experimental Test of the Model for Field Vegetables." Annals of Botany **88**: 293-306.

Harper, H. (2011). New Updates to the Florida Runoff Concentration (emc) Database. Tampa, Florida, Florida Stormwater Association.

Harper, H. H. and D. M. Baker (2007). Evaluation of Current Stormwater Design Criteria within the State of Florida, Florida Department of Environmental Protection.

Harrison, R. and J. Webb (2001). "A review of the effect of N fertilizer type on gaseous emissions." Advances in Agronomy **73**: 65-108.

He, Z. L., et al. (1999). "Ammonia volatilization from different fertilizer sources and effects of temperature and soil pH." Soil Science **164**(10): 750-758.

Helling, C. S., et al. (1964). "Contribution of organic matter and clay to soil cation-exchange capacity as affected by the pH of the saturating solution." Proceedings - Soil Science Society of America **28**(4): 517-520.

Holford, I. C. R. (1997). "Soil Phosphorus: Its Measurement, and its Uptake by Plants." Australian Journal of Soil Research **35**(2): 227-239.

Hora, T. S. and M. R. S. Iyengar (1960). "Nitrification by Soil Fungi." Archiv Fur Mikrobiologie **35**(3): 252-257.

Hosking, J. S. (1948). "The cation exchange capacity of soils and soil colloids 2. The contribution from the sand, silt, and clay fractions of organic matter." Journal of the Council for Scientific and Industrial Research **21**: 38-50.

Hutson, J. L. and R. J. Wagenet (1991). "Simulating nitrogen dynamics in soils using a deterministic model." Soil Use and Management **7**(2): 74-78.

Irmak, S., et al. (2005). "Using Modified Bellani Plate Evapotranspiration Gauges to Estimate Short Canopy Reference Evapotranspiration." Journal of Irrigation and Drainage Engineering **131**(2): 164-175.

Kakuturu, S., Chopra, M., Hardin, M., Wanielista, M. (2013). "Total Nitrogen Losses from Fertilized Turfs on Simulated Highway Slopes in Florida." Journal of Environmental Engineering **139**(6): 829-837.

Karpinets, T. V., et al. (2004). "Predictive mechanistic model of soil phosphorus dynamics with readily available inputs." Soil science Society of America Journal **68**(2): 644-653.

Kunimatsu (1999). "Loading Rates of Nutrients Discharging From a Golf Course And Neighboring Forested Basin." Water Science and Technology **39**(12): 99-107.

Lipiec, J. and W. Stepniewski (1995). "Effects of Soil Compaction and Tillage Systems on Uptake and Losses of Nutrients." Soil and Tillage Research **35**: 37-52.

Mangani, G., et al. (2005). "Evaluation of the pollutant content in road runoff first flush waters." Water, Air, and Soil Pollution **160**(1-4): 213-228.

Mengel, D. B. (2014). "Fundamentals of Soil Cation Exchange Capacity (CEC)." Agronomy Guide. 2014, from https://www.extension.purdue.edu/extmedia/AY/AY-238.html.

Millenium Ecosystem Assessment (2005). Ecosystems and Human Well-Being: Synthesis. Millenium Ecosystem Assessment. Washington, D.C., Island Press.

Milroy, S. P., et al. (2008). "Systems analysis of wheat production on low water-holding soils in a Mediterranean-type environment II. Drainage and nitrate leaching." Field Crops Research **107**: 211-220.

Mueller, D. and D. Helsel (2013). Nutrients in the Nations Waters--Too Much of a Good Thing?, U.S. Geological Survey. **Circular 1136**.

Myrold, D. D. and N. R. Posavatz (2007). "Potential importance of bacteria and fungi in nitrate assimilation in soil." Soil Biology & Biochemistry **39**: 1737-1743.

Pang, Z., et al. (2013). "Impacts of Human Activities on the Occurrence of Groundwater Nitrate in an Alluvial Plain: A Multiple Isotopic Tracers Approach." Journal of Earth Science **24**(1): 111-124.

Panno, S. V., et al. (2001). "Determination of the sources of nitrate contamination in karst springs using isotopic and chemical indicators." Chemical Geology **179**: 113-128.

Paramasivam, S., et al. (2000). "Tranformation and Transport of Nitrogen Forms in a Sandy Entisol Following a Heavy Loading of Ammonium Nitrate Solution: Field Measurements and Model Simulations." Journal of Soil Contamination **9**(1): 65-86.

Parr, J. F. and J. C. Engibous (1966). "Patterns of NH3 Distribution in the Soil." Anhydrous Ammonia Agronomy Workshop: 4-1-4-8.

Petrovic, A. M. (1990). "The Fate of Nitrogenous Fertilizers Applied to Turfgrass." Journal of Environmental Quality **19**(1): 1-14.

Pitt, R., et al. (2004). The National Stormwater Quality Database (NSQD, version 1.1), Department of Civil and Environmental Engineering, University of Alabama.

Pohlert, T., et al. (2007). "Integration of a detailed biogeochemical model into SWAT for improved nitrogen predictions—Model development, sensitivity, and GLUE analysis." Ecological Modelling **203**: 215-228.

Radulov, I., et al. (2011). "Mineral Fertilization Influence on Soil pH, Cationic Exchange Capacity and Nutrient Content." Journal of Agricultural Science **43**(3): 7.

Richardson, A. E. and R. J. Simpson (2011). "Soil Microorganisms Mediating Phosphorus Availability." Plant Physiology **156**(3): 989-996.

Salazar, O., et al. (2009). "Evaluation of the DRAINMOD-N II model for predicting nitrogen losses in a loamy sand under cultivation in south-east Sweden." Agricultural Water Management **96**: 267-281.

Sartain, J. B. (1998). "The Florida Fertilizer Label."

Schindler, D. W. (1978). "Factors Regulating Phytoplankton Production and Standing Crop in the World's Freshwaters." Limnology and Oceanography **23**(3): 478-486.

Shuman, L. M. (2001). "Phosphate and Nitrate Movement Through Simulated Golf Greens." Water, Air, and Soil Pollution **129**(1-4): 305-318.

Shuman, L. M. (2002). "Phosphorus and nitrate nitrogen in runoff following fertilizer application to turfgrass." Journal of Environmental Quality **31**(5): 1710-1715.

Shuman, L. M. (2003). "Fertilizer source effects on phosphate and nitrate leaching through simulated golf greens." Environmental Pollution **125**: 413-421.

Shuman, L. M. (2006). "Normal and Flush Irrigation Effects on Nitrogen Leaching from Simulated Golf Greens in the Greenhouse." Communications in Soil Science and Plant Analysis **37**(3-4): 605-619.

Singh, K. G. and S. K. Sondhi (2001). "Validation of a Fertilizer Nitrogen Model during Crop Production." Journal of Agricultural Engineering Research **78**(3): 317-324.

Stark, J. M. and M. K. Firestone (1994). "Mechanisms for soil moisture effects on activity of nitrifying bacteria." Applied and Environmental Microbiology **61**(1): 218-221.

State Erosion and Sediment Control Task Force (2013). State of Florida Erosion and Sediment Control Designer and Reviewer Manual, FDOT & FDEP.

Stepniewski, W. and J. Glinski (1985). Soil Aeration and its Role for Plants. Boca Raton, FL, CRC Press.

The University of Arizona (1998). "Environmental Factors that Affect Plant Growth." from http://ag.arizona.edu/pubs/garden/mg/botany/environmental.html#Top.

Tisdale, S. L., et al. (1985). Soil Fertility and Fertilizers. New York, New York, Macmillan Publishing Company.

Tomasky, G., et al. (1999). "Nutrient Limitation of Phytoplankton Growth in Waquoit Bay, Massachusetts, USA: A Nutrient Enrichment Study." Aquatic Ecology **33**(2): 147-155.

Trenholm, L. E., et al. (2013). "Nitrate Leaching and Turf Quality in Newly Sodded St. Augustinegrass." Journal of Plant Nutrition **36**(12): 1935-1943.

Tucker, M. R. (1999). "Essential Plant Nutrients." from http://www.ncagr.gov/agronomi/pdffiles/essnutr.pdf.

USGS (1996). Nitrate in Ground Waters of the US - Assessing the Risk. Reston, VA, U.S. Geological Survey.

USGS (2010). Nutrient in the Nation's Streams and Groundwater, 1992-2004, Reston, VA.

Weather Underground (2014). "UCF Area / WUCF-FM." from http://www.wunderground.com/personal-weather-station/dashboard?ID=KFLORLAN72#history/data.

Whitehead, D. C. and N. Raistrick (1990). "Ammonia Volatilization from five nitrogen compounds used as fertilizers following surface application to soils." Journal of Soil Science **41**: 387-394.

Wolkowski, R. P. (1990). "Relationship Between Wheel-Traffic Induced Soil Compaction, Nutrient Availability, and Crop Growth - A Review." Journal of Production Agriculture **3**(4): 460-469.