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Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions: Examination of Lower Slopes and Rainfall Intensities Taking into Account Overland Flow

Work Performed for the Florida Department of Transportation

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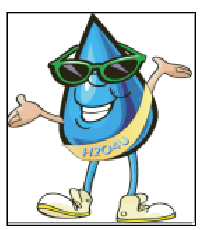

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DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation. Furthermore, the authors are not responsible for the actual effectiveness of these control options or drainage problems that might occur due to their improper use. This does not promote the specific use of any of these particular systems.

METRIC CONVERSION

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
In	Inches	25.4	Millimeters	mm
Ft	Feet	0.305	Meters	m
Yd	Yards	0.914	Meters	m
Mi	Miles	1.61	Kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
Ac	Acres	0.405	Hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
fl oz	fluid ounces	29.57	Milliliters	mL
Gal	Gallons	3.785	Liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
Oz	Ounces	28.35	Grams	G
Lb	Pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				

Mm	Millimeters	0.039	Inches	in
M	Meters	3.28	Feet	ft
M	Meters	1.09	Yards	yd
Km	Kilometers	0.621	Miles	mi

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
Ha	Hectares	2.47	Acres	ac
km^2	square kilometers	0.386	square miles	mi^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		VOLUME		
mL	Milliliters	0.034	fluid ounces	fl oz
L	Liters	0.264	Gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		MASS		
G	Grams	0.035	Ounces	oz
Kg	Kilograms	2.202	Pounds	lb

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF

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16. Abstract
The Florida Department of Transportation has taken steps to reduce the amount of phosphorus and the time release of fertilizer compounds in all of its operations. Consequently, there may be a reduction in the mass of phosphorus released to adjacent water bodies. This research project aims to provide a scientific basis for quantifying the reduction in nutrient losses from highway slopes, due to changes in fertilization practices. There were two phases of tests conducted (1) steep embankment slopes and direct rainfall intensities, and (2) gentle embankment slopes, low rainfall intensities and overland flow that represents a typical highway embankment in Florida.

Phase one had 46 tests and phase two had 34 tests conducted at the University of Central Florida, using the field-scale rainfall simulator and test bed for evaluating the effects of changes in FDOT's highway fertilization practices. These tests simulated three slopes and three rainfall intensities. The tests were conducted on two sod-soil combinations - Argentine Bahia over AASHTO A-3 soil and Pensacola Bahia over AASHTO A-2-4 soil. Two N-P-K fertilizers were tested reflecting the change in FDOT practice, namely 10-10-10 or 16-0-8 (Slow Release). Run-off and base flow water samples were collected and analyzed to determine the mass of total nitrogen (TN) and total phosphate (TP). The mass balance of nutrients in the test bed was also analyzed based on weather data, available theoretical models, and field test data.

The study showed that the 16-0-8 (SR) on A-3 soil results in 66.5% reduction of total nitrogen compared to 10-10-10. Lack of phosphorus in 16-0-8 (SR) did not deter the growth of Argentine Bahia. Argentine Bahia over A-3 had resulted in 28.6 % less loss of TN, and about 24.4 % less loss of TP, compared to the Pensacola Bahia over A-2-4 due to the higher infiltration capacity of A-3 soil compared with A-2-4 soil. The results of the tests conducted without fertilization confirmed the lack of sufficient insitu nutrients in borrow area soils, and thus the need for highway fertilization. In all the tests, the turbidity and concentration of total solids were within acceptable limits, which proves the usefulness of these turf grasses in preventing soil erosion. Overall, the loss of nutrients increased with steepness of slope and rainfall intensity but some exceptions were caused by accumulation of nutrients, seasonal variations between different tests, and the bio-physicochemical interactions of the soil-nutrient-turf system with the weather.

17. Key Word
Stormwater, Consumer Fertilizer, Nutrient Loading, Nitrogen, Phosphorus, Rainfall Intensity, Slope, Best Management Practices (BMPs)

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EXECUTIVE SUMMARY

Optimum fertilization of turf grasses is essential for simultaneous prevention of both soil erosion and nutrient pollution. This is a critical issue in Florida as summer rainfall is quite intensive and environmental protection agencies are restoring water bodies by implementing Basin Management Action Plans (BMAPs). The Florida Department of Transportation recently changed its highway fertilization practices to reduce loss of nutrients and to meet the designated targets for water quality restoration, also called Total Maximum Daily Loads (TMDLs). Phase #1 of this research project began in July 2008 (FDOT research project BDK78-977-04) to provide a scientific basis for quantifying the reduction in nutrient losses from highway slopes, due to changes in fertilization practices. Our prime research objective was simulating the factors that result in loss of nutrients from fertilized highway slopes namely, rainfall intensity, highway slope, soil type, sod type, and roadway overland flow simulating Florida geological and meteorological conditions.

The experimental investigations were conducted using a custom designed field-scale test bed and rainfall simulator at the Stormwater Management Academy Research and Testing Laboratory (SMARTL) at the University of Central Florida. The test bed is 30 ft. long, 8 ft. wide, and 1 ft. deep, and is hydraulically adjustable to a desired slope. Highway embankments in southern and central Florida are typically constructed with A-3 type soil, classified as per the American Association of State Highway and Transportation Officials (AASHTO) system, and covered with Argentine Bahia sod for erosion prevention. In northern Florida, A-2-4 type soils and Pensacola Bahia sod are more prevalent.

The rainfall intensities and slopes used in this study closely simulate the conditions on Florida's highways. The test bed was filled with A-3 or A-2-4 soil and was compacted to simulate highway embankment construction. Argentine or Pensacola Bahia sod was laid on the

compacted soil and allowed to establish roots before commencing the testing. Tests were first conducted on desired slopes with desired rainfall intensities, without any fertilizer, for establishing baseline conditions for that soil-turf combination. Then, tests were continued by applying fertilizer at a rate to result in 1 lb or 0.5 lb of nitrogen (N) per 1000 ft^2, and other corresponding nutrients per the fertilizer formulation. The run-off and base flow samples were collected and analyzed for evaluating the loss of nutrients. Two composite fertilizers consisting of nitrogen (N), phosphate (P), and potash (K) were used. Either a common fertilizer (10-10-10 N-P-K), representing FDOT's past practice, or a slow release fertilizer, 16-0-8 (SR) N-P-K, that represents FDOT's current practice. Some portion of 16-0-8 is slow release (SR) nitrogen, i.e., polymer or sulfur-coated urea instead of ammonium sulfate.

Forty-six tests were conducted in this study (described in Tables 3.1 and 3.2). Seven tests were conducted on Argentine Bahia sod over A-3 soil, using 10-10-10 @ 1 lb of N per 1000 ft^2. Three of the seven tests were on a 25% slope (4 horizontal to 1 vertical) with three different rainfall intensities of 0.5 in/hr, 1 in/hr, and 3 in/hr. The remaining four tests were at slopes of 33% and 50% at rainfall intensities of 0.5 in/hr, and 1 in/hr. At the same slopes and rainfalls, seven tests were conducted using 16-0-8 (SR) @ 1 lb of N per 1000 ft^2. At FDOT's request for evaluating the effect of their reduction in fertilization application, seven tests were repeated using 16-0-8 (SR) @ 0.5 lb of N per 1000 ft^2. Similarly, 14 tests were done on Pensacola Bahia sod over A-2-4 soil, using 10-10-10 @ 1 lb of N per 1000 ft^2 and 16-0-8 (SR) @ 0.5 lb of N per 1000 ft^2. Nine tests were conducted without any fertilizer application to evaluate the baseline level of nutrients in the tested soil-turf combinations. These tests were conducted on a 25% slope at three different rainfall intensities of 0.5 in/hr, 1 in/hr, and 3 in/hr. All these 44 tests were conducted as one-day tests, with each simulated one-hour rainfall, preceded by an irrigation event that represents FDOT's practice of wetting after fertilization and followed by a postrainfall flush event for washing out the nutrients remaining in the test bed after the simulated rainfall.

In addition, two tests were conducted as seven-day tests on a 33% slope at a rainfall intensity of 3 in/hr, applied on days 1, 3, and 7, for evaluating the loss of nutrients in a series of storms that are common in Florida. The measured volumes of run-off and base flow, together with nutrient concentrations of tested water samples, were used for determining the losses of nitrogen and phosphate during the pre-irrigation, simulated rain, and flush events. As about five weeks were needed for changing soil, laying sod, and allowing it to establish roots, these 46 tests were conducted on four soil-turf combinations. Though flush events were applied after each simulated rainfall for removing the post-test nutrients in the test bed, there was some nutrient accumulation in the soil, as it is bound to happen on FDOT's fertilized highway embankments. Based on the theoretical models and parametric values for nutrient uptake by grass and the physicochemical soil-nutrient-weather interactions, this nutrient accumulation in these four soil-turf combinations was analyzed. The measured losses of nutrients were scrutinized, with and without this modeling basis, and were compared in order to meet the specific objectives of this study.

Comparing the performance of 10-10-10 with 16-0-8 (SR), both @ 1 lb of N/1000 ft^2, on Argentine Bahia over A-3 soil, showed that 16-0-8 (SR) results in a 66.5 % reduction of total nitrogen (TN) lost to the environment. The growth of grass was comparable in both cases, and the water collected was low in turbidity and total suspended solids. The measured value of total phosphate in the seven tests using 10-10-10 was 20.85 g (2.1% of applied P), while just 0.73 g of total phosphate was measured in the seven tests using 16-0-8 (SR). This 0.73 g is from the original P in borrowed soil. These findings confirm the usefulness of slow release fertilizers in reducing the nitrogen leaching to water bodies and that highway turfs can be grown even when eliminating phosphate addition.

The performance of Pensacola Bahia sod over A-2-4 was compared to Argentine Bahia sod over A-3, with regard to the fourteen corresponding tests on each combination. These tests showed that Argentine over A-3 had resulted in 28.6 % less loss of TN and about 24.4 % less loss of TP compared to the Pensacola over A-2-4. It was determined that this is essentially due to the higher infiltration capacity of the A-3 soil compared to the A-2-4 soil which allowed for reduced run-off and more seeping in of nutrients. Therefore, it is suggested that the highway slopes be provided with a surface layer of A-3 soil, even if the rest of the embankment is built with A-2-4.

At the request of FDOT, the differences between one-day and seven-day tests as well as the differences between 1 lb and 0.5 lb of N per 1000 ft^2 application rates while using 16-0-8 (SR) were analyzed. Counter-intuitively, the application rate of 0.5 lb of N resulted in more losses than the 1 lb of N application rate, while the one-day tests resulted in more losses than during the first day of the seven-day tests. Though definitive conclusions are elusive, our results suggested that this was likely due to the nutrient accumulation in the test bed, the variations in the nutrient uptake by grass, and the physicochemical soil-nutrient-weather interactions making the nutrients either available or unavailable for leaching. The nutrient mass balance analyses presented in chapter 5 are limited by the availability of theoretical models and parametric values.

Very low masses of nutrients (4.14 g of TN and 7.29g of TP) were measured in the water collected from the six tests conducted without fertilizer application. These tests suggest the need for highway fertilization. In all the tests, the turbidity and suspended solids were very low, which prove the efficiency of Argentine and Pensacola Bahia turfs in preventing soil erosion.

Phase #1 results showed it was determined that the evaluation of the effect of low rainfall intensities and overland flow on nutrient loss was also important. 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 of N per 1000 ft^2. Comparing the tests performed at 0.25 in/hr on A-2-4 soil with Pensacola Bahia sod for 10-10-10 and 16-0-8, it was found that there was a 41.6% reduction in total nitrogen (TN) and a 93% reduction in total phosphorus (TP) on that soil type for the 16-0-8 fertilizer type. Comparison of the tests performed at 0.25 in/hr on A-3 soil with Argentine Bahia sod showed similar results: a 67.6% reduction in total nitrogen (TN) and 80% reduction in total phosphorus (TP) when using the 16-0-8 fertilizer compared to the 10-10-10 fertilizer. Results at 0.1 in/hr, available only for A-2-4 soil with Pensacola Bahia sod, showed that, at this intensity, there was no significant benefit to the switch in fertilizers, and infact 16-0-8 showed greater losses than 10-10-10. This may be attributed to more nutrients inherent to the soil and sod used for the 16-0-8 trials in addition to higher average temperatures occurring during testing at this 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. It should be noted however that the losses were not significant for either fertilizer type. The small rainfall volume applied resulted in little water collected as either base flow or runoff and therefore less water to wash the nutrients either through or off the test bed.

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 fertilizer resulted in 85.9% less TN lost and 99% less TP lost at 0.25 in/hr compared, to the combination of A-2-4 soil and Pensacola Bahia sod. This difference can be at least partially attributed to the fact that runoff, which was only generated from A-2-4 soil, was a significant source of these losses. At 0.1 in/hr, there was no significant difference in TN lost; however, 58.3% less TP was lost from A-3 soil and Argentine Bahia sod than the A-2-4 soil and Pensacola Bahia sod, although losses from both soil types were low. The low rainfall volume resulted in not much fertilizer being washed off or through the soil and sod test area. Examination of the 16-0-8 (SR) fertilizer showed that 92.2% less TN was lost and 95% less TP was lost from the A-3 soil and Argentina Bahia sod compared to the A-2-4 soil and Pensacola Bahia sod. This can be attributed to the higher infiltration capacity of the A-3 soil compared with the A-2-4 soil resulting in no runoff being generated for any tests with the A-3 soil as well as possible higher nutrient uptake capacity of Argentine Bahia sod compared with the Pensacola Bahia sod.

A significant difference of this phase of testing from the first is that soil sampling was performed to analyze the total nitrogen and total phosphorus present in the soil as well as the cationic exchange capacity (CEC) for all tests. The cationic exchange capacity tended to decrease with fertilizer application over time, likely due to exchange sites being utilized by cations introduced to the soil via fertilizer, and/or a decline in soil pH because 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.

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CHAPTER 1. INTRODUCTION

1.1 Background

The eutrophication problems of lakes and estuaries are generally attributed to improper disposal of organic wastes and indiscriminate application of fertilizers. The reasons for excessive fertilization include the need for higher food production, fertilizer subsidies, golf courses, lack of awareness of general public in addition to their eagerness to maintain lush green lawns for serving their economic interests. Several water bodies in Florida, as in many other places of the world, have been identified as overloaded with excessive nutrients. Several chemical forms of nitrogen and phosphorous have been identified as the problem compounds. The eutrophication of these surface water bodies has resulted in many harmful algal blooms (HAB). Excessive growth and decay of algae in the surface waters causes depletion of dissolved oxygen levels, production of neurotoxins that cause mass mortalities in fish, seabirds and marine mammals, and ill health of humans on consumption of seafood contaminated by toxic algae (Landsberg, 2002). This problem is of high concern to the tourism and fishing industries in Florida.

Florida has several surface water bodies that are identified as polluted with excessive nutrients, such as nitrates and phosphates. Since excessive nutrients cause algal blooms and deplete dissolved oxygen levels in surface waters, these water bodies do not currently meet the water quality requirements for recreational use and for the propagation and maintenance of a healthy and well-balanced population of fish and wildlife. The Florida Department of Environmental Protection (FDEP) has drawn up some Basin Management Action Plans (BMAPs) and adopted targets for water quality restoration, also called as Total Maximum Daily

Loads (TMDLs). Inappropriate fertilization practices are believed to be causing this nutrient pollution because fertilizer based nutrients get washed out through surface runoff and subsurface flow. This problem is more acute in Florida because the state receives more intense rainfall and tropical storms, and its sandy soils are free draining and less resistant to erosion.

The FDEP is working implement to successfully the BMAPs by encouraging all public and private agencies to adopt better fertilization practices for preventing nutrient pollution. The Florida Department of Transportation (FDOT) fertilizes its highway embankments for establishment and maintenance of healthy utility turf-grass that is useful for providing aesthetic beauty, resistance to soil erosion, and other environmental benefits of plant life. Preventing erosion of highway slopes is essential, for not only preventing environmental degradation, but also for preventing collapse of highway slopes and damaging roadways.

However, considering the nutrient overloading of water bodies and for improving the environmental quality, the FDOT has changed its fertilization practices by switching to fertilizers with slow release nitrogen and no phosphorous. Specifically, FDOT has discontinued the use of N-P-K (nitrogen-phosphorus-potassium) fertilizers such as 10-10-10 and has started using fertilizers such as 16-0-8 (SR), where SR stands for slow release. The purpose of slow release fertilizers is to reduce washing out of nitrogen and making it gradually available for plant growth. Because Florida’s soils are naturally rich in phosphorous, it is believed that there is no need for phosphates in the fertilizer compositions.

The research described in this report was conducted between May 2008 and July 2010 for evaluating the reduction in loss of nutrients from highway slopes as a result of the changes in the fertilization practices of FDOT. The results of this research study are analyzed and presented in this report with the objective of assisting the FDOT in further improving its fertilization practices for successfully meeting the TMDL targets of BMAPs. The primary objective of the study is the evaluation of the nutrient levels in post-storm flows from fertilized highway slopes with respect to the 10-10-10 fertilizer used by the FDOT in the past, and the 16-0-8 (SR) fertilizer that is currently being used by the FDOT.

The rate at which nutrients wash out in the runoff and base flow primarily depends on

1) fertilizer composition and chemistry;
2) the chemical characteristics, such as pH, original concentration of nutrients, mineral composition, cation exchange capacity, aerobic conditions, etc., of the soil;
3) the physical properties, such as geological profile, grain size distribution, clay content, mass density, moisture content, etc., of the soil;
4) the biological conditions that include vegetation characteristics and growth phase, microbial activity, etc., of the soil;
5) topographical conditions such as field dimensions, proximity to surface water bodies, surface slope, undulations, etc.; and
6) atmospheric characteristics such as precipitation, temperature variations, wind speed, day light hours, etc.

The combination of these conditions in Florida is unique and considerably different from that in other US states or foreign countries. Primarily because of Florida's sub-tropical location, receiving several high-intensity rains and storms in summers, overlaid by erosion-prone sandy soils on cavernous limestone formations, and ecosystem that is sensitive to the health of lakes, estuaries and coastal waters. The existing data and models in the available literature (as described in the next chapter) are not sufficient for satisfactorily evaluating the impact of the fertilization practices of FDOT. Thus, this research was necessary and was therefore conducted using the unique facilities at UCF that simulated these typical Florida conditions as closely as possible for estimating the washing out of nutrients from typically fertilized highway slopes. There were two phases of tests conducted in the research (1) direct rainfall (0.5, 1.0, and 3.0 in/hr.) on steep embankment slopes (25, 33, and 50 percent), and (2) overland flow from highway shoulders and direct rainfall (0.25 and 0.1 in/hr) on a gentle embankment slope (typical highway cross section of 16.67 percent).

1.2 Research Objectives and Experimental Setup for Phase #1

This experimental investigation was conducted at the Stormwater Management Academy's Research and Testing Laboratory (SMARTL), a research unit of the University of Central Florida, Orlando. The SMARTL facilities utilized in this research includes the field-scale slope-adjustable soil test bed and computer-controlled rainfall simulator that simulated the desired precipitation over the simulated highway slope (Figure 1), and the chemical analysis equipment. The field-scale test bed measures 30 ft. (9.16 m) in length, 8 ft. (2.44 m) in width, and 1 ft. (0.31 m) in depth. A hydraulic ram can adjust the bed to a desired slope. The 30 ft. (9.16 m) long rainfall simulator can be hoisted and positioned with a gantry crane above the test bed at a desired height and slope. A height of 13 feet (4.03 m) was used to maintain proper terminal velocity of raindrops hitting the bed. The rainfall simulator consists of several spray nozzles, which are computer-controlled for creating the desired rainfall intensity. Sufficient storage and filtration facilities exist at the site for ensuring adequate potable water supply to the simulator.

Arrangements were made for collecting runoff at the end of the test bed, and collection of base flow at two hundred and seventy (270) points below the test bed. These points were bundled into three groups (upstream, U/S; midstream, M/S; downstream, D/S) for facilitation of sample collection and chemical analysis.

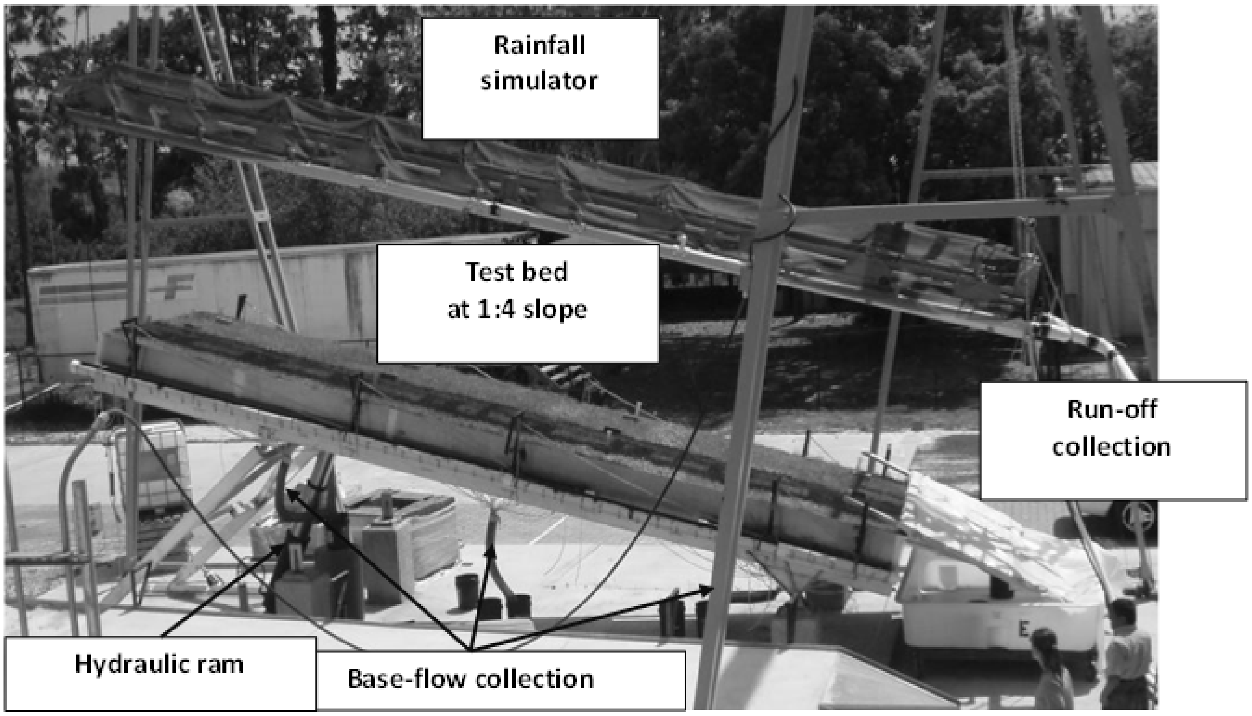

Figure 1: Experiment on a Test Bed Slope of 1:4 (V:H) – Sandy Soil with Argentine Bahia

The water samples were collected from the run-off and base flow for every test at regular time intervals, and physicochemical parameters, viz., turbidity, pH, alkalinity, and the concentration of nutrients (total nitrogen, total phosphorous) and total solids, etc., were determined in the SMA chemistry laboratory. The chemical analysis of the water samples is carried out using standard laboratory procedures, reagents and the Hach DR-5000 Spectrophotometer (Figure 2), which is a complete scanning UV/VIS spectrophotometer with a wavelength range of 190 to 1100 nm.

The turbidity values of the water samples were measured using a Hach 2100P Portable Turbidimeter and following the 2130B Nephelometric Method outlined in Standard Methods. The pH was measured using an Accumet AR 50 pH/Ion/Conductivity meter with the AccuFET

Field Effect Transistor (FET) pH electrode (indicating electrode and reference electrode), the Accumet 2-Cell Conductivity Cell, and the Accumet Automatic Temperature Compensation (ATC) probe. The Alkalinity was measured following the 2005 Standard Methods section 2320B Titration Method. The TN concentration was measured using the Hach Method 10071 for the low range detection of total nitrogen (0.5 to 25.0 mg/L as N) which utilizes the Persulfate Digestion Method. The TP concentration was measured using the Hach Method 8180 (0.06 to 3.5 mg/L as PO_4^{3-}) which uses an acid hydrolysis method. The total solids values were tested following the 2005 Standard Methods section 2540B Total Solids Dried at 103 – 105°C (APHA, 2005 and Hach, 2009).

Figure 2: Hach DR-5000 Spectrophotometer for Determining Nutrient Concentrations

The concentrations of total nitrogen (TN) and total phosphorus (TP), and the measured volumes of run-off and base flow were used in the evaluation of nutrients lost from the applied fertilizers on the simulated slopes. A complete description of experimental parameters and related data is presented in the third chapter.

The specific objectives of this research study were:

- Comparing the nutrient utilization efficiency (NUE) of a fertilizer used in the past (10-10-10) with that of a fertilizer that is now being used (16-0-8 SR) for quantifying the environmental benefits of changes in FDOT's practices.
- Evaluating the loss of nutrients from two types of soil-sod combinations that represent typical conditions in northern Florida and other parts of Florida.
- Understanding the influence of slope on the loss of nutrients from highway slopes
- Understanding the effect of rainfall intensity on the loss of nutrients from highway slopes
- Developing a scientific basis for estimating the nutrient utilization efficiency (NUE) of other fertilizers, and for improving best management practices (BMPs).

1.3 Socio-economic Necessity of Minimizing Nutrient Losses

The global economic loss based on the cost of nutrient wash out, cost of water treatment, and the impact on flora and fauna is estimated to be 15.9 billion US dollars for only nitrogen in fertilizers applied to cereal crops (Delgado, 2000). The total economic losses considering all nutrients and all purposes would be several hundred billion in US dollars. Therefore, it is necessary to minimize the loss of fertilizer nutrients for economic well-being as well as for environmental protection.

Under these conditions, the fertilization practices of non-agricultural consumers are coming under more severe criticism as their application is not for essential food production, but for non-food purposes such as erosion-control, aesthetics, improving air quality, sports, tourism, etc. Establishment of grass on highway slopes is essential for preventing rill and gully erosion that degrades the environment, in addition to increasing the risk of slope failures. Highway slopes are generally well connected to streams that drain into surface water bodies, thus, inappropriate fertilization practices of highway agencies are likely to cause eutrophication problems. Therefore, there is a greater need for optimizing the application of consumer fertilizers by the highway agencies. The nutrient wash out problem is more acute in Florida's summers because Florida receives more intense rainfall in summer (Harper and Baker, 2007) and consumers apply more fertilizers in summer for enhancing plant growth that also serves the purpose of preventing soil erosion.

Several local governments in Florida are contemplating legal measures to regulate the use of consumer fertilizers for preventing the undesirable environmental degradation that results from improper fertilizer application. Sarasota County has recently adopted an ordinance (Sarasota, 2007) regulating the use of consumer fertilizers. Their ordinance stipulates an annual maximum limit of 0.5 lb of phosphorus (P_2O_5) and 4 lb of nitrogen applied per 1000 square feet (Dubberly, 2007). In addition, it makes mandatory that at least 50% of the nitrogen content shall be “Slow Release Nitrogen” as per “Guaranteed Analysis Label”. It also prohibits application of any consumer fertilizer during the rainy summer season (called Restricted Season), from June 1 to September 30.

These recent local government ordinances are based on the premise that soils in many parts of Florida are naturally rich in phosphorous that is needed for plants' metabolic processes, growth, flowering, ripening of fruits, etc. It is believed that this excessive phosphorus is naturally leaching in surface runoff and base flow. Therefore, some counties think that it is required to put a legal maximum limit (even zero) to the phosphorus content of consumer fertilizers. Due to moderate to high permeability of Florida's soils, the soil nitrogen leaches at a faster rate because some forms of soil nitrogen are soluble and because high-intensity precipitation results in excessive surface and subsurface flows that can potentially transport this nitrogen into ground and surface waters. Therefore, local governments are of the opinion that it is required to legally mandate that at least 50% of the nitrogen content shall be “Slow Release Nitrogen” so that most of the nitrogen is gradually absorbed by plants. Prohibiting the use of fertilizers during rainy summer season is also intended because nutrients are more likely to wash off at that time.

Several researchers (Hochmuth et al., 2009) of the Institute of Food and Agricultural Sciences at the University of Florida (IFAS-UF) however have disputed these contentions, because fertilization in summer is essential as plants grow fastest in summer and need fertilizer nutrients mostly during that time. These researchers have argued that fertilization in other seasons may only starve and hamper the growth of vegetation, and result in more nutrient losses. It is also argued that phosphorus-rich-soils exist only in some parts of Florida, and even in those soils, the phosphorus may not be in a form readily available for either plant uptake or leaching.

This study was undertaken for examining these issues, and for developing a scientific basis for improving the turf fertilization practices of FDOT and other users in Florida. Considering the eutrophication issues hastened by rapid urbanization and tourism development in Florida, appropriate changes to turf fertilization are imperative to alleviate these problems. The unique facilities at the UCF-SMA were used for simulating Florida specific conditions that included locally used turf grass types, sandy soils, slopes, weather conditions, generally unnoticed microbial activity, and high-intensity precipitation. Chapter 2 provides a brief review of existing literature for setting the necessary background for the remaining chapters. The experimental data, discussion of results, and conclusions are presented in chapters 3 through 9.

CHAPTER 2. LITERATURE REVIEW

In view of the need to efficiently improve the turf fertilization practices, it is necessary to study the loss of nutrients from fertilized sod-covered soil slopes under typical rainfall conditions. With this objective, a thorough review of the available scientific literature on nutrient losses from fertilized soils has been conducted. The literature reviewed included several papers published by the researchers of the Institute of Food and Agricultural Sciences at the University of Florida (IFAS-UF). This review indicated that the conditions of FDOT's fertilized highway slopes are much different from the cases reported so far in the literature. The reported cases pertain to agricultural, horticultural, urban landscape applications, but not to fertilized highways slopes. This fact underlines the importance of the present study. Presented in the next few paragraphs are the important noteworthy points of the reviewed literature.

2.1 Observations on Fertilizer Nutrients in Water Bodies

Olson et al. (1972) studied the influence of fertilizer practices on the quality of water and environment in Nebraska by measuring the extent of nitrogen and phosphorus movement in the groundwater below the root zone. They studied penetration of nutrients in deep profiles of land devoted to wheat fallow, irrigated alfalfa, grass and heavily fertilized corn. That study revealed the influence of fertilization, geological conditions, sewage, and industrial wastes on eutrophication. Mulligan (1973) studied the effect of eutrophication and growth of algae in New York State due to water pollution caused by fertilizer based nitrogen and phosphorus. Halliday and Wolfe (1991) studied the statewide groundwater pollution in Texas due to the use of nitrogen fertilizers, and analyzed the data for borehole water quality using Geographic Information Systems.

Andersen et al. (2001) studied 17 agricultural catchments in Denmark and applied empirical models for analyzing the hydrology, fertilizer nitrogen input, and nitrogen leaching from the root zone. They reported that Danish agricultural areas contributed about 80% of the diffuse N-loading that resulted in eutrophication of some of their coastal waters. Bowman et al. (2002) conducted a greenhouse study by growing six types of warm season turf grasses in sand-filled columns. The nitrate leaching varied for different grasses based on their nutrient uptake capacity and growth phase. Higher losses were noted during the period of establishment.

Shuman (2002) conducted an investigation of N and P in runoff from fertilized Bermuda grass established on twelve individual plots (7 m x 3.6 m) laid down at 5% slope. The study was conducted in sandy loam soils. Fertilizers were applied at three mass rates, with the maximum rate being 24 kg of N per hectare, using 10-10-10 fertilizers. This study concluded that phosphorus loss in runoff was immediate, while the nitrogen loss was delayed due to nitrification of ammonia.

Wikramanayake et al. (2003) have presented the results of a field study that monitored the concentrations of nitrogen and phosphorous leaching from fertilized rice farms in Sri Lanka. Their results showed that about 52% of applied nitrogen and 6% applied phosphorus were lost due to heavy rains and flooding. Keating (2004) presented a summary of best management practices for careful and timely application of nitrogen fertilizers for helping plant growth while preventing water pollution. Kaffka (2005) investigated the impact of irrigation practices in the Upper Klamath Basin of Oregon and California. The study found considerable increases in the concentrations of nitrogen and phosphorous in the water samples collected from tile drains.

2.1.1 Mechanistic Models of Nutrient Processes and Leaching – Nitrogen, N

Hutson and Wagenet (1991) presented LEACHM (Leaching Estimation and Chemistry Model), a suite of models that also included the nitrogen component LEACHN. This continues to be one of the more well-known deterministic models for simulating nitrogen dynamics in soil. This model considers the transformations of urea, ammonium, nitrate, and the organic pools based on the influence of temperature and water content. Recent successful applications of LEACHN include that of Paramasivam et al. (2000) for liquid ammonium nitrate on a sandy soil field site in Florida, and that of Singh and Sondhi (2001) for urea on clayey loam and loamy sand in India. Recently, Follett (2008) published a comprehensive review of nitrogen transformation and transport processes.

Other important recent studies conducted on nutrient leaching in foreign countries include that of Polhlert et al. (2007), Milroy et al. (2008), Cao and Wang (2007), and Salazar et al. (2009). Pohlert et al. (2007) integrated the Soil and Water Assessment Tool (SWAT) with a set of algorithms covering processes such as decomposition, growth of nitrifying bacteria, nitrification, N-emissions during nitrification and denitrification, N-uptake by plants and N transport due to water fluxes. The predictions of the improved biogeochemical model, SWAT-N, were used for comparison with a lysimeter dataset of a long term fertilization experiment conducted in eastern Germany. It concluded that decomposition rates, pH, and soil porosity controlled nitrogen leaching and gaseous emissions.

Cao and Wang (2007) applied the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model for assessing nitrate leaching from an agricultural catchment in southeast China. They reported that the model produced acceptable results for sugarcane, banana, and vegetable fields, but the results for paddy fields were not acceptable. Milroy et al. (2008) investigated the drainage and nutrient leaching in areas of Australia that experience Mediterranean-type environments and receive excessive winter rainfalls when evaporation is minimal. Their study revealed that small differences in soil type (loamy sand vs. acid loamy sand, or loamy sand vs. sand) may result in marked differences in nutrient leaching. Salazar et al. (2009) simulated drainage and nitrate leaching using the DRAINMOD-N II model, and compared the results with observations from loamy sand under wheat-sugarbeet-barley crop rotation in a cold region of Sweden.

2.1.2 Mechanistic Models of Nutrient Processes and Leaching – Phosphorus, P

Greenwood et al. (2001a) presented a mechanistic model for calculating the phosphorus levels in soils, considering the interactions between extractable and non-extractable soil P, plant characteristics and its P uptake, and the soil and weather data. Their model is based on the soil properties, maximum potential yield, daily rainfall, mean air temperature and evaporation from an open water surface. Greenwood et al. (2001b) described the calibration of that model for six different species, and its subsequent testing against results of independent experiments on the same soil type. The paper discussed the strengths and weaknesses of that model and its utility as a short cut for predicting short-term optimal P requirements of some crops.

Karpinets et al. (2004) presented the same model after some improvements and making it useful for long-term calculations of phosphorus balance. This model considers extractable phosphorus (X), soil-adsorbed phosphorus (Y), solubility-product type mineral buffer phosphorus (P_{buffer}), and the interactions between X and Y, and between X and P_{buffer}. Their model considered net addition of phosphorus, based on plant uptake and fertilization, and its partitioning between X and Y. This improved model was calibrated using measurements from long-term experiments and found to be satisfactory in comparison to data from six soils from four countries, viz., USA, Russia/Ukraine, Philippines, and England. The approach presented by

Hansen et al. (2002) is also similar in treating the phosphorus in three interacting pools, viz., soluble P that is readily available for plant uptake and wash out, reactive P that can quickly dissolve and join soluble P, and the stable P that is unavailable for plants or leaching due to its strong attachment to soil particles.

Vadas et al. (2008) reported an empirical model for predicting the concentration of phosphorus in runoff from surface-applied fertilizer. Their model was developed based on their simulated rainfall experiments and published runoff studies. This model releases the soil-adsorbed P for each rain event and distributes it between runoff and infiltration based on the runoff to rain ratio. The model was validated using data from 11 runoff studies that represented a series of runoff events for a variety of fertilizer types, soil cover types, fertilizer P adsorption amounts, storm hydrology conditions (i.e., runoff to rain ratio), and plot or field sizes (0.2 m^2 to 9.6 ha). However, their analysis showed model predictions could be quite sensitive to rainfall and runoff data. Kim and Gilley (2008) utilized artificial neural network (ANN) methods trained with back-propagation (BP) algorithm, and found that the concentrations of ammonium and dissolved phosphorus in overland flow are related to the measurements of runoff, pH, and electrical conductivity.

Davison et al. (2008) presented a process-based model called PSYCHIC (phosphorus and sediment yield characterization in catchments) that essentially covered the transfer pathways including the release of desorbable soil phosphorus (P), detachment of suspended solids and associated particulate P, incidental losses from fertilizer applications, losses from hard standings, the transport of all the above to watercourses in under-drainage and via surface pathways, and losses of dissolved P from point sources. However, their model is also sensitive to a number of crop and animal husbandry decisions, as well as to environmental factors such as soil type and field slope angle.

2.1.3 Effect of Soil Compaction

Soil compaction results in smaller pore sizes, low aeration status and an increase in the ratio of runoff to infiltration. Lipiec and Stepniewski (1995) discussed the effects of compaction, such as reduction in nutrient uptake due to inhibited root growth, changes in the rates of different nitrogen transformations, and increase in nitrogen losses via surface runoff and volatilization. This publication is of special importance to the present study as simulated fertilized highway slopes have been simulated by compacting the soil following roadway construction practices, which may contribute to higher nutrient losses in runoff.

2.1.4 Nutrient Uptake by Plants

Nye and Tinker (1977), and Barber (1984) presented the earliest known mechanistic models of nutrient uptake by different plants. Chen and Barber (1990) verified the Barber-Cushman model for phosphorus uptake under a range of pH conditions by conducting pot experiments in silty loam soils. Roose and Fowler (2004) further improved the model by considering the root branching structure and combining phosphorus uptake with water uptake as phosphorus is a highly buffered nutrient. Shimozono et al. (2008) studied the dynamics of nutrient leachate and turf grass growth in sands amended with food-waste compost in pots, and examined the nutrient uptake under the given conditions. Wright et al. (2007) investigated the effect of compost source and application rate on soil macronutrient availability and their uptake by St. Augustine grass and Bermuda grass. Bowman et al. (2002) specifically described nitrogen uptake by six warm-season turf grasses.

2.1.5 Studies on Florida on Turf Grasses and Citrus Plantations

Some of the research studies conducted by the University of Florida on fertilizer leaching have focused on home lawns and citrus plantations. Erickson et al. (1999) described the Florida Yards and Neighborhoods (FYN) program, which developed a research facility consisting of eight hydrologically isolated plots with lysimeters for sample collection. The test plots were laid at a fixed 10% slope with sandy soils. Their paper reported details on the nitrogen uptake and leaching using St. Augustine (SA) grass and mixed-ornamental species (MS). While SA grass is the predominant lawn grass used by homeowners in Florida, the MS landscape is a suggested alternative consisting of 12 ornamental species and no turf-grass.

Erickson et al. (2001) gave the actual comparison of results from these two alternative residential landscapes. They concluded that St. Augustine grass was more efficient at using applied N and minimizing N leaching compared with the alternative landscape. Moreover, they also pointed to areas of concern with respect to N management practices on alternative landscapes. Erickson et al. (2005) described the leaching of phosphorus (P) and potassium (K) from the same study. They observed that the leaching losses were high during establishment of grass and after severe storms, again SA landscape minimizing these losses compared with the MS landscape. They also concluded that in both the landscapes, the leaching losses of P, and perhaps K, were high enough to raise concern over ecological impacts on neighboring hydrologically linked systems.

In a recent publication, Erickson et al. (2010) described the effect of different sod production methods, irrigation practices and fertilization regimes on the nitrate and phosphate leaching from St. Augustine grass plots. Their investigation revealed that fertilization at 30 days after installation has resulted in significant reduction in leaching due to higher capacity of the grass for nutrient uptake. Trenholm and Unruh (2007) investigated the fertilization requirements of St. Augustine grass by studying the visual quality of grass grown at two climatically different sites. They concluded that the length of the growing season, adequacy of pest control, and biotic or abiotic stresses result in different fertilization requirements.

Saha et al. (2007) investigated the effect of fertilizer source on nitrate leaching by growing St. Augustine grass and a mix of common Florida ornamentals in 300-L plastic pots in a controlled environment. They used fine sand and applied two types of quick-release fertilizers (QRF) and one slow-release fertilizer (SRF). They observed that less nitrate leached from St. Augustine grass than from mixed ornamentals; also, less nitrate leached from SRF than from QRF, which is obvious. Paramasivam et al. (2000) applied liquid ammonium nitrate on a sandy soil field site, typically used for citrus production in central Florida, and studied the leaching by collecting water samples at regular intervals. Their field measurements compared satisfactorily with model predictions using LEACHM.

2.2 Relevance of Reviewed Literature to this Study

The studies reported in the research literature primarily focused on agricultural and horticultural issues at scales such as farm/catchment, or home lawn. Therefore, the emphasis was on different crops for food production, or high-maintenance turf grasses for aesthetics, but not on the FDOT's prime concern of utility turf grasses for erosion control. Most of the investigators used loamy soils and clayey soils, considered better for moisture retention and crop production. Only a few studies focused on clean sands, or sands with minimal silt, typically used by FDOT as these soils are locally available and considered better for road construction. However, the nutrient transformations and their interactions with soil-water-biota are essentially same. Therefore, this study appropriately modified and adopted the mechanistic models, found in the literature, for interpretation of results.

Presented in Chapter 3 are the details and results of all experimental investigations in phase #1 of the research. Chapter 4 presents the details and experimental results for phase #2. A complete discussion, comparison, and interpretation of results are presented in chapters 5 through 8.

CHAPTER 3. EXPERIMENTAL FINDINGS OF PHASE #1

The field-scale experimental investigations were conducted by compacting the selected soil in the field-scale test bed, establishing the chosen sod, allowing sufficient time for penetration of roots into soil, adjusting the test bed to the desired slope, simulating the desired rainfall and collecting water samples (runoff and base flow) for further chemical analysis. The details of the field-scale test set-up and chemical analysis arrangements was described in chapter 1. The soils, turf grasses, slopes, and rainfall intensities were selected for this study after a thorough review of the literature including the research conducted by the by the Institute of Food and Agricultural Sciences at the University of Florida and discussions with several stakeholders (agencies, consultants etc.). The chosen parameters, as described in the following paragraphs, were discussed at the outset of the project with the FDOT Project Manager. These experimental variables were finally adopted for this study after further discussions with other officials of FDOT and concerned agencies in a meeting of the Technical Advisory Committee on September 15, 2008. The methods for fertilizer application, grass establishment and maintenance, and collection and analysis of water samples were determined after visiting an on-going fertilizer leaching research site at the University of Florida - Plant Science Research & Education Unit, Citra, Florida, and discussions with Dr. Laurie Trenholm, the principal investigator of that research facility.

Two types of soils were chosen considering the local availability, suitability for highway construction, and the FDOT's practice of soil classification as per the American Association of State Highway and Transportation Officials (AASHTO) system. As locally available free-draining coarse-grained soils provide better slope stability, typical FDOT roads in central and southern parts of Florida are built with AASHTO A-3 soil (clean sand) and are covered by

Argentine Bahia grass, which is a low-maintenance drought-resistant variety used as highway utility turf. In northern parts of Florida, FDOT's roads are built with AASHTO A-2-4 soil (silty sand) and are covered by Pensacola Bahia grass, which is also cold resistant in addition to being a low-maintenance drought-resistant utility turf (FDOT, 1992).

The two soil-turf combinations described above were the ones studied in this project. The soils were first compacted in the test bed to an average dry density of approximately 106 lb/ft^3 (1.7 g/cm^3), which is a typically desired value for highway construction. The field density values were determined by using a nuclear density gauge and following the ASTM D6938-08a: Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth). Green Images Nursery, located at Christmas, FL 32709, supplied the Argentine Bahia sod tiles, and Paff Landscape, Inc. in Brooksville FL, 34604 supplied the Pensacola Bahia sod tiles for this study. The compacted soil in the test bed was scarified to a depth of about one to two inches prior to the application of the purchased sod tiles, which were applied tightly together. The established sod was regularly watered for three weeks (unless there was a natural rainfall), thus allowing sufficient time for roots to grow into the compacted soil before the commencement of the experimental investigations. These three weeks have also resulted in the decimation of any gap between the compacted soil and sod that could have resulted in preferential flow paths and unintentional soil erosion of the soil under the sod.

Based on a report of Harper and Baker (2007) on the rainfall patterns and intensities in Florida, three rainfall intensities were chosen for this study, 0.5 inches/hour (12.5 mm/hour), 1 inch/hour (25 mm/hour), 3 inches/hour (76 mm/hour). The highway slopes are usually designed based on soil strength, drainage conditions, and other engineering considerations. They typically vary from 1:4 to 1:2, vertical to horizontal. For this study, three side slopes were chosen (1:4, 1:3, and 1:2) and the slope of test bed was adjusted accordingly using the hydraulic lifting system. The objective of varying the rainfall intensity and soil slope was to study the effect of these parameters on the loss of nutrients following fertilizer application on these two soil-turf combinations. In addition, there is sheet flow from travel lanes onto the shoulders of highways as well, which was included in phase #2 of the study. Sheet flow was not part of the study in phase #1, but the choice of the range of rainfall intensities is sufficient to account for some of these sheet flow effects from adjoining impermeable areas.

A typical past practice of FDOT was to apply a 10-10-10 N-P-K (nitrogen-phosphorus-potassium) fertilizer to result in approximately 1 lb of N per 1000 ft^2 (in SI units, approximately 450 grams of N per 93 m^2 area). This is the application rate recommended for home lawns in Florida by the UF-IFAS after their extensive research. FDOT later changed its fertilization policy by replacing 10-10-10 fertilizers with fertilizers containing some portion of slow-release nitrogen and no phosphorus, e.g., 16-0-8 N-P-K (SR), to protect the environment, considering the fact that Florida's soils are generally rich in phosphorus. Currently, FDOT is applying fertilizers at a rate resulting in approximately 0.5 lb of N per 1000 ft^2 (in SI units, approximately 225 grams of N per 93 m^2 area) using the 16-0-8 N-P-K (SR) fertilizer.

Incidentally, these rates are the same as the fertilization application rates recommended by the IFAS-UF researchers (Trenholm and Unruh, 2005) for home lawns in Florida. However, the present study became essential, as the conditions of FDOT's fertilized highways are considerably different from conditions of home lawns. Table 1 presents a summary of the experimental parameters. The test series outlined in Table 1 reflects the FDOT highway construction and fertilization practices, as well as weather conditions in Florida. The tests with 16-0-8 N-P-K (SR) were conducted on A-3 soil at both the application rates of 1.0 lb and 0.5 lb of N per 1000 ft^2 at the request of FDOT. However, the tests with 16-0-8 N-P-K (SR) were conducted on A-2-4 soil only at the FDOT's current application rates of 0.5 lb of N per 1000 ft^2.

Table 1: Variables in Experiments on Nutrient Losses from Fertilized Highway Slopes

Test Series	Soil-sod Combination	Slopes (Vertical: Horizontal)	Rainfall Intensities (inch per hour)	Fertilizer N-P-K, Application Rate
1	AASHTO A-3 Soil (clean sand) covered by Argentine Bahia	1:4	0.5, 1, and 3	None
		1:4	0.5, 1, and 3	10-10-10 1 lb of N per 1000 ft^2
		1:3	0.5, and 1	
		1:2	0.5, and 1	
		1:4	0.5, 1, and 3	16-0-8 (SR) 1 lb of N per 1000 ft^2
		1:3	0.5, and 1	
		1:2	0.5, and 1	
		1:4	0.5, 1, and 3	16-0-8 (SR) 0.5 lb of N per 1000 ft^2
		1:3	0.5, and 1	
		1:2	0.5, and 1	
2	AASHTO A-2-4 Soil (silty sand) covered by Pensacola Bahia	1:4	0.5, 1, and 3	None
		1:4	0.5, 1, and 3	10-10-10 1 lb of N per 1000 ft^2
		1:3	0.5, and 1	
		1:2	0.5, and 1	
		1:4	0.5, 1, and 3	16-0-8 (SR) 0.5 lb of N per 1000 ft^2
		1:3	0.5, and 1	
		1:2	0.5, and 1	

In addition, tests were also conducted without applying any fertilizers, for evaluating the leachable nutrients in the soil-sod combinations and to serve as a baseline. As per FDOT's suggestion to examine the loss of nutrients in the case of a series of storms subsequent to fertilization, two more tests were conducted as seven-day tests for studying such a worst-case-scenario. These two tests were conducted using the 10-10-10 fertilizer at 3 inch/hour rainfall intensity, one each on A-3 soil and A-2-4 soil. The results of these tests are compared with results of one-day tests, conducted with similar parameters. For serving as a common basis, the fertilizer was applied on the first day only, for both one-day and seven-day tests. The one-day tests received a simulated rainfall of 3 in/hr for one hour on Day 1, while the seven-day tests received simulated rainfall of 3 in/hr for one hour on Days 1, 3, and 7.

3.1 Challenges in Field-Scale Experiments

The field-scale test bed at the research facility is open to the atmosphere. While this is advantageous in being similar to the real-world situation, it also posed several experimental challenges. The tasks of compacting 240 ft^3 (6.883 m^3) of soil, establishing sod, and waiting three weeks for root growth translated into a total time requirement of one month for changing the soil-sod in the test bed. Considering the time and cost constraints, and after discussions with FDOT Project Manager, the soil-sod combinations were changed only when the fertilizer type was changed.

The second experimental challenge was maintaining the soil moisture in the test bed. Only two tests could be conducted per week due to manpower requirements. The exposure of the test bed to Florida's hot and stormy weather meant quick wetting and drying of soil and thus different starting moisture content values for tests conducted. The third experimental challenge was to bring the soil nutrient concentrations to original levels before each test or to flush out leftover fertilizers as much as possible after each test and mathematically working out the soil nutrient balance at the beginning of each subsequent test. In view of the strong soil-plant-nutrient interactions, it was not possible to achieve the former and thus the latter option was adopted as described in chapter 4. The final challenge was dealing with the residual fertilizer on the sod from the nursery where it was purchased. This was addressed by thoroughly washing the sod tiles after placement on the test bed.

For overcoming the challenges described above and for making the test results comparable to each other, a testing protocol described here was developed and followed. In each test, the fertilizer was first applied, followed by a constant wetting event (irrigation) of 0.5 inch per hour rainfall for 30 minutes. This constant wetting event ensured near saturation of soil and soaking-in of fertilizer below the turf grass at the start of the simulated rain event. This constant wetting event is incidentally a standard practice followed by the FDOT contractors. Very little, if any, quantities of run-off and base flow were observed during the constant wetting events.

The constant wetting event was followed by the desired simulated rainfall for one hour. Twelve rain gauges were set-up on the test bed for measuring the actual rainfall intensity and to make sure that the rainfall simulator produced the desired rainfall. In general, the measured rainfall intensities were very close to the desired ones, the differences were basically due to wind conditions. Considerable quantities of run-off and base flows were observed during the simulated rainfall. Each simulated rainfall event was followed by a constant flush rainfall at an intensity of 3-in/hr for two hours. Considerable quantities of run-off and base flow were also observed during the flush rainfall events. The water samples were collected during all events at frequent time intervals, volumes were measured, and the chemical analysis was conducted. These results were used for determining the volume of water and the mass of nutrients that washed out of the test bed during each test. The mass balance of water and nutrients in the test bed was calculated based on these results and based on the inter-test processes considering the biological properties of the grass and the weather data.

Table 2 presents the actual chronological sequence of all tests conducted in this study. Description of the results of these test series are presented in chapter 3. Further discussion of results and related comparisons of the effect of different parameters on the nutrient losses are presented in chapters 5 through 7.

Table 2: Chronological Sequence of Field-Scale Simulated-Rainfall Experiments

Test #	Soil	Bahia Sod	Fertilizer*	Slope	inch/hr	Date
1	A-3	Argentine	10-10-10	25%	0.5	5/27/2009
2	A-3	Argentine	10-10-10	25%	1	6/3/2009
3	A-3	Argentine	10-10-10	25%	3	6/10/2009
4	A-3	Argentine	10-10-10	33%	0.5	6/22/2009
5	A-3	Argentine	10-10-10	33%	1	6/29/2009
6	A-3	Argentine	10-10-10	50%	0.5	7/2/2009
7	A-3	Argentine	10-10-10	50%	1	7/6/2009
Change of Soil						
8	A-3	Argentine	None	25%	0.5	8/17/2009
9	A-3	Argentine	None	25%	1	8/20/2009
10	A-3	Argentine	None	25%	3	8/24/2009
11	A-3	Argentine	16-0-8	25%	3	8/27/2009
12	A-3	Argentine	16-0-8	25%	0.5	8/31/2009
13	A-3	Argentine	16-0-8	25%	1	9/3/2009
14	A-3	Argentine	16-0-8	33%	1	9/10/2009
15	A-3	Argentine	16-0-8	33%	0.5	9/14/2009
16	A-3	Argentine	16-0-8	50%	1	9/17/2009
17	A-3	Argentine	16-0-8	50%	0.5	9/21/2009
18	A-3	Argentine ***7-day***	10-10-10	33%	3	10/13/2009
19	A-3	Argentine	16-0-8 (0.5 lb)	25%	1	10/26/2009
20	A-3	Argentine	16-0-8 (0.5 lb)	25%	3	10/29/2009
21	A-3	Argentine	16-0-8 (0.5 lb)	25%	0.5	11/5/2009
22	A-3	Argentine	16-0-8 (0.5 lb)	50%	0.5	11/12/2009
23	A-3	Argentine	16-0-8 (0.5 lb)	50%	1	11/17/2009
24	A-3	Argentine	16-0-8 (0.5 lb)	33%	0.5	11/19/2009
25	A-3	Argentine	16-0-8 (0.5 lb)	33%	1	11/23/2009
Change of Soil						
26	A-2-4	Pensacola	None	25%	0.5	1/14/2010
27	A-2-4	Pensacola	None	25%	1.0	1/21/2010
28	A-2-4	Pensacola	None	25%	3.0	1/28/2010
29	A-2-4	Pensacola	10-10-10	25%	0.5	2/1/2010
30	A-2-4	Pensacola	10-10-10	25%	3.0	2/4/2010
31	A-2-4	Pensacola	10-10-10	25%	1.0	2/8/2010
32	A-2-4	Pensacola	10-10-10	33%	0.5	2/11/2010
33	A-2-4	Pensacola	10-10-10	33%	1.0	3/4/2010
34	A-2-4	Pensacola	10-10-10	50%	0.5	3/8/2010
35	A-2-4	Pensacola	10-10-10	50%	1.0	3/15/2010
36	***A-2-4***	***Pensacola 7-day***	***10-10-10***	***33%***	***3.0***	3/23/2010
37	A-2-4	Pensacola	None	25%	0.5	4/1/2010
38	A-2-4	Pensacola	None	25%	1.0	4/5/2010
39	A-2-4	Pensacola	None	25%	3.0	4/8/2010

Test #	Soil	Bahia Sod	Fertilizer*	Slope	inch/hr	Date
Change of Soil						
40	A-2-4	Pensacola	16-0-8 (0.5 lb)	25%	0.5	5/20/2010
41	A-2-4	Pensacola	16-0-8 (0.5 lb)	25%	1.0	5/13/2010
42	A-2-4	Pensacola	16-0-8 (0.5 lb)	25%	3.0	5/17/2010
43	A-2-4	Pensacola	16-0-8 (0.5 lb)	33%	0.5	5/27/2010
44	A-2-4	Pensacola	16-0-8 (0.5 lb)	33%	1.0	5/24/2010
45	A-2-4	Pensacola	16-0-8 (0.5 lb)	50%	0.5	6/1/2010
46	A-2-4	Pensacola	16-0-8 (0.5 lb)	50%	1.0	6/4/2010

*Fertilizer application @ 1 lb of N per 1000 ft^2, unless otherwise noted.

3.2 AASHTO A-3 Soil with Argentine Bahia

3.2.1 No Application of Fertilizer

As shown in Table 1 and Table 2, three (3) tests were run without fertilizer for establishing a base line for this soil-sod combination. The no-fertilizer tests were run at a slope of 25% (1:4) and at 0.5, 1.0, and 3.0 in/hr rainfall intensities (12.7, 25.4, and 76.2 mm/hr) and are used for determining the general level of nutrients in the virgin soil and any nutrients that were brought in by the sod.

Table 3 presents the actual rainfall intensities that were applied to the test bed calculated based on the measurement of twelve rain gauges set up on the test bed. The volumes of applied rain are calculated by multiplying the area of the test bed with the total actual average rainfall intensities applied during irrigation and simulated rain events. Similarly, the runoff and base flow volumes are also based on the actual collected and measured flow quantities during irrigation and simulated rain events. The percentage of runoff volume to the total outflow volume ranged from 0.00% to 36.77%. This runoff percentage generally increased with rainfall intensity, but the variation is nonlinear due to the variations in the initial soil moisture content and evapotranspiration conditions. This percentage is one of several factors that might have influenced the loss of nutrients as the higher energy of run-off, compared to that of base flow, could have helped in carrying out more fertilizer particles.

Table 3: Volumes of Rainfall Applied, Runoff, and Base Flow Collected on A-3 Soil, Argentine Bahia Sod, and No Fertilizer

Fertilization type and Slope	**No Fertilizer 1:4 Slope**		
Intended intensity [in/hr]	0.5	1.0	3.0
Avg. actual intensity [in/hr]	0.45	1.11	2.82
Flow volumes in liters (L)			
Applied	388.2	773.7	1736.7
Base flow	344.0	666.8	1002.2
Runoff	0.0	2.6	582.8
Runoff as percentage of Total Collected [%]	0.00	0.39	36.77

Table 4 presents the average chemical parameters measured in these three tests. The concentration of total solids ranged from 30.4 mg/L to 255.3 mg/L, and turbidity values ranged from 2.0 to 5.7 NTU, demonstrating the capacity of Argentine Bahia in preventing erosion for the range of rainfall intensities tested. The range of pH values was from 7.2 to 7.6, and the alkalinity ranged from 94.4 mg/L to 114.7 mg/L (as $CaCO_3$). This is indicative of the system being chemically neutral.

Table 4: Total Solids, pH, Alkalinity, and Turbidity in Tests on A-3 Soil, Argentine Bahia Sod, and No Fertilizer

Slope and Soil Type	**1:4 Slope and A-3 Soil**		
Intended intensity [in/hr]	0.5	1.0	3.0
Total Solids [mg/L]	30.4	255.3	205.7
pH	7.6	7.4	7.2
Alkalinity [mg/L]	114.7	94.4	98.3
Turbidity [NTU]	5.7	3.0	2.0

Table 5 presents the the masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flow were measured for the no fertilizer condition (no fertilization practice on the test beds for this series of tests). The TN mass lost in all three tests was, as expected, low. The percentage of TN lost in runoff to the total loss, in base flow and runoff, ranged from 0.00%

to 8.28%. The percentage of TP lost in runoff to the total loss, in base flow and runoff, ranged from 0.00% to 84.96%.

Table 5: Distribution of Nutrient Loss between Runoff and Base Flow on A-3 Soil, Argentine Bahia Sod, and No Fertilizer on a 1:4 Embankment Slope

Fertilization type and Slope	**No Fertilizer and 1:4 Slope**		
Rainfall intensity [in/hr]	**0.5**	**1.0**	**3.0**
TN Mass			
Base flow	0.05	0.02	1.78
Runoff	0.00	0.00	0.00
Total	0.05	0.02	1.78
Ratio of loss: runoff/total [%]	0.00	8.28	0.00
TP Mass			
Base flow	0.04	0.07	0.02
Runoff	0.00	0.00	0.13
Total	0.04	0.07	0.15
Ratio of loss: runoff/total [%]	0.00	2.50	84.96

Figure 3 presents the test-wise loss of total nitrogen (TN in runoff + base flow) for all three tests in this series. It can be seen from this figure that the mass of TN collected did not vary much with change in intensities from 0.5 to 1.0 in/hr but increased significantly with the 3 inch/hr rainfall intensity. The 3 in/hr rainfall intensity test was also the only test that produced significant runoff showing the correlation between runoff and nutrient loss from soils. Figure 4 presents the test-wise loss of total phosphate (TP in runoff + base flow) for all three tests in this series. It can be seen from the figure that the TP losses, while minor, increased with an increase in rainfall intensity. Obviously, there is no linear relationship between the mass of nutrient-loss and rainfall intensity. As no fertilizer was added, nutrient loss is governed by a host of bio-geochemical processes that are examined in detail in chapter 5.

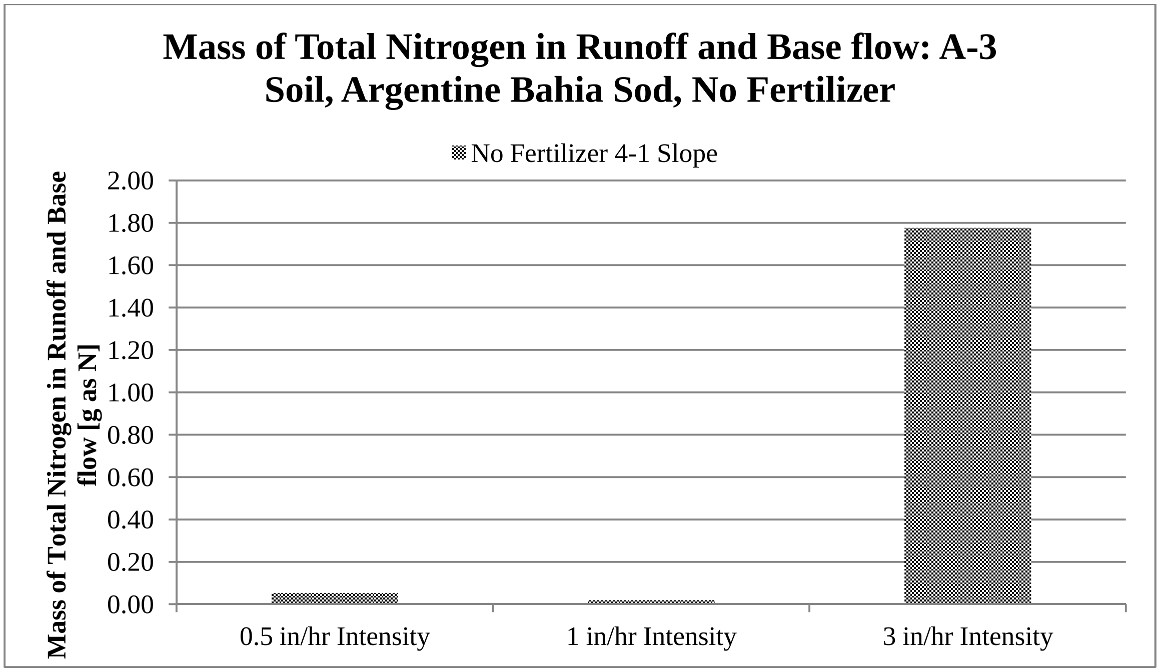

Figure 3: Mass of Total Nitrogen (TN) Collected – A-3 Soil, Argentine Bahia, and No Fertilizer on a 1:4 Embankment Slope

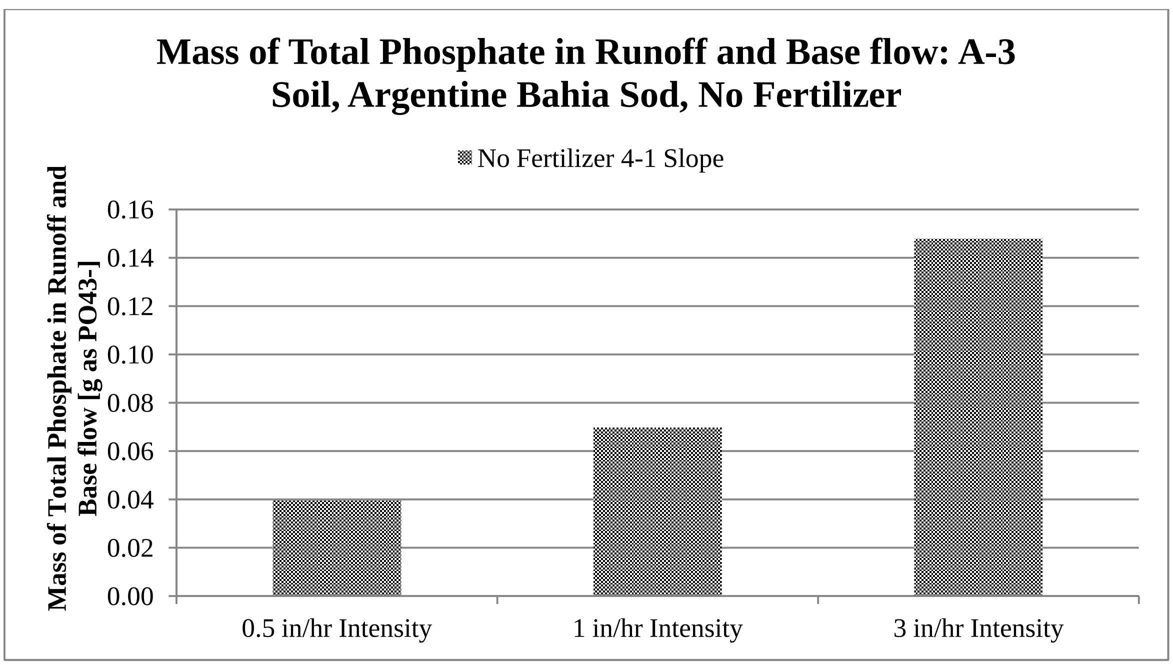

Figure 4: Mass of Total Phosphate (TP) Collected – A-3 Soil, Argentine Bahia Sod, and No Fertilizer on a 1:4 Embankment Slope

3.2.2 10-10-10 N-P-K Fertilization Practice @ 1 lb of N per 1000 ft^2

Table 6 presents the actual rainfall intensities that were applied to the test bed calculated based on the measurement of twelve rain gauges set up on the test bed. The volume of applied rain is calculated by multiplying the area of the test bed with the total actual average rainfall intensities applied during irrigation and simulated rain events. Similarly, the runoff and base flow volumes are also based on the actual collected and measured flow quantities during irrigation and simulated rain events. The percentage of runoff volume to the total outflow volume ranged from 8.91% to 79.1%. This runoff percentage generally increased with rainfall intensity but not necessarily steepness of slope. The variation with rainfall intensity is nonlinear due to the variations in the initial moisture content and evapotranspiration conditions. This percentage is one of the several factors that might have influenced fertilizer nutrient loss.

Table 6: Volumes of Rainfall Applied, Runoff, and Base Flow Collected on A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

Slope and Soil Type	**1:4 Slope A-3 Soil**			**1:3 Slope A-3 Soil**		**1:2 Slope A-3 Soil**	
Intended intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	0.5	1.0
Avg. actual intensity [in/hr]	0.444	0.831	2.683	0.438	0.890	0.500	1.025
Flow volumes in liters (L)							
Applied	384.6	658.3	1665.9	356.3	608.8	411.8	707.7
Base flow	295.9	101.8	306.6	143.7	150.7	220.8	248.2
Runoff	29.0	241.7	1160.7	82.4	314.7	142.4	383.7
Runoff as percentage of Total Collected (%)	8.91	70.37	79.1	36.44	67.61	39.21	60.72

Table 7 presents the average chemical parameters measured in the series of seven tests. The concentration of total solids ranged from 425.6 mg/L to 738.7 mg/L, and turbidity values ranged from 1.9 to 4.6 NTU, demonstrating the capacity of Argentine Bahia in preventing erosion for the range of tested slopes and rainfall intensities. The range of pH values was from 7.0 to 7.4, and the alkalinity range was from 144.0 mg/L to 237.6 mg/L (as $CaCO_3$), which are indicative of the chemical neutrality of the system. The applied mass of total nitrogen was 106.06 g as N, and that of total phosphate was 142.12 g as PO_4^{3-} for all the seven tests in the series.

Table 7: Total Solids, pH, Alkalinity, and Turbidity on A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

Slope and Soil Type	**1:4 Slope A-3 Soil**			**1:3 Slope A-3 Soil**		**1:2 Slope A-3 Soil**	
Intended intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	0.5	1.0
Total Solids [mg/L]	NA	501.3	520.7	425.6	536.7	NA	738.7
pH	7.0	7.4	7.4	7.2	7.3	7.2	7.0
Alkalinity [mg/L]	144.0	189.4	237.6	173.5	195.0	183.9	159.7
Turbidity [NTU]	1.9	2.7	2.6	4.6	3.2	3.5	1.9

Table 8 presents the masses of total nitrogen (TN) and total phosphorous (TP) collected in runoff and base flows. The ratio of TN lost in runoff to the total loss, base flow and runoff, ranged from 0.827 to 0.996, clearly suggesting the role of runoff in fertilizer nutrient losses. Most of the fertilizer particles that could get into the soil either got adsorbed by soil particles, taken up by grass or were not able to be fully mobilized and carried away by the base flow. The same ratio for TP ranged from 0.869 to 1.000, again reinforcing the role of runoff in fertilizer nutrient losses.

Table 8: Distribution of Nutrient Loss between Runoff and Base Flow on A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

Slope and Soil Type	**1:4 Slope A-3 Soil**			**1:3 Slope A-3 Soil**		**1:2 Slope A-3 Soil**	
Rainfall intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	0.5	1.0
TN Mass [g as N]							
Base flow	0.5	0.3	0.2	0.3	0.2	0.7	0.7
Runoff	2.5	17.1	57.6	7.3	33.0	9.6	26.4
Total	3.0	17.4	57.8	7.6	33.1	10.2	27.1
Ratio of loss: runoff/total	0.827	0.984	0.996	0.957	0.995	0.935	0.974
TP Mass [g as PO_4^{3-}]							
Base flow	0.1	0.1	0.0	0.1	0.1	0.0	0.1
Runoff	0.5	7.7	78.5	8.2	18.0	12.8	19.6
Total	0.6	7.8	78.6	8.4	18.1	12.8	19.7
Ratio of loss: runoff/total	0.869	0.993	1.000	0.983	0.996	0.998	0.996

Figure 5 presents the test-wise loss of total nitrogen (TN in runoff + base flow) for all the seven tests in this series. In genral, the TN losses increase with an increase in either slope, or rainfall intensity, or both. The only exceptions to these trends are the loss of TN in one test at 1 in/hr intensity on the 1:3 slope, which might have been affected by local or temporal issues, such as unintended fertilizer concentration in the test bed, unintended sample concentration, or over estimation by laboratory equipment. Figure 6 presents the test-wise loss of total phosphate (TP in runoff + base flow) for all the seven tests in the series. The plot shows that the fertilizer TP losses generally increase with an increase in either slope, or rainfall intensity, or both. There is no linear relationship between the mass of fertilizer nutrient loss and these two parameters (rainfall intensity and slope), as the loss is also governed by a host of bio-geochemical processes that are examined in detail in chapter 5.

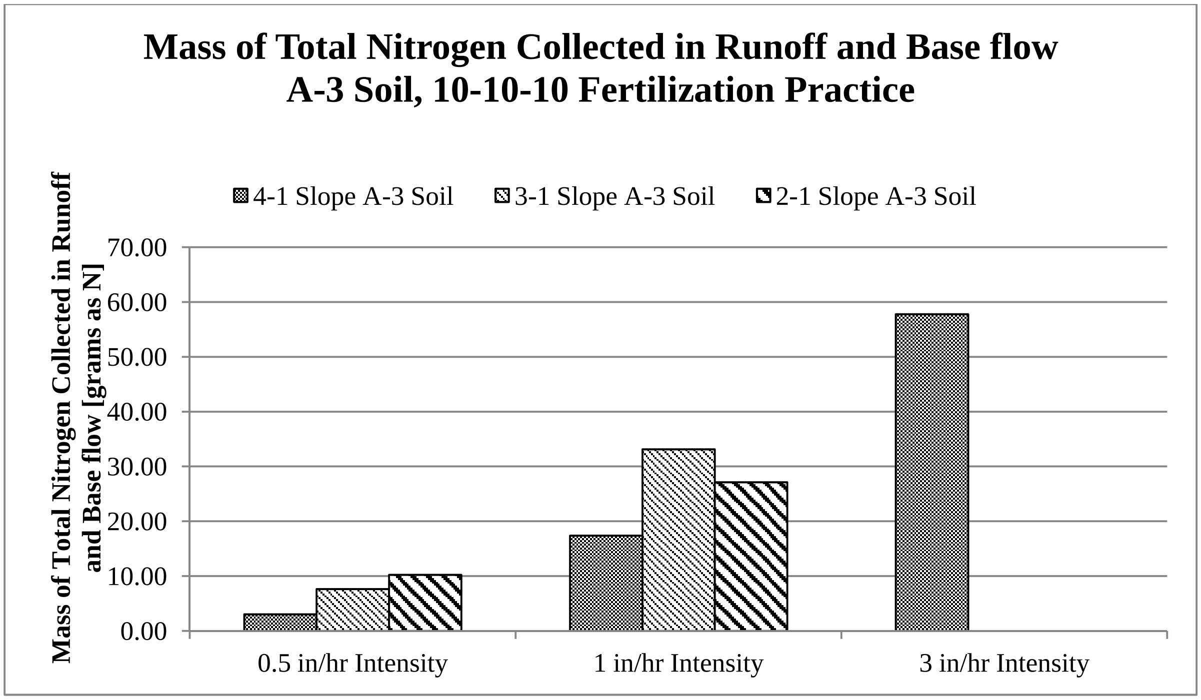

Figure 5: Mass of Total Nitrogen (TN) Collected – A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

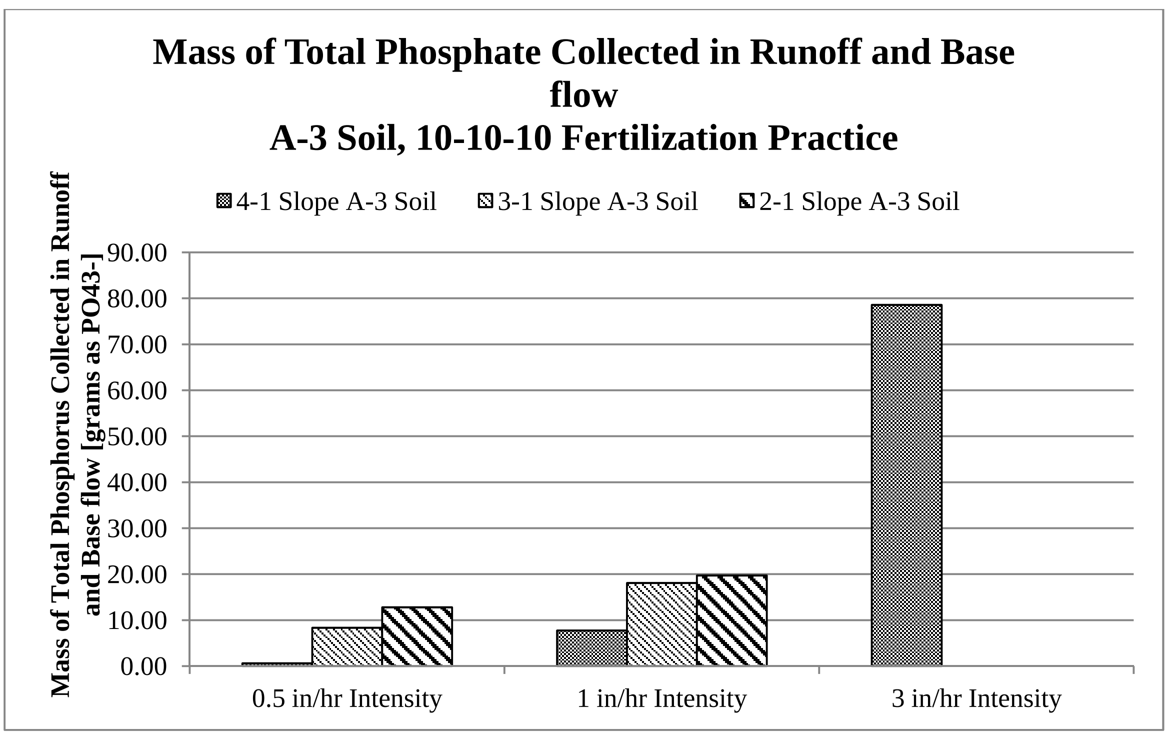

Figure 6: Mass of Total Phosphate (TP) Collected – A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

3.2.3 10-10-10 N-P-K Fertilization Practice @ 1 lb of N per 1000 ft^2 (Seven-Day Test)

Table 9 presents the actual rainfall intensities that were applied to the test bed calculated based on the measurement of twelve rain gauges set up on the test bed. The volume of applied rain is calculated by multiplying the area of the test bed with the total actual average rainfall intensities applied during irrigation and simulated rain events. Similarly, the runoff and base flow volumes are also based on the actual collected and measured flow quantities during irrigation and simulated rain events. The percentage of runoff volume to the total outflow volume ranged from 45.48% to 67.49% in this test series.

Table 9: Volumes of Rainfall Applied, Runoff, and Base FlowCollected on on A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

	1:3 Slope (Seven-Day Test)		
Intended intensity [in/hr]	3.0, Day One	3.0, Day Three	3.0, Day Seven
Avg. actual intensity [in/hr]	2.28	2.13	2.31
Flow volumes in liters (L)			
Applied	1399.3	1204.6	1310.8
Base flow	521.6	444.0	326.4
Runoff	451.5	370.3	677.6
Runoff as percentage of Total Collected [%]	46.40	45.48	67.49

Table 10 presents the average chemical parameters measured in each of the three tests. The concentration of total solids ranged from 676.73 mg/L to 952.36 mg/L, and turbidity values ranged from 1.17 to 2.03 NTU, again demonstrating the capacity of Argentine Bahia in preventing erosion for the high rainfall intensities tested in this series. Due to the larger rainfall intensities used in this test series, runoff volumes generated were larger resulting in elevated total solids values when compared to the other series presented above. In spite of the higher values of total solids, the turbidity values were still quite low. Thus, the values would not have resulted in the violation of the FDEP's discharge standard of 29 NTU's above background. The range of pH values was from 7.02 to 7.32, and the alkalinity range was from 112.49 mg/L to 148.73 mg/L (as $CaCO_3$), which are indicative of the chemical neutrality of the system. The applied mass of total nitrogen was 106.06 g as N, and that of total phosphate was 142.12 g as PO_4^{3-} for the first of the three tests in this series, or for day one only.

Table 10: Total Solids, pH, Alkalinity, and Turbidity in Tests on A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

	1:3 Slope (Seven-Day Test)		
Intended intensity [in/hr]	3.0, Day One	3.0, Day Three	3.0, Day Seven
Total Solids [mg/L]	676.73	952.36	824.36
pH	7.18	7.02	7.32
Alkalinity [mg/L]	112.49	148.73	118.55
Turbidity [NTU]	1.25	1.17	2.03

Table 11 presents the masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flows. The percentage of TN lost in runoff to the total loss in base flow and runoff, ranged from 2.16% to 33.21%. The percentage of TN lost in runoff was highest on day one, and continually decreases until day seven. It is an indication that the nitrogen loss in the applied 10-10-10 fertilizer is initially high in runoff but as time passes, the ammonia was converted to nitrate and then leached out through the base flow. That is, TN loss in runoff decreases with time while TN loss in base flow increases with time. The same percentage for TP ranged from 96.00% to 99.78%, reinforcing the role of runoff in TP loss of applied fertilizer.

Table 11: Distribution of Nutrient Loss between Runoff and Base Flow: A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

	1:3 Slope (Seven-Day Test)		
Rainfall intensity [in/hr.]	3.0, Day One	3.0, Day Three	3.0, Day Seven
TN Mass			
Base flow	25.96	23.22	18.49
Runoff	12.91	2.16	0.41
Total	38.86	25.38	18.90
Percentage of loss: runoff/total [%]	33.21	8.53	2.16
TP Mass			
Base flow	0.03	0.09	0.00
Runoff	13.45	2.21	1.16
Total	13.47	2.31	1.16
Percentage of loss: runoff/total [%]	99.78	96.00	99.58

Figure 7 presents the test-wise loss of total nitrogen (TN in runoff + base flow) for all three tests in this series, which shows that the TN losses in general decrease with time. Figure 8 presents the test-wise loss of total phosphate (TP in runoff + base flow) for all three tests in this series, which shows that the fertilizer TP losses also decrease with time. This was the expected response since no additional fertilizers are added after the initial fertilization on day one.

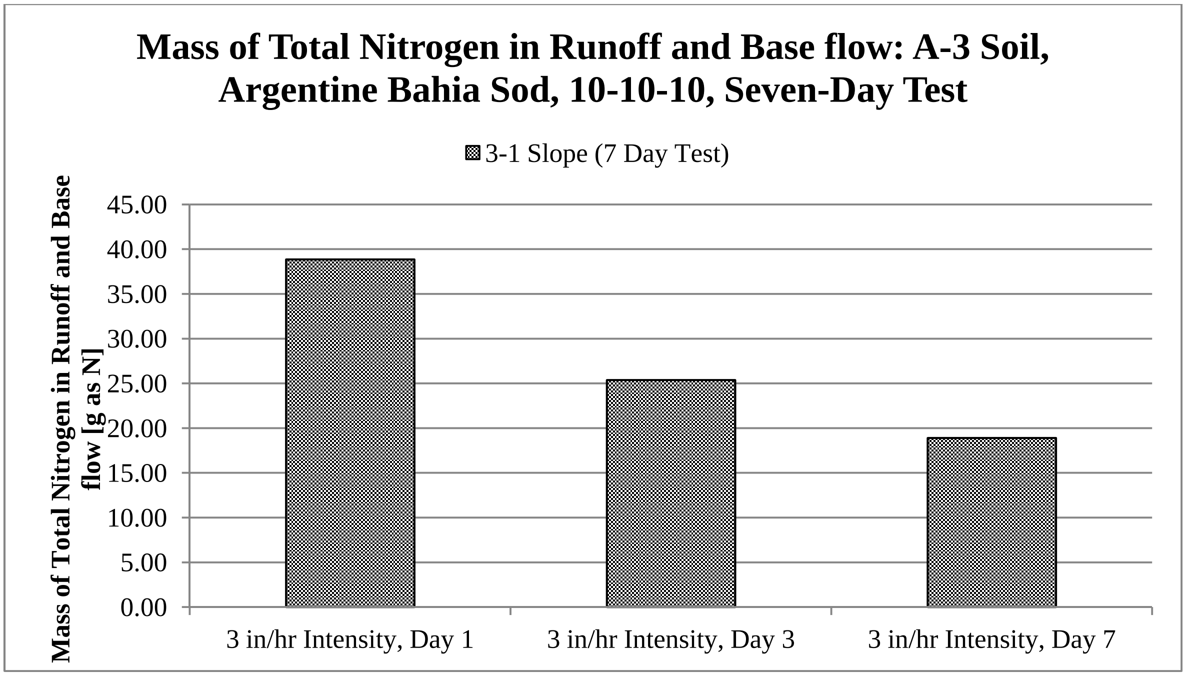

Figure 7: Mass of Total Nitrogen (TN) Collected – A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

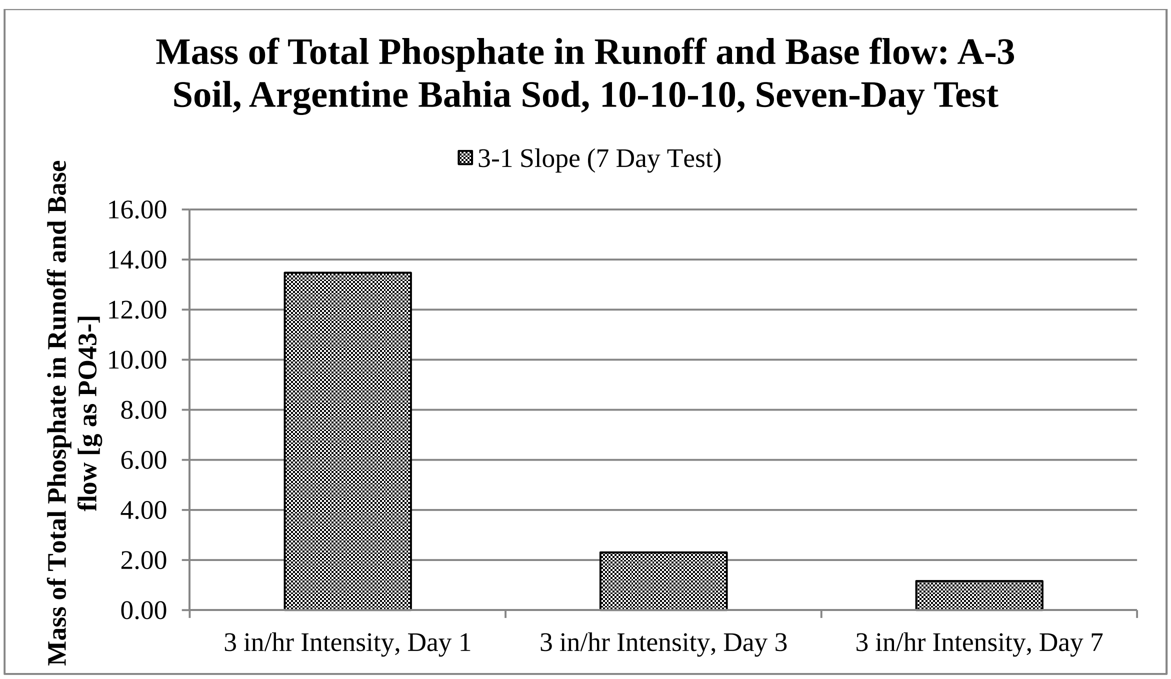

Figure 8: Mass of Total Phosphate (TP) Collected – A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

3.2.4 16-0-8 (SR) N-P-K Fertilization Practice @ 1 lb of N per 1000 ft^2

Table 12 presents the actual rainfall intensities, volumes of applied rain, runoff and base flow, based on the actual measurements during the irrigation and simulated rain events. The percentage of runoff volume to the total outflow volume ranged between 0% and 36% and generally increased with steepness of slope and/or rainfall intensity.

Table 12: Volumes of Rainfall Applied, Runoff, and Base Flow Collected on A-3 Soil, Argentine Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 1 lb of N per 1000 ft^2

Slope	**1:4**			**1:3**		**1:2**	
Intended intensity [in/hr.]	0.5	1.0	3.0	0.5	1.0	0.5	1.0
Avg. actual intensity [in/hr.]	0.50	1.12	2.91	0.56	1.10	0.52	1.02
Flow volumes in liters (L)							
Applied	428.3	783.4	1794.5	475.2	772.8	459.2	707.9
Base flow	362.1	720.1	992.8	386.1	567.0	370.8	637.1
Runoff	0.0	2.2	561.7	0.0	35.9	0.0	31.5
Runoff as percentage of Total Collected [%]	0.00	0.31	36.13	0.00	5.96	0.00	4.71

Table 13 presents the average chemical parameters measured in this series of seven tests. The concentration of total solids ranged from 155.7 mg/L to 544.0 mg/L, and turbidity values ranged from 0.8 to 2.8 NTU, once again demonstrating the capacity of Argentine Bahia in preventing erosion for the range of tested slopes and rainfall intensities. The range of pH values was from 6.6 to 7.6, and the alkalinity range was from 103.8 mg/L to 141.9 mg/L (as $CaCO_3$), which are indicative of the chemical neutrality of the system. The applied mass of total nitrogen was 106.06 g as N, and that of total phosphorous was 0.00 g as PO_4^{3-} for all the seven tests in the series.

Table 13: Total Solids, pH, Alkalinity, and Turbidity in Tests on A-3 Soil, Argentine Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 1 lb of N per 1000 ft^2

Slope	**1:4**			**1:3**		**1:2**	
Intended intensity [in/hr.]	0.5	1.0	3.0	0.5	1.0	0.5	1.0
Total Solids [mg/L]	374.0	281.8	155.7	428.6	401.3	544.0	389.3
pH	7.5	7.4	7.6	7.2	7.4	6.6	7.5
Alkalinity [mg/L]	116.0	119.2	104.8	126.9	141.9	103.8	136.0
Turbidity [NTU]	1.3	N/A	2.8	0.9	N/A	0.8	0.8

Table 14 presents the masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flows. The percentage of TN lost in runoff to the total lost in base flow and runoff ranged from 0.00% to 67.32%. Only for the 1 to 4 slope at 3 in/hr rainfall intensity, the percent of TN lost in runoff was significant; in the other tests of this series, the predominant mode of TN loss was through base flow. This was because all of the tests, except the 3 in/hr test, did not produce significant runoff, so most of the water collected during the tests was from base flow. The same percentage for TP mass loss ranged from 0.00% to 63.15%. Since most of the volume collected from this series of tests was from base flow, it is not surprising that the percentage is so low for all intensities except 3 in/hr. As the 16-0-8 (SR) fertilizer contained no phosphorus, obviously very low masses of TP were collected.

Table 14: Distribution of Nutrient Loss between Runoff and Base Flow on A-3 Soil, Argentine Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 1 lb of N per 1000 ft^2

Slope	**1:4**			**1:3**		**1:2**	
Rainfall intensity [in/hr.]	0.5	1.0	3.0	0.5	1.0	0.5	1.0
TN Mass [g as N]							
Base flow	2.51	9.83	0.29	8.19	10.74	10.28	8.35
Runoff	0.00	0.06	0.59	0.00	0.78	0.00	0.78
Total	2.51	9.89	0.87	8.19	11.52	10.28	9.13
Percent of loss: runoff/total [%]	0.00	0.63	67.32	0.00	6.73	0.00	8.59
TP Mass [g as PO_4^{3-}]							
Base flow	0.04	0.05	0.15	0.08	0.03	0.04	0.04
Runoff	0.00	0.00	0.26	0.00	0.03	0.00	0.02
Total	0.04	0.05	0.41	0.08	0.06	0.04	0.06
Percent of loss: runoff/total [%]	0.00	3.03	63.15	0.00	44.25	0.00	41.28

Figure 9 presents the loss of total nitrogen (TN in runoff + base flow) for all the seven tests in this series. It can be seen from the figure that the TN losses in general increase with an increase in either slope, or rainfall intensity, or both. The only exceptions to this trend are the loss of TN in one test at 1 in/hr intensity on the 1 in 2 slope and the loss of TN in the 3 in/hr intensity on the 1 in 4 slope. These might have been affected by local or temporal issues, such as unintended fertilizer concentration/dilution in the test bed, flow and nutrient washout through macro-pores in the test bed. Obviously, there is no linear relationship between the mass of fertilizer nutrient loss and these two parameters (rainfall intensity and slope), as the loss is also governed by a host of bio-geochemical processes that are examined in detail in chapter 5.

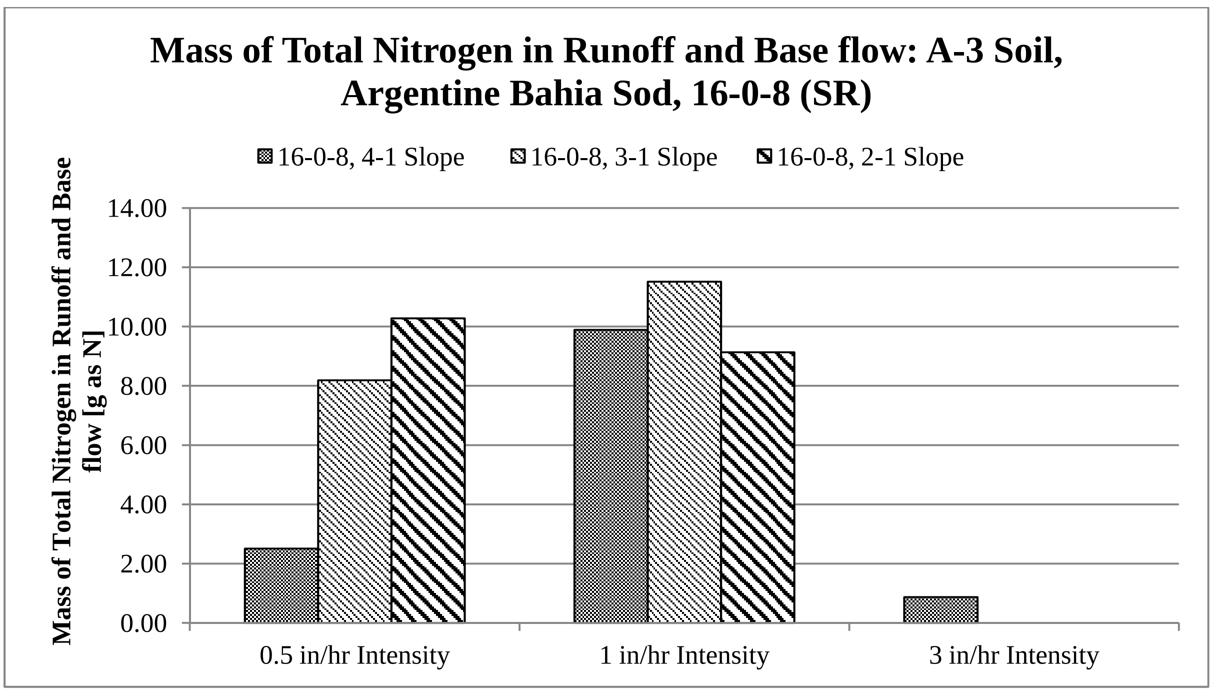

Figure 9: Mass of Total Nitrogen (TN) Collected – A-3 Soil, Argentine Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 1 lb of N per 1000 ft^2

Figure 10 presents the loss of total phosphate (TP in runoff + base flow) for all the seven tests in the series. It can be seen from the figure that the TP mass losses are insignificant, which was due to was no phosphorus in the fertilizer applied for these tests.

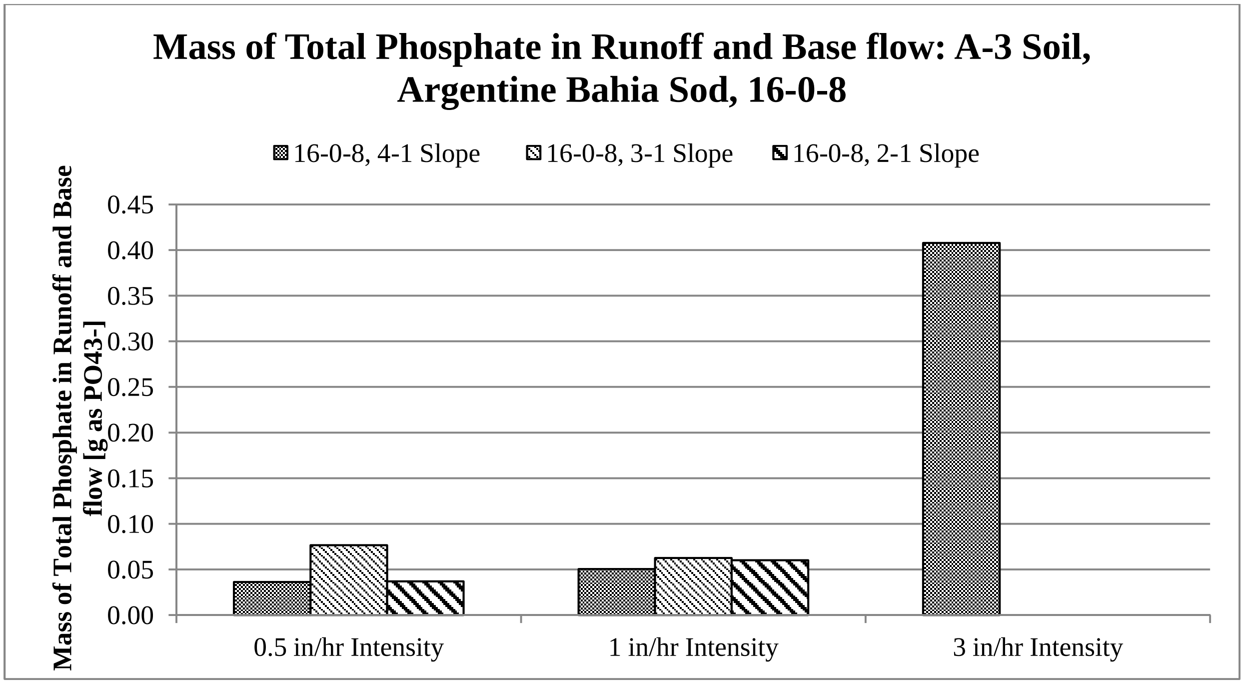

Figure 10: Mass of Total Phosphate (TP) Collected – A-3 Soil, Argentine Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 1 lb of N per 1000 ft^2

3.2.5 16-0-8 (SR) N-P-K Fertilization Practice at 0.5 lb of N per 1000 ft^2

Table 15 presents the actual rainfall intensities, volumes of applied rain, runoff and base flow, based on the actual measurements during the irrigation and simulated rain events. There was little to no runoff for all intensities except for the 3 in/hr rainfall intensity, this may be due to higher infiltration capacity during the winter season (thinner grass blades, more soil storage, etc.). The percentage of runoff volume to the total outflow volume ranged from 0.00% to 41.08%.

Table 15: Volumes of Rainfall Applied, Runoff, and Base Flow Collected on A-3 Soil, Argentine Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 0.5 lb of N per 1000 ft^2

Slope	1:4			1:3		1:2	
Intended intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	3.0	0.5
Avg. actual intensity [in/hr]	0.50	1.12	2.91	0.56	1.10	0.52	1.02
Flow volumes in liters (L)							
Applied	365.7	725.6	1540.8	453.0	825.9	400.0	776.3
Base flow	280.8	396.1	810.2	410.1	681.5	399.5	629.1
Runoff	0.0	32.3	564.8	0.0	70.8	0.0	120.9
Runoff as percentage of Total Collected [%]	0.00	7.54	41.08	0.00	9.42	0.00	16.12

Table 16 presents the average chemical parameters measured in this series of seven tests. The concentration of total solids ranged from 259.27 mg/L to 1009.67 mg/L, and turbidity values ranged from 0.6 to 3.7 NTU, once again demonstrating the capacity of Argentine Bahia in preventing erosion for the range of tested slopes and rainfall intensities. The range of pH values was from 6.89 to 7.48, and the alkalinity range was from 137.00 mg/L to 177.44 mg/L (as $CaCO_3$), which are indicative of the chemical neutrality of the system. The applied mass of total nitrogen was 53.03 g as N, and that of total phosphorous was 0.00 g as PO_4^{3-} for all the seven tests in the series.

Table 16: Total Solids, pH, Alkalinity, and Turbidity in Tests on A-3 Soil, Argentine Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 0.5 lb of N per 1000 ft^2

Slope	1:4			1:3		1:2	
Intended intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	3.0	0.5
Total Solids [mg/L]	319.11	1009.67	259.27	462.22	414.33	344.00	348.40
pH	7.03	7.26	7.48	7.02	6.89	7.45	7.28
Alkalinity [mg/L]	155.22	155.08	142.36	150.11	137.00	177.44	147.57
Turbidity [NTU]	2.5	3.7	2.9	0.9	0.6	1.8	1.3

Table 17 presents the masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flows. The percentage of TN lost in runoff to the total lost in base flow and runoff, ranged from 0.00% to 55.78%. Only the 3 in/hr intensity had considerable TN loss in runoff; for the other tests in the series the predominant mode of TN loss was through base flow.

This was because all of the tests, except the 3 in/hr test, did not produce significant runoff so most of the water collected during the tests was from base flow. The same percentage for TP mass loss ranged from 0.00% to 77.27%. The high percentage here does not lead to any conclusions since the TP mass collected from both runoff and base flow was insignificant. The fertilizer mix used contained no phosphorus, it is expected that low TP masses were collected.

Table 17: Distribution of Nutrient Loss between Runoff and Base Flow on A-3 Soil, Argentine Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 0.5 lb of N per 1000 ft^2

Slope	**1:4**			**1:3**		**1:2**	
Rainfall intensity [in/hr]	**0.5**	**1.0**	**3.0**	**0.5**	**1.0**	**3.0**	**0.5**
TN Mass							
Base flow	2.35	20.71	4.35	5.64	4.14	3.37	11.75
Runoff	0.00	0.41	5.49	0.00	0.40	0.00	2.32
Total	2.35	21.12	9.84	5.64	4.54	3.37	14.06
Percent of loss: runoff/total [%]	0.00	1.94	55.78	0.00	8.81	0.00	16.47
TP Mass							
Base flow	0.03	0.04	0.20	0.02	0.07	0.05	0.06
Runoff	0.00	0.12	0.68	0.00	0.07	0.00	0.10
Total	0.03	0.16	0.88	0.02	0.14	0.05	0.16
Percent of loss: runoff/total [%]	0.00	76.94	77.27	0.00	49.28	0.00	62.46

Figure 11 presents the test-wise loss of total nitrogen (TN in runoff + base flow) for all the seven tests in this series. It can be seen from the figure that the TN losses, in general increase with an increase in either slope, or rainfall intensity, or both. The only exceptions to this trend are the loss of TN in three tests, namely: 0.5 in/hr intensity on the 1 in 3 slope, 1.0 in/hr intensity on the 1 in 4 slope, and the 1.0 in/hr intensity on the 1 in 3 slope. These might have been affected by local or temporal issues, such as unintended fertilizer concentration/dilution in the test bed, unintended sample concentration, or under/over estimation by laboratory equipment. There is no linear relationship between the mass of fertilizer nutrient loss and these two parameters (rainfall intensity and slope), as the loss is also governed by a host of biogeochemical processes.

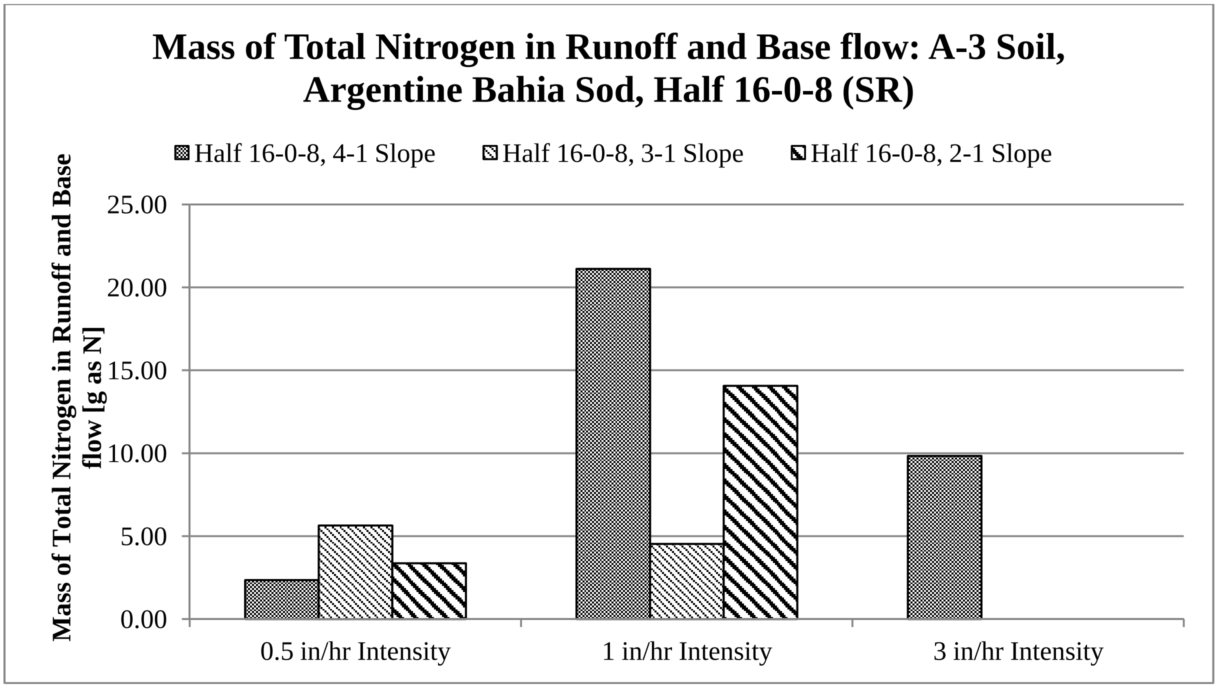

Figure 11: Mass of Total Nitrogen (TN) Collected – A-3 Soil, Argentine Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 0.5 lb of N per 1000 ft^2

Figure 12 presents the loss of total phosphate (TP in runoff + base flow) for all the seven tests in the series. It can be seen from the figure that the TP losses are insignificant and the observable trend is that losses increase with increasing rainfall intensity. This is to be expected as there was no phosphorus in the fertilizer applied for these tests and higher intensities will produce more mass given that a larger volume of runoff and base flow is generated and thus collected.

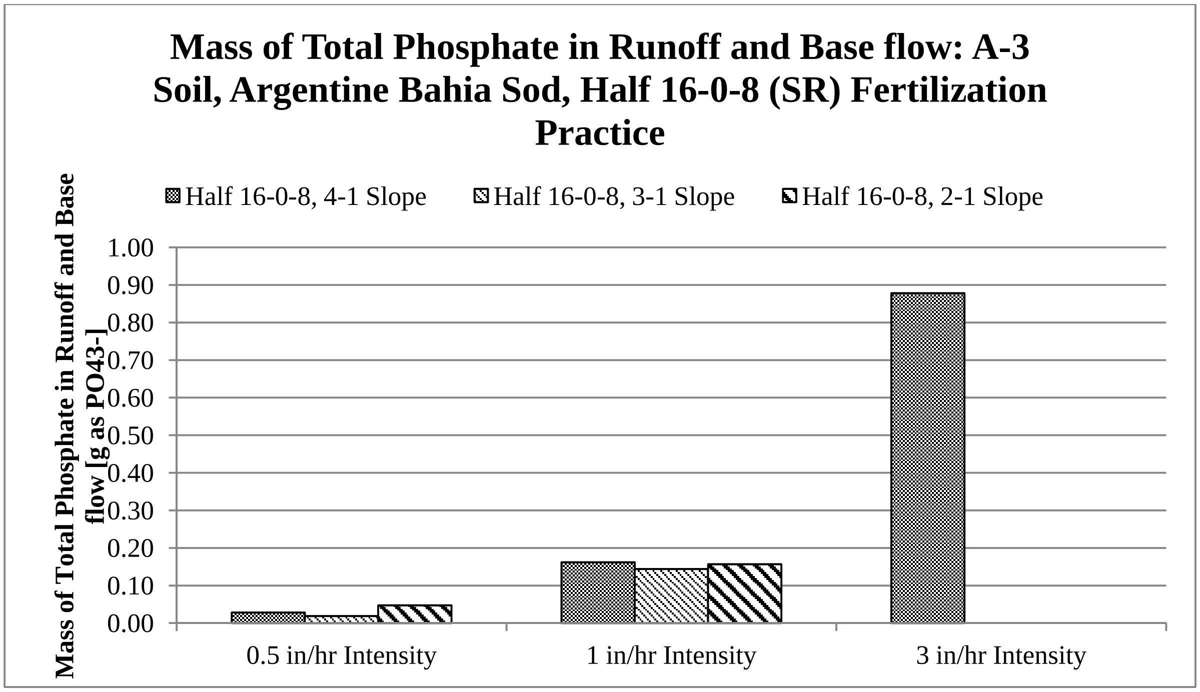

Figure 12: Mass of Total Phosphate (TP) Collected – A-3 Soil, Argentine Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 0.5 lb of N per 1000 ft^2

3.3 AASHTO A-2-4 Soil with Pensacola Bahia Sod

3.3.1 No Application of Fertilizer

As shown in Table 2 earlier, two series comprising of three tests each were run on this soil-sod combination without fertilizer to establish a base line for this type of soil and sod. The no fertilizer tests were run at a slope of 25% and at 0.5, 1.0, and 3.0 inches per hour (12.7, 25.4, and 76.2 mm/hr) and used to determine the general level of nutrients in the soil and if any nutrients were brought in from the sod.

Table 18 presents the actual rainfall intensities that were applied to the test bed calculated based on measurement from twelve rain gauges. Also shown on the plot are the volumes of applied rain, runoff and base flow for the three tests in this series. The percentage of runoff volume captured to total collected volume ranged from 68.97% to 98.5%. The percentage of runoff volume to total captured volume generally increased with rainfall intensity, but the variation is nonlinear due to the variable nature of the initial moisture content and evapotranspiration conditions. This percentage is one of several factors that may have influenced the loss of nutrients applied as fertilizer because the higher energy of run-off, compared to that of base flow, could have helped in carrying out more fertilizer particles.

Table 18: Volumes of Rainfall Applied, Runoff, and Base Flow Collected on A-2-4 Soil, Pensacola Bahia Sod, and No Fertilizer on a 1:4 Embankment Slope

Slope and Soil Type	1:4 Slope, A-2-4 Soil (first run)			1:4 Slope, A-2-4 Soil (second run)		
Intended intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	3.0
Avg. actual intensity [in/hr]	0.49	1.10	3.01	0.51	1.03	2.80
Flow volumes in liters (L)						
Applied	410.6	771.6	1844.3	424.7	725.6	1713.1
Base flow	70.8	107.7	113.2	50.2	8.9	19.9
Runoff	157.4	424.9	1209.5	299.7	506.3	1303.0
Runoff as percentage of Total Collected [%]	68.97	79.78	91.44	85.64	98.28	98.5

Table 19 presents the average chemical parameters measured in these six tests. The concentration of total solids ranged from 84.9 mg/L to 166.2 mg/L for the first run and 210.2 to 258.2 mg/L for the second run, and turbidity values ranged from 9.4 to 21.4 NTU for the first run and 4.0 to 5.9 NTU for the second run, demonstrating the capacity of Pensacola Bahia in preventing erosion for the range of rainfall intensities tested. These results also show the benefit of allowing sod to establish roots as the first run has higher turbidity values than the second run. The range of pH values was from 6.8 to 7.0 and 6.6 to 7.0 for the first and second run, respectively, and the alkalinity ranged from 48.7 mg/L to 50.4 mg/L (as $CaCO_3$) and 59.6 mg/L to 78.5 mg/L for the first and second run respectively. This is indicative of the system being chemically neutral.

Table 19: Total Solids, pH, Alkalinity, and Turbidity in Tests on A-2-4 Soil, Pensacola Bahia Sod, and No Fertilizer on a 1:4 Embankment Slope

Slope and Soil Type	1:4 Slope, A-2-4 Soil (first run)			1:4 Slope, A-2-4 Soil (second run)		
Intended intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	3.0
Total Solids [mg/L]	166.2	84.9	125.3	258.2	211.3	210.2
pH	6.8	7.0	6.9	6.6	7.0	6.6
Alkalinity [mg/L]	50.4	48.7	50.2	59.6	78.5	73.6
Turbidity [NTU]	21.4	14.1	9.4	4.0	5.9	5.3

Table 20 presents the measured masses of total nitrogen (TN) and total phosphorous (TP) collected in runoff and base flow for the no fertilizer (no fertilizer was added to the test beds for this series of tests). The TN mass lost in all six tests was low. The percent of TN lost in runoff to the total loss, base flow, and runoff, ranged from 68.24% to 87.81% for the first run and 69.67% to 84.61% for the second run. The percent of TP lost in runoff to the total loss, base flow, and runoff, ranged from 96.53% to 99.57% for the first run and 99.64% to 99.88% for the second run. These percentages for both TN and TP tend to increase with increasing rainfall intensity and thus runoff volume, showing again the role of runoff in nutrient transport. However, the total mass lost is low making the discharge unlikely to have a negative effect on a receiving body.

Table 20: Distribution of Nutrient Loss between Runoff and Base Flow on A-2-4 Soil, Pensacola Bahia Sod, and No Fertilizer on a 1:4 Embankment Slope

Slope and Soil Type	1:4 Slope, A-2-4 Soil (first run)			1:4 Slope, A-2-4 Soil (second run)		
Rainfall intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	3.0
TN Mass						
Base flow	0.15	0.21	0.13	0.93	0.08	0.17
Runoff	0.36	0.46	0.97	2.14	0.37	0.93
Total	0.51	0.67	1.11	3.08	0.45	1.09
Ratio of loss: runoff/total [%]	69.83	68.24	87.81	69.67	82.60	84.61
TP Mass						
Base flow	0.11	0.01	0.01	0.01	0.00	0.01
Runoff	3.01	1.59	2.31	1.95	1.87	4.02
Total	3.12	1.59	2.32	1.95	1.87	4.03
Ratio of loss: runoff/total [%]	96.53	99.57	99.44	99.64	99.88	99.87

Figure 13 presents the loss of total nitrogen (TN in runoff + base flow) for all six tests in this series. It can be seen from the figure that the mass of TN collected did not vary much over any of the intensities but slightly increased with the 3 in/hr rainfall intensity for both runs. The 0.5 in/hour second run test is the only test that does not fit this trend which could be due to left over fertilizer remaining in the test bed from a previous test or human/lab error. Figure 14 presents the test-wise loss of total phosphorus (TP in runoff + base flow) for all six tests in this series. It can be seen from the figure that the TP losses are minor and show no obvious trends with respect to intensity. Obviously, there is no linear relationship between the mass of nutrient loss and this parameter (rainfall intensity), as no fertilizer was added and nutrient loss is also governed by a host of biogeochemical processes that are examined later.

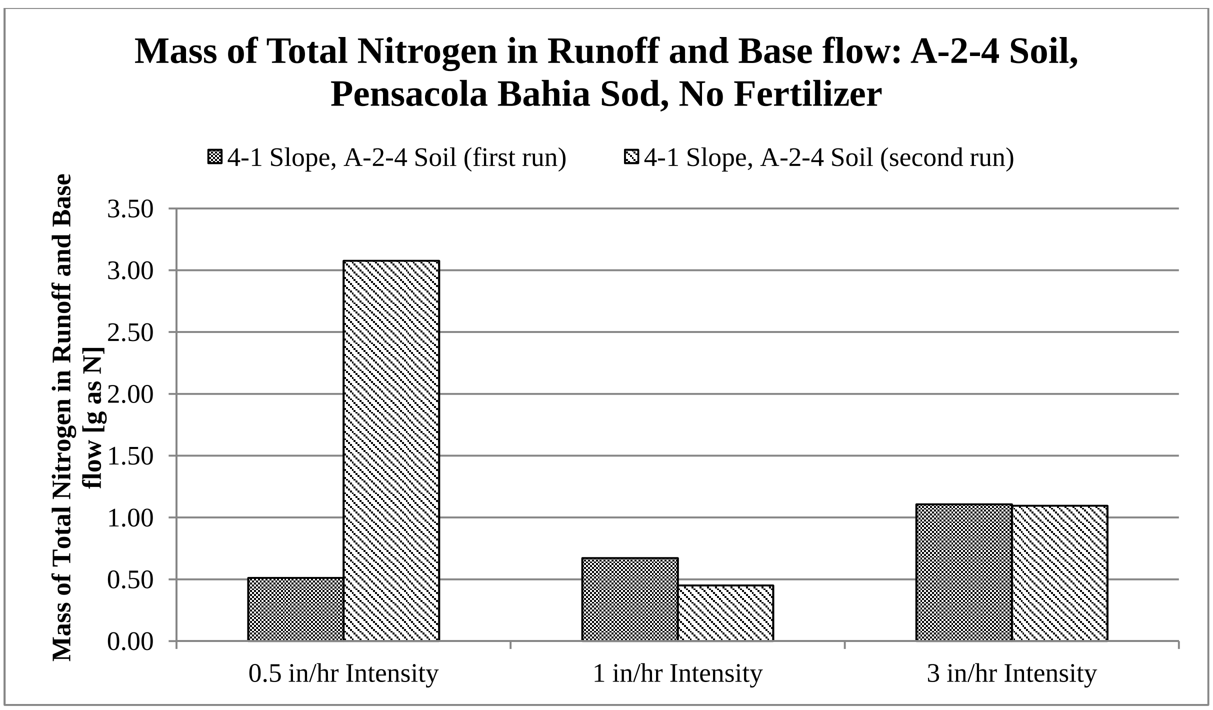

Figure 13: Mass of Total Nitrogen (TN) Collected – A-2-4 Soil, Pensacola Bahia Sod, and No Fertilizer

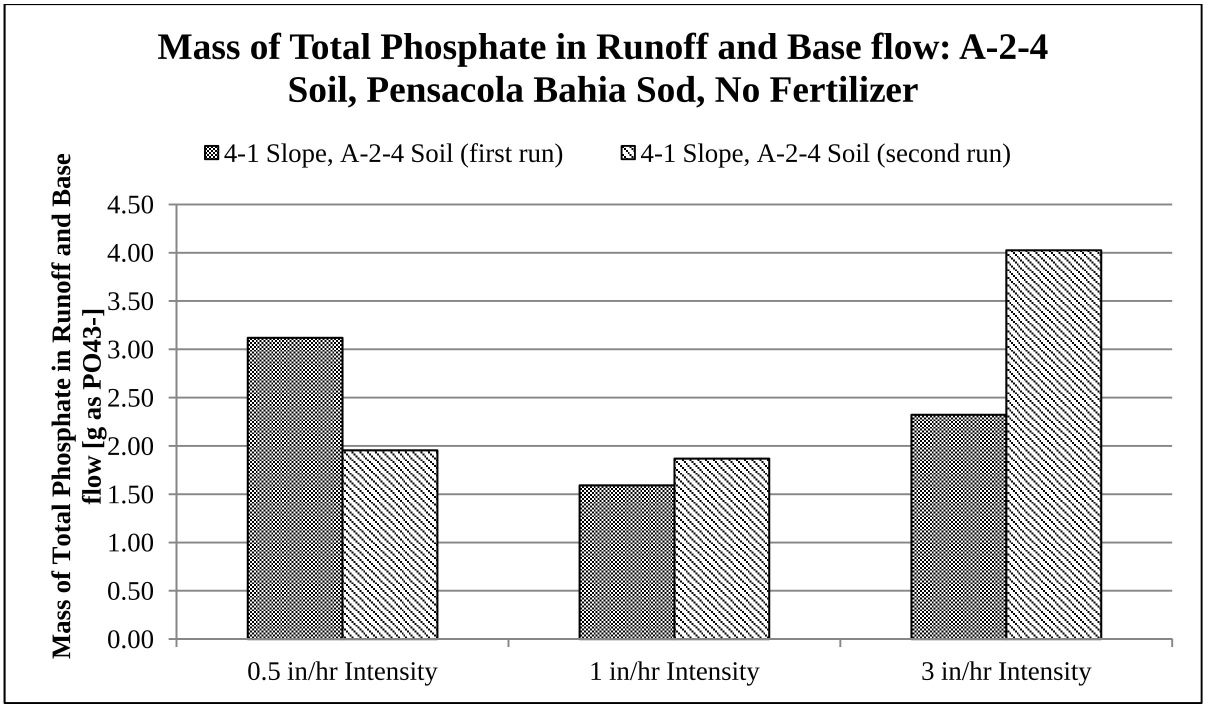

Figure 14: Mass of Total Phosphate (TP) Collected – A-2-4 Soil, Pensacola Bahia Sod, and No Fertilizer

3.3.2 10-10-10 N-P-K Fertilization Practice @ 1 lb of N per 1000 ft²

Table 21 presents the actual rainfall intensities, volumes of applied rain, runoff and base flow, based on the actual measurements during the irrigation and simulated rain events. The percentage of runoff volume to the total outflow volume ranged from 64.8% to 91.93% and generally increased with steepness of slope and/or rainfall intensity.

Table 21: Volumes of Rainfall Applied, Runoff, and Base Flow Collected on A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice

Slope and Soil Type	1:4 Slope and A-2-4 Soil			1:3 Slope and A-2-4 Soil		1:2 Slope and A-2-4 Soil	
Intended intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	0.5	1.0
Avg. actual intensity [in/hr]	0.74	1.09	2.97	0.50	0.98	0.55	0.99
Flow volumes in liters (L)							
Applied	588.7	765.7	1841.2	430.6	664.2	458.9	697.3
Base flow	107.9	74.2	113.6	68.7	74.6	79.1	74.2
Runoff	198.6	497.2	1294.0	265.9	459.8	282.3	462.0
Runoff as percentage of Total Collected [%]	64.8	87.02	91.93	79.46	86.04	78.1	86.17

Table 22 presents the average chemical parameters measured in the series of seven tests. The concentration of total solids ranged from 244.4 mg/L to 500.0 mg/L, and turbidity values ranged from 8.2 to 19.4 NTU, demonstrating the capacity of Pensacola Bahia in preventing erosion for the range of tested slopes and rainfall intensities. The range of pH values was from 6.5 to 7.0, and the alkalinity range was from 44.4 mg/L to 57.7 mg/L (as $CaCO_3$), which are indicative of the chemical neutrality of the system.

Table 22: Total Solids, pH, Alkalinity, and Turbidity in Tests on A-2-4 Soil and Pensacola Bahia Sod, and 10-10-10 Fertilization Practice

Slope and Soil Type	1:4 Slope and A-2-4 Soil			1:3 Slope and A-2-4 Soil		1:2 Slope and A-2-4 Soil	
Intended intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	0.5	1.0
Total Solids [mg/L]	331.6	348.6	244.4	349.3	344.9	500.0	363.1
pH	6.8	6.9	7.0	6.6	6.7	6.5	6.6
Alkalinity [mg/L]	50.4	57.7	52.3	55.1	49.8	44.4	44.8
Turbidity [NTU]	8.2	9.9	11.8	8.8	11.6	13.8	19.4

The applied mass of total nitrogen was 106.06 g as N, and that of total phosphate was 142.12 g as PO_4^{3-} for all the seven tests in the series. Table 23 presents the masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flows. The percent of TN lost in runoff to the total loss, base flow and runoff, ranged from 91.17% to 99.09%, clearly suggesting the role of runoff in fertilizer nutrient losses. Either most of the fertilizer particles that could get into the soil was adsorbed by soil particles, taken up by grass, or the runoff mobilized it and carried it away. The same percentage for TP ranged from 99.81% to 99.98%, again reinforcing the role of runoff in fertilizer nutrient losses. It can be seen from Table 23 above that the TN losses are largely from runoff. Table 21 shows that with the exception of the 0.5 in/hr test on the 1 in 4 slope, all the tests have about the same percent runoff and thus similar mass of TN loss.

Table 23: Distribution of Nutrient Loss between Runoff and Base Flow on A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice

Slope and Soil Type	1:4 Slope A-2-4 Soil			1:3 Slope A-2-4 Soil		1:2 Slope A-2-4 Soil	
Rainfall intensity [in/hr.]	0.5	1.0	3.0	0.5	1.0	0.5	1.0
TN Mass							
Base flow	0.14	0.35	0.29	0.29	1.17	1.05	0.35
Runoff	15.43	38.49	24.83	29.30	30.55	33.06	3.66
Total	15.57	38.85	25.12	29.58	31.73	34.11	4.01
Percentage of loss: runoff/total [%]	99.08	99.09	98.86	99.03	96.30	96.92	91.17
TP Mass							
Base flow	0.02	0.02	0.02	0.02	0.01	0.01	0.01
Runoff	8.40	44.84	24.12	19.95	30.48	26.03	39.06
Total	8.42	44.86	24.14	19.97	30.49	26.04	39.07
Percentage of loss: runoff/total [%]	99.81	99.95	99.91	99.92	99.96	99.96	99.98

Figure 15 presents the test-wise loss of total nitrogen (TN in runoff + base flow) for all the seven tests in the series. All tests in this series show a significant increase in TN mass loss above the 0.5 in/hr test on the 1 in 4 slope. The only exception to this trend is the loss of TN in one test at 1 in/hr intensity on the 1 in 2 slope, which might have been affected by local or temporal issues, such as unintended fertilizer concentration in the test bed, or other unidentified error.

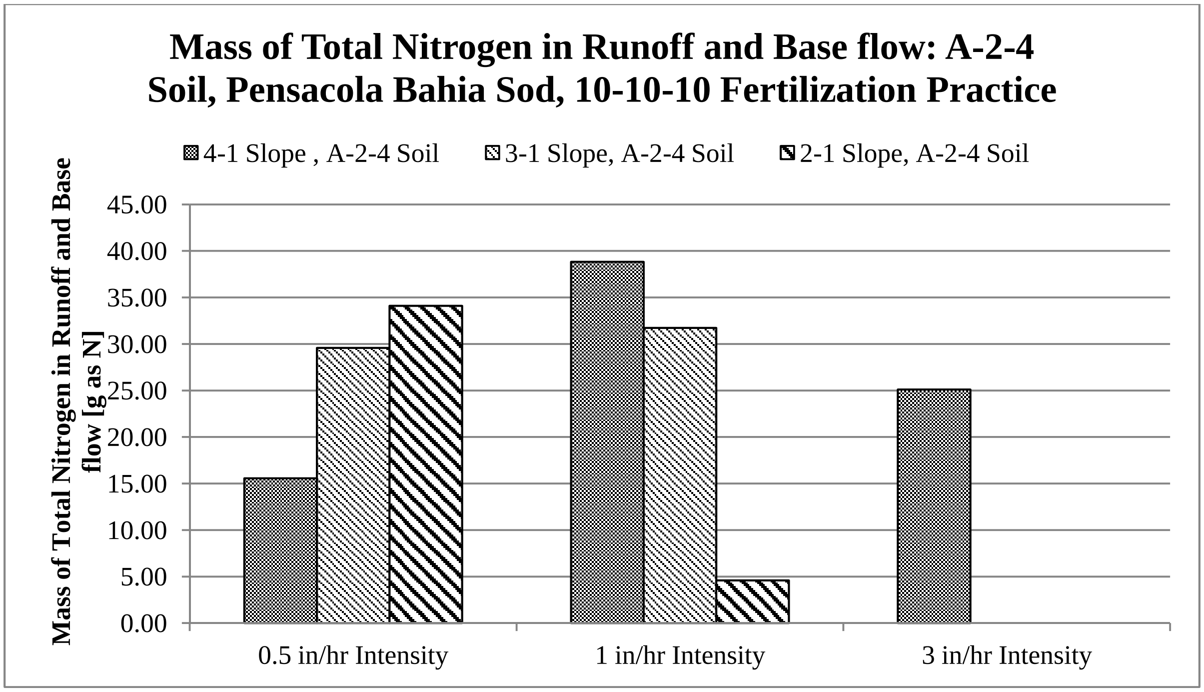

Figure 15: Mass of Total Nitrogen (TN) Collected – A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice

Figure 16 presents the test-wise loss of total phosphate (TP in runoff + base flow) for all the seven tests in the series. It can be seen from the figure that the fertilizer TP losses, in general, increase with an increase in either slope, or rainfall intensity, or both. The only exception to this is the 1 in/hr intensity test on 1 in 4 slopes, which might have been affected by local or temporal issues, such as unintended fertilizer concentration in the test bed, unintended sample concentration, or under/over estimation by laboratory equipment. There is no linear relationship between the mass of fertilizer nutrient loss and these two parameters (rainfall intensity and slope), as the loss is also governed by a host of biogeochemical processes.

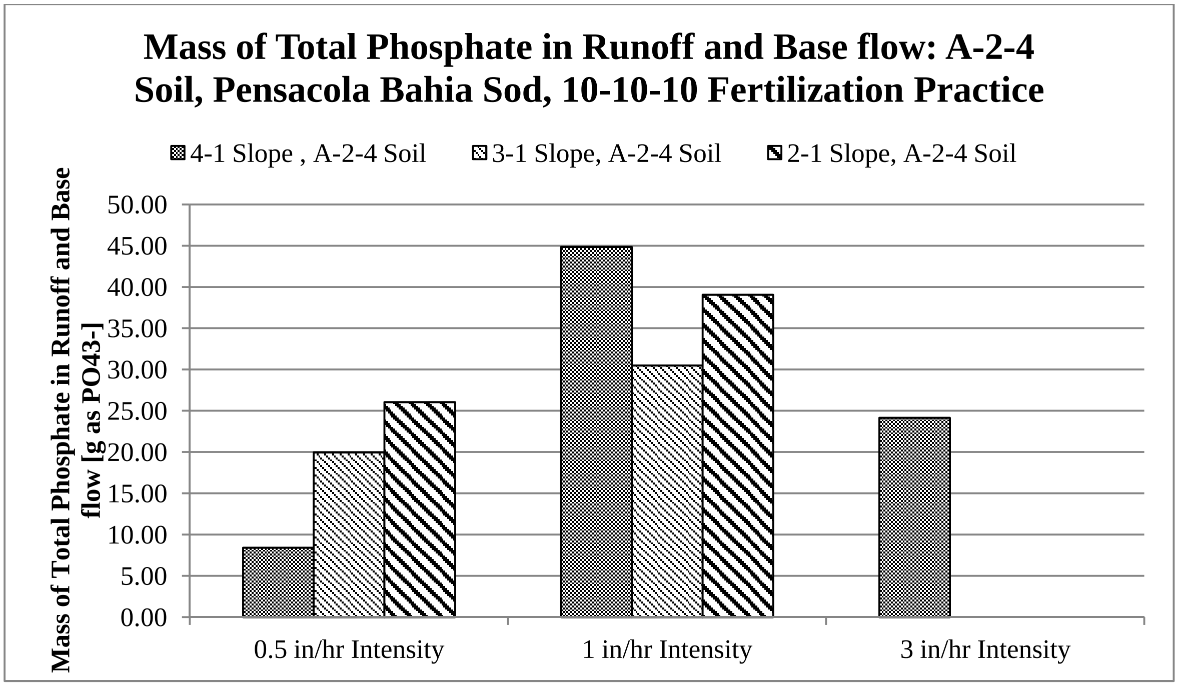

Figure 16: Mass of Total Phosphate (TP) Collected – A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice

3.3.3 10-10-10 N-P-K Fertilization Practice @ 1 lb of N per 1000 ft^2 (Seven-Day Test)

Table 24 presents the actual rainfall intensities, volumes of applied rain, runoff and base flow, based on the actual measurements during the irrigation and simulated rain events. The percentage of runoff volume to the total outflow volume ranged from 88.8% to 92.83%, showing no real trend due to the hydraulic properties of this soil type as well as the variable nature of the initial moisture content and evapotranspiration conditions.

Table 24: Volumes of Rainfall Applied, Runoff, and Base Flow Collected on A-2 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

Slope and Soil Type	**1:3 Slope and A-2-4 Soil**		
Intended intensity [in/hr]	**3.0, Day One**	**3.0, Day Three**	**3.0, Day Seven**
Avg. actual intensity [in/hr]	2.65	2.68	2.68
Flow volumes in liters (L)			
Applied	1627.0	1514.9	1514.9
Base flow	99.9	95.3	52.4
Runoff	823.4	755.4	678.1
Runoff as percentage of Total Collected [%]	89.18	88.80	92.83

Table 25 presents the average chemical parameters measured in each of the three tests. The concentration of total solids ranged from 326.67 mg/L to 398.22 mg/L, and turbidity values ranged from 7.5 to 12.6 NTU, again demonstrating the capacity Pensacola Bahia in preventing erosion for the high rainfall intensities tested in this series. The range of pH values was from 6.53 to 6.87, and the alkalinity range was from 40.44 mg/L to 61.33 mg/L (as $CaCO_3$), which are indicative of the chemical neutrality of the system.

Table 25: Total Solids, pH, Alkalinity, and Turbidity in Tests on A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

Slope and Soil Type	**1:3 Slope and A-2-4 Soil**		
Intended intensity [in/hr]	**3.0, Day One**	**3.0, Day Three**	**3.0, Day Seven**
Total Solids [mg/L]	326.67	381.78	398.22
pH	6.65	6.53	6.87
Alkalinity [mg/L]	51.89	40.44	61.33
Turbidity [NTU]	8.7	12.6	7.5

The applied mass of total nitrogen was 106.06 g as N, and that of total phosphate was 142.12 g as PO_4^{3-} for the first of the three tests in this series, or for day one only. Table 26 presents the masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flows. The percentage of TN lost in runoff to the total lost in base flow and runoff, ranged from 62.90% to 94.20%. The percentage of TN lost in runoff is highest in day one and continually decreases to day seven, showing that the nitrogen loss in applied 10-10-10 fertilizer is initially high in runoff but is largely washed off, adsorbed in the soil bed, or utilized by the sod by the seventh day. The same percentage for TP ranged from 98.91% to 99.92%, reinforcing the role of runoff in TP loss of applied fertilizer.

Table 26: Distribution of Nutrient Loss between Runoff and Base Flow on A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

Slope and Soil Type	**1:3 Slope and A-2-4 Soil**		
Rainfall intensity [in/hr]	**3.0, Day One**	**3.0, Day Three**	**3.0, Day Seven**
TN Mass			
Base flow	2.14	2.68	1.23
Runoff	34.75	16.83	2.09
Total	36.89	19.51	3.32
Percent loss: runoff/total [%]	94.20	86.24	62.90
TP Mass			
Base flow	0.06	0.04	0.01
Runoff	77.53	4.02	5.02
Total	77.59	4.07	5.03
Percent loss: runoff/total [%]	99.92	98.91	99.84

Figure 17 presents the loss of total nitrogen (TN in runoff + base flow) for all three tests in this series. It can be seen from the figure that the TN losses in general decrease with time. This is to be expected as the nitrogen applied as fertilizer is either washed off with runoff, adsorbed in the soil bed, or utilized by the sod. Figure 18 presents the test-wise loss of total phosphate (TP in runoff + base flow) for all three tests in this series. It can be seen from the figure that the fertilizer TP losses also decrease with time. This is the expected response since no additional fertilizers are added after the initial fertilization on day one, in addition more could be adsorbed to the soils surface since A-2-4 soil has a higher surface area than A-3 soil.

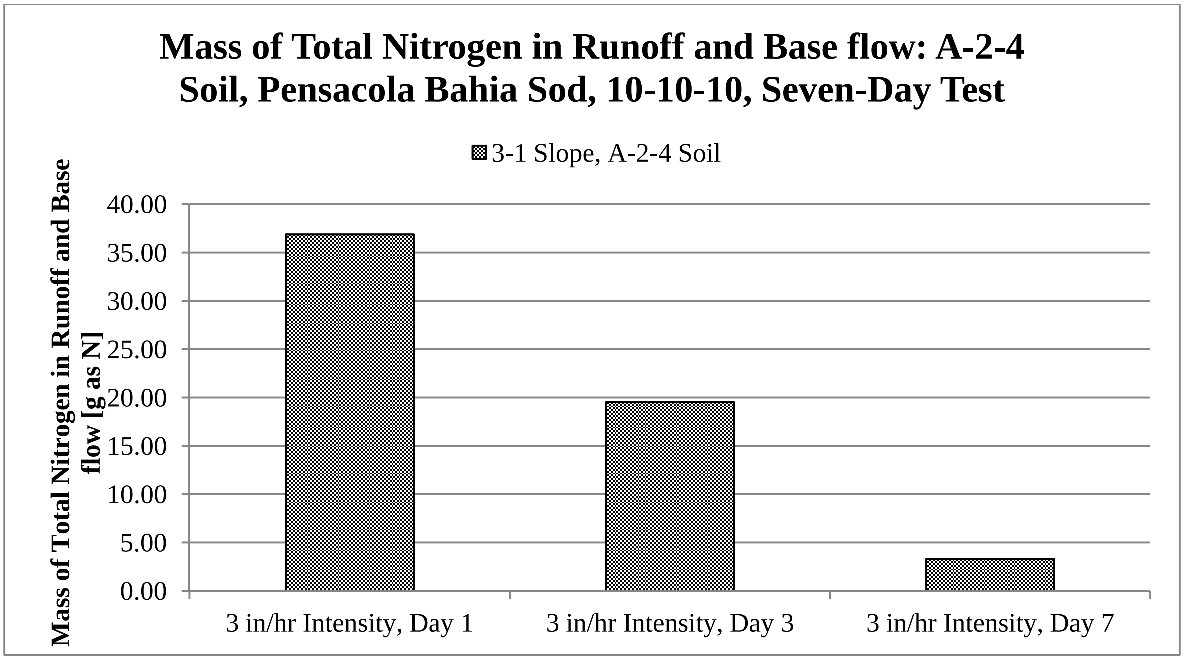

Figure 17: Mass of Total Nitrogen (TN) Collected – A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

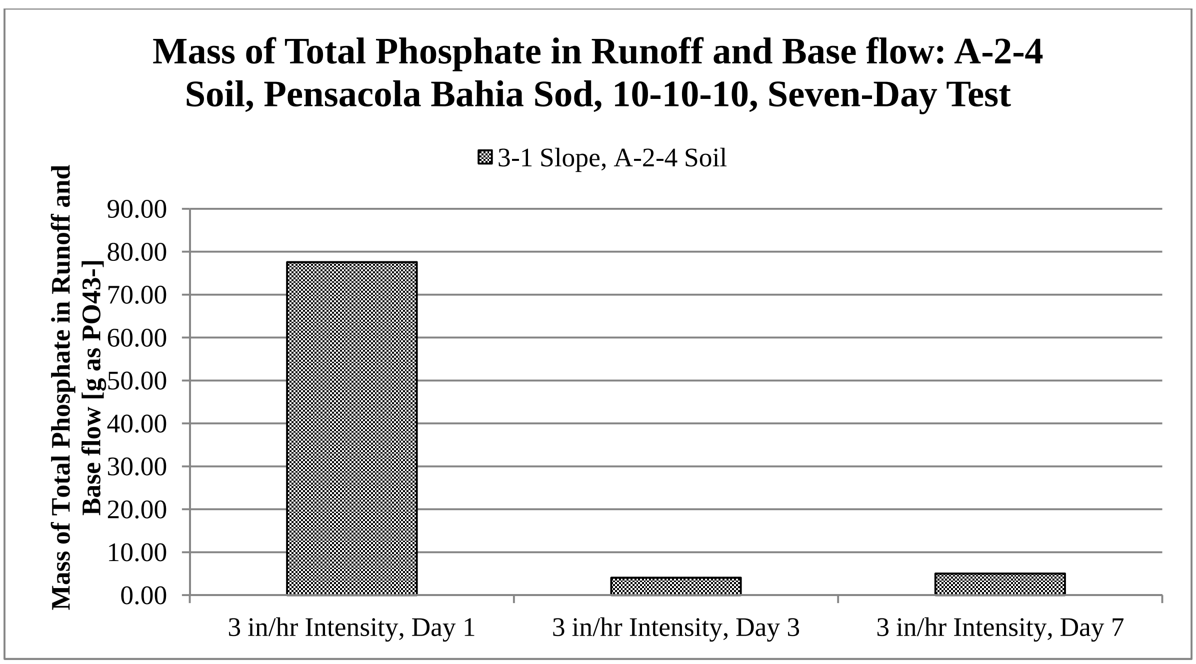

Figure 18: Mass of Total Phosphate (TP) Collected – A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

3.3.4 16-0-8 (SR) N-P-K Fertilization Practice at 0.5 lb of N per 1000 ft²

Table 27 presents the actual rainfall intensities, volumes of applied rain, runoff, and base flow, based on the actual measurements during the irrigation and simulated rain events. The percentage of runoff volume to the total outflow volume ranged from 78.19% to 94.07% and generally increased with steepness of slope and/or rainfall intensity, but the variation is nonlinear due to the variable nature of the initial moisture content and evapotranspiration conditions.

Table 27: Volumes of Rainfall Applied, Runoff, and Base Flow Collected on A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 0.5 lb of N per 1000 ft²

Slope and Soil Type	1:4 Slope and A-2-4 Soil			1:3 Slope and A-2-4 Soil		1:2 Slope and A-2-4 Soil	
Intended intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	0.5	1.0
Avg. actual intensity [in/hr]	0.533	1.071	3.108	0.533	1.183	0.550	1.127
Flow volumes in liters (L)							
Applied	469.6	742.1	1913.7	464.8	811.7	464.8	799.9
Base flow	71.9	120.0	89.5	79.8	38.0	81.7	81.6
Runoff	281.8	430.2	1388.2	327.8	602.1	307.4	596.0
Runoff as percentage of Total Collected [%]	79.66	78.19	93.94	80.42	94.07	78.99	87.95

Table 28 presents the average chemical parameters measured in this series of seven tests. The concentration of total solids ranged from 153.0 mg/L to 255.6 mg/L, and turbidity values ranged from 10.9 to 28.3 NTU, once again demonstrating the capacity of Pensacola Bahia in preventing erosion for the range of tested slopes and rainfall intensities, even on a highly erodible soil like the tested A-2-4 soil. The range of pH values was from 5.9 to 7.1, and the alkalinity range was from 8.2 mg/L to 42.2 mg/L (as $CaCO_3$), which are indicative of the chemical neutrality of the system. However, it should be noted that all the alkalinity values, were quite low when compared to the A-3 soil values implying that some buffering did take place.

Table 28: Total Solids, pH, Alkalinity, and Turbidity in Tests on A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 0.5 lb of N per 1000 ft^2

Slope and Soil Type	1:4 Slope and A-2-4 Soil			1:3 Slope and A-2-4 Soil		1:2 Slope and A-2-4 Soil	
Intended intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	0.5	1.0
Total Solids [mg/L]	206.3	156.3	153.0	255.6	243.6	237.3	188.0
pH	7.1	6.1	6.4	6.2	6.4	6.5	5.9
Alkalinity [mg/L]	42.2	20.4	39.5	30.6	28.9	38.1	8.2
Turbidity [NTU]	15.3	11.2	15.4	11.3	28.3	15.8	10.9

The applied mass of total nitrogen was 53.03 g as N, and that of total phosphate was 0.00 g as PO_4^{3-} for all the seven tests in the series. Table 29 presents the masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flows. The percentage of TN lost in runoff to the total loss in base flow and runoff, ranged from 98.03% to 99.69%. Each value of rainfall intensity tested had significant TN mass loss in runoff; TN mass loss was insignificant in base flow. This was because the A-2-4 soil did not produce significant base flow so a majority of the water collected was from runoff. The same percentage for TP mass loss ranged from 85.27% to 95.74%. Since most of the volume collected from this series of tests was from runoff, it is not surprising that the percentage is so high for all intensities. In addition, the fertilizer mix used contained no phosphorus, so it is expected that low masses were collected and the percent collected as runoff did not follow any observable trends.

Table 29: Distribution of Nutrient Loss between Runoff and Base Flow on A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 0.5 lb of N per 1000 ft^2

Slope and Soil Type	1:4 Slope and A-2-4 Soil			1:3 Slope and A-2-4 Soil		1:2 Slope and A-2-4 Soil	
Rainfall intensity [in/hr]	0.5	1.0	3.0	0.5	1.0	0.5	1.0
TN Mass							
Base flow	0.1	0.2	0.1	0.2	0.1	0.0	0.0
Runoff	17.2	17.4	46.0	18.7	21.6	1.5	2.2
Total	17.4	17.6	46.1	18.9	21.7	1.5	2.3
Percent loss: runoff/total [%]	99.24	98.59	99.69	99.06	99.55	98.32	98.03
TP Mass							
Base flow	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Runoff	0.2	0.7	0.9	0.2	0.5	0.1	0.2
Total	0.2	0.7	1.0	0.3	0.6	0.2	0.3
Percent loss: runoff/total [%]	89.81	93.59	95.74	87.51	95.66	85.27	94.60

Figure 19 presents the test-wise loss of total nitrogen (TN in runoff + base flow) for all the seven tests in this series. It can be seen from this figure that the TN losses in general increase with an increase in either slope, or rainfall intensity, or both. The only exceptions to this trend are the loss of TN in both of the 1 in 2 slope tests, which might have been affected by local or temporal issues, such as unintended fertilizer concentration in the test bed, unintended sample dilution, or other unidentified error. Figure 20 presents the test-wise loss of total phosphate (TP in runoff + base flow) for all the seven tests in the series. It can be seen from this figure that the TP mass losses are insignificant. This is to be expected as there was no phosphate in the fertilizer applied for these tests.

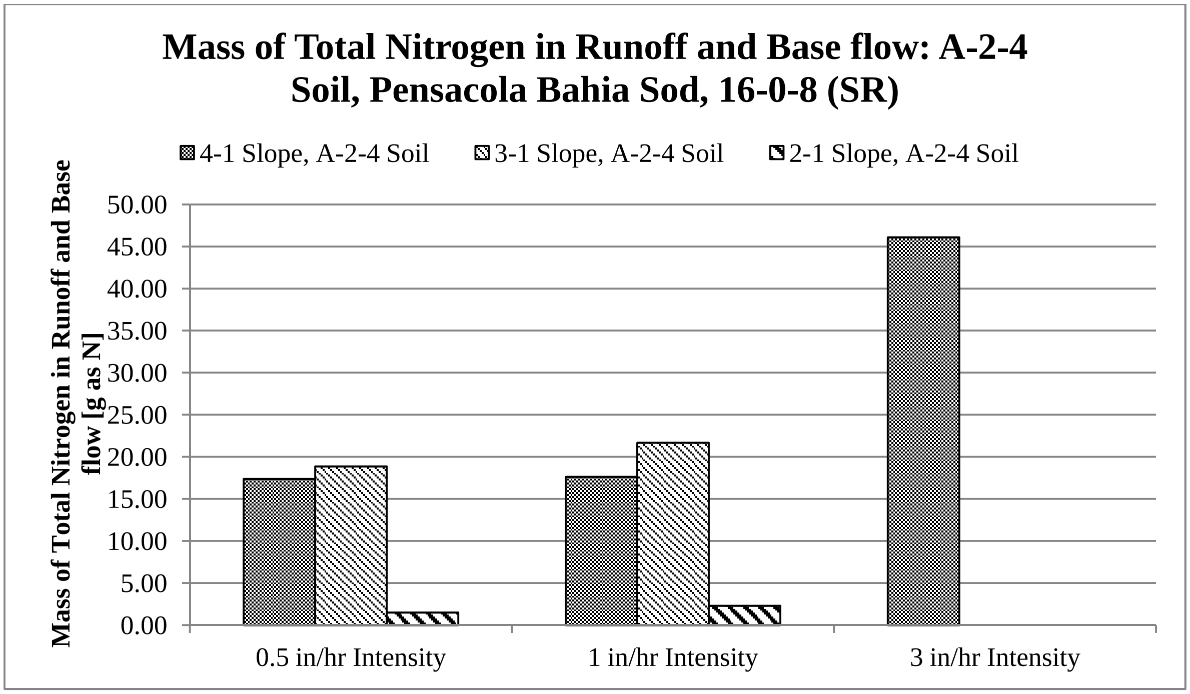

Figure 19: Mass of Total Nitrogen (TN) Collected – A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 0.5 lb of N per 1000 ft^2

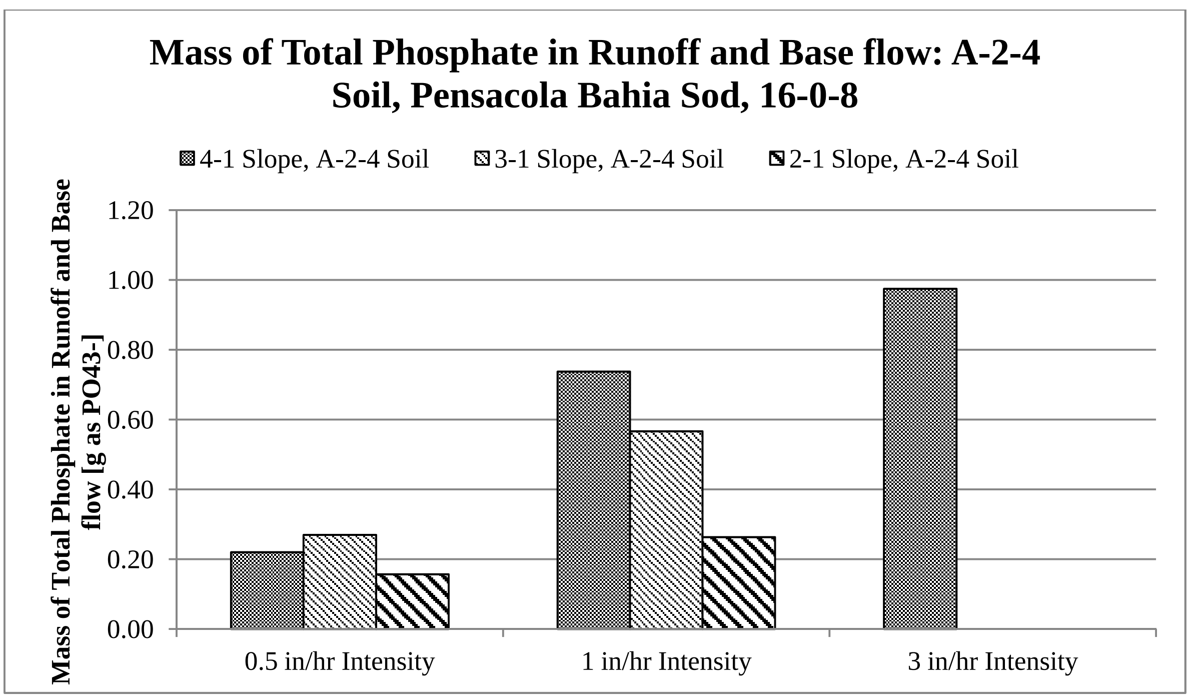

Figure 20: Mass of Total Phosphate (TP) Collected – A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 (SR) Fertilization Practice @ 0.5 lb of N per 1000 ft^2

CHAPTER 4. EXPERIMENTAL FINDINGS OF PHASE #2

The effect of slope on nutrient losses is intuitive: the steeper the slope, the greater the erosive power of water traveling downhill. Phase #1 of the study conducted tests on three relatively steep embankment slopes of 25, 33, and 50 percent. Such steep embankment slopes are not common in Florida; however, there are some certain steep highway side slopes, shoulders, and embankments. The typical slope of highway shoulders and embankments in Florida is 16.67 percent. Furthermore, phase #1 considered relatively high rainfall intensities of 0.5, 1.0, and 3.0 in/hr. Presented in Table 30 is the percentage of rain events that occur within various rainfall event intervals for different cities in Florida. On average, 75 percent of rainfall events are equal or less than 0.5 inch.

Thus, phase #2 of the study focused on the effect of an embankment slope (16.67 percent) and two rainfall intensities (0.1 and 0.25 in/hr) on the reduction of nutrient losses, due to changes in fertilization practices. The study analyzed two different soil and sod combinations – Argentine Bahia on A-3 (sandy) soil and Pensacola Bahia on A-2-4 (silty sand) soil. Both of these soil/sod combinations were initially tested with no fertilizer to establish a nutrient baseline. Subsequently applied on the soil/sod combinations was either a 10-10-10 fertilizer or 16-0-8 fertilizer practice at a rate consistent with FDOT highway shoulder or embankment fertilization practices. The application rate of fertilizer was 0.5 lb of N per 1000 ft^2.

Table 30: 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
Melbourne	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**

4.1 Experimental Setup for Phase #2

As in phase #1 of the study, this study also developed nutrient and water balances of the test bed to determine the fate of the nutrients applied to the soil/sod combination. 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. The experimental setup was an open system subjected to natural occurring activities that significantly have effect on the quantification of certain parameters. Of particular concern was the volatilization and biological processes occurring within the soil. To account for volatilization and biological processes, the research monitored the climatic conditions during testing, such as amount of natural rainfall occurring between tests, amount of sunlight, ambient temperature, etc., and used available database from previous research. The water balance involved the measurement of the moisture content of the soil – before and after testing, the volume of water in runoff and base flow, the amount of simulated rainfall, the volume of actual rainfall occurring between tests, and evapotranspiration rates.

In addition to nutrient and water balance, the research obtained soil samples from the test bed and investigated for total nitrogen, total phosphorus, and cationic exchange capacity. The soil sample collected was at the same location the moisture content was measured, prior to a test, to determine pre-existing nutrients in addition to its cationic exchange capacity (CEC). Knowledge of the cationic exchange capacity aids in the understanding of how soil fertility changes and is impacted over time because of fertilization. Assessing the changing soil fertility because of fertilization allows for understanding its nutrient retention capacity and by extension the capacity of the soil to protect groundwater from contamination. The determination of these factors aids in the adjustment of fertilizer application frequency and quantity.

4.2 Test Bed Construction, Operation, and Rainfall Simulation

The construction and modification to the test bed was to simulate typical highway shoulders and embankments on a 30-foot long by 8-foot wide area as shown in Figure 21. The test bed area had two sections: a concrete section designed to generate overland flow that simulates actual conditions occurring on a highway during rainfall; and a compacted soil and sod combination section that is consistent with the test bed condition in phase #1. Half (15 feet) the length of the test bed had concrete pavement and the other half filled with three-foot deep layer of compacted soil. The soil compaction was in accordance to standard practice, where each 6-inch lifts of soil was compacted using a 6.5 HP Compact vibrator plate manufactured by Central Machinery of Camarillo, CA. The measurement of the density of the soil in the test bed was verified using a nuclear density probe (MC-1 Density and Moisture Gauge; CPN International Inc., Raleigh, NC) and later, the sand-cone method (AASHTO T-191; ASTM D-1556). The surface of the compacted soil was scarified to a depth of 1 to 2 inches prior to the placement of purchased sod tiles. Irrigation of the sod on the test bed was 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 21: Aerial View of Elevated Test Bed

Prior to testing on the elevated test bed, the varying slopes of the concrete and sod combination were two percent for the 15-foot concrete slab, followed by a six percent for the first five feet of the soil/sod section, and 16.67 percent (1:6 slope) for the remaining 10 feet. This combination of slopes represents a typical highway cross-section found in Florida. Figure 22 shows the entire side view of the elevated test bed prior to testing.

Figure 22: Elevated Side View of Test Bed.

The rainfall simulator is computer-controlled to achieve consistently the desired rainfall intensity and raindrop sizes during testing. A gantry crane hoisted and positioned the rainfall simulator to an appropriate height of seven feet (2.13 m) and slope above the test bed as shown in Figure 23. However, during testing, twelve rain gauges set up on the test bed measured the amount of simulated rainfall intensity and volume.

Figure 23: Side View of Test Bed, Rainfall Simulator, and Gantry Crane

4.3 Soil Characterization

Soil classification by sieve analysis (full and washed) was as specified in AASHTO M-145-91, AASHTO T-88, ASTM C-117, and ASTM C 136-01. The soil classification for both soil types investigated were A-3 (sandy soil) and A-2-4 (silty sand soil). The moisture-density relationship of both soil types was determined using the standard Proctor test as described in AASHTO T-99 and 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 attain its maximum dry density. Moisture content sampling was in accordance to AASHTO T-265 and ASTM D 2216. Prior to each test, soil sampled at depth of six to eight inches at two locations, as shown in Figure 24, was tested for moisture content. The average of the measured moisture contents becomes the moisture content of the soil.

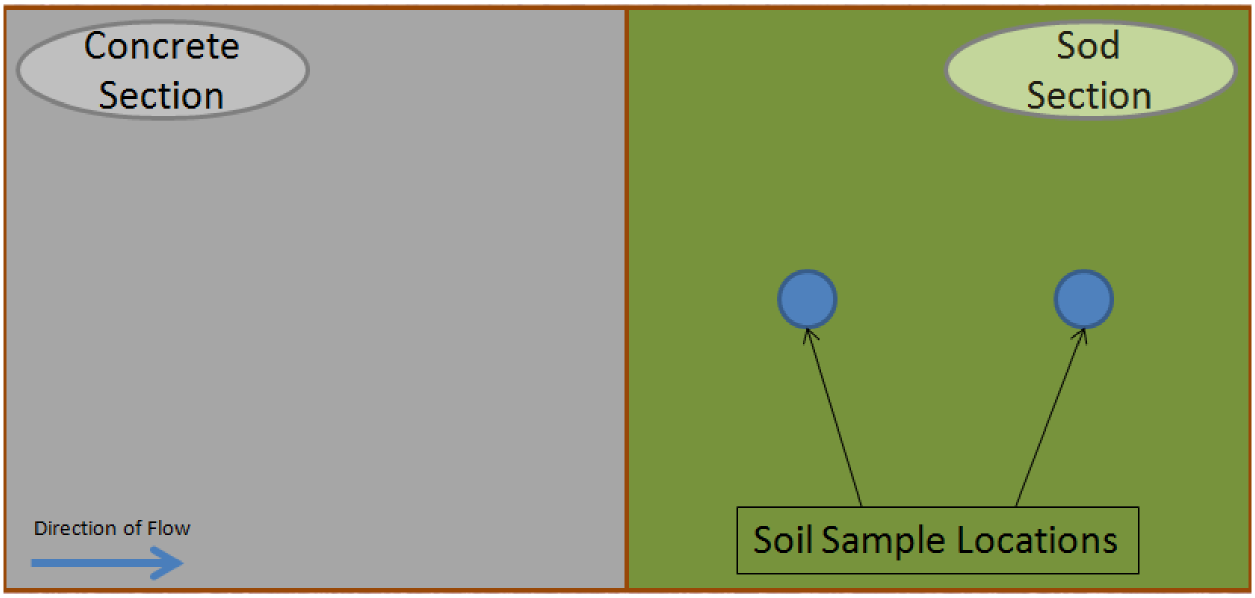

Figure 24: Soil Sample and Moisture Content Locations.

4.4 Test Bed Sampling

4.4.1 Collection and Analysis of Test Bed Effluent

Effluent samples were collected from surface runoff and base flow. Figure 25 shows the troughs, located at the downstream end of the test bed collected surface runoff. Figure 26 shows the tubes underneath the test bed collected base flow into two barrels: one located upstream, just after the concrete section; and the second located downstream towards the end of the test bed. Collection of effluent from the test bed continued throughout the duration of the entire test. Samples collected from the cumulative volumes of either base flow and/or runoff at the end of each test were preserved with sulfuric acid, if needed, and/or filtered with a 0.45-micron nylon filter. Environmental Research and Design (ERD) located in Orlando, Florida conducted the analyses for all samples collected in the phase #2 study.

Figure 25: Downstream Collection Troughs and Sinks.

Figure 26: Base flow Collection Tubes and Barrels.

4.4.2 Collection and Analysis of Soil Samples

Soil samples were collected at the two locations shown in Figure 24: the upstream location was approximately five feet away from the concrete section, and the downstream location was five feet away from the downstream end of the test bed. After the collection of soil sample from the specified locations, the sampling locations were refilled with the appropriate soil type – either A-2-4 or A-3, depending on the type of soil in the test bed. All soil samples were analyzed for total nitrogen, total phosphorus, and cationic exchange capacity at ERD, Orlando, Florida.

4.5 Weather Data Acquisition

Local weather data was obtained from www.wunderground.com, 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 two miles from the testing site, uses an Ultimeter 2100 to acquire typically reported weather data. 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 obtained from NOAA, the National Climatic Data Center, which is reported by The Florida Climate Center (2014).

4.6 Soil and Sod Acquisition

Both the soil and sod were sourced locally. 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. Both sod varieties were acquired locally. Duda Sod in Oviedo, Florida supplied the Argentine Bahia grass sod, while Chipola Turf Farms in Kinard, Florida supplied the Pensacola Bahia grass sod.

4.7 Test Results

Table 31 presents the actual chronological sequence of all tests conducted in phase #2 of this study. There were two soil types used for testing and for each soil type, there was a replacement with new soil for a different fertilization practice – 10-10-10 or 16-0-8. Thus, there were three soil changes during testing, and on every soil and fertilization practice. There were 10 tests conducted – four no-fertilization and six fertilization. The total tests conducted were 38 tests – 20 tests for A-2-4 and Pensacola Bahia sod and 18 tests for A-3 and Argentine Bahia sod, two of the tests were incomplete. Presented in the subsequent sections of chapter 4 are the descriptions of the results of these test series. In chapters five through seven, are further discussion of results and related comparisons of the effect of different parameters on the nutrient losses.

Table 31: Chronological Sequence of Tests

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	0.10	2/27/2013
4	A-2-4	Pensacola	None	0.10	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	0.10	4/10/2013
10	A-2-4	Pensacola	10-10-10	0.10	5/11/2013
Soil Change 1					
11	A-2-4	Pensacola	16-0-8	0.25	6/12/2013
12	A-2-4	Pensacola	16-0-8	0.25	6/15/2013
13	A-2-4	Pensacola	16-0-8	0.10	6/19/2013
14	A-2-4	Pensacola	16-0-8	0.10	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	0.10	9/14/2013
20	A-3	Argentine	None	0.10	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	0.10	10/5/2013
24	A-3	Argentine	10-10-10	0.10	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	0.10	1/20/2014
30	A-3	Argentine	None	0.10	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
35	A-3	Argentine	16-0-8	0.10	NA
36	A-3	Argentine	16-0-8	0.10	NA

* indicates a seven-day test

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

4.8.1 No Application of Fertilizer

The four tests performed without fertilizer application was to establish a baseline for the A-2-4 soil/ Pensacola Bahia sod combination. The purpose of establishing a baseline was to determine the level of nutrients in the soil and in the sod. There were repeat tests for all combinations of simulated rainfall intensities (0.25 or 0.1 in/hr) on the soil/sod combination.

Table 32 presents the average of the actual rainfall intensity for each simulated rainfall intensities applied to the test bed, the corresponding applied rainfall volumes and the respective volumes of collected runoff and base flow. It is important to note that for this series, runoff was generated for only one 0.1 in/hr. test. This variation 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 tests.

Table 32: Volumes of Rainfall Applied, Runoff, and Base flow Collected on A-2-4 Soil, Pensacola Bahia Sod, and No Fertilizer

Intended intensity [in/hr]	**0.10**	**0.25**
Average actual intensity [in/hr]	0.11	0.26
Flow Volumes in Liters (L)		
Applied	176.0	448.1
Base flow Collected	36.8	163.8
Runoff Collected	33.7	0.0
Soil Moisture Content [%]	14.6	11
Runoff as Percentage of Total Collected [%]	47.80	0.00

Table 33 presents the concentration of total solids and alkalinity, and the pH measurements for the 0.25 and 0.10 in/hr. rainfall intensities. The concentration of total solids ranged from 180.8 mg/L to 199.3 mg/L, while the alkalinity ranged from 84 to 101.3 mg/L as $CaCO_3$. During this series of tests, there was no measurement of the pH but rather adopted from the phase #1 study that used the identical soil and sod combination. The soil and sod combination had similar chemical neutrality based on the assumption of the comparable alkalinity values in phase #1 (**Error! Reference source not found.**).

Table 33: Total Solids, Alkalinity, and pH in Tests on A-2-4 Soil, Pensacola Bahia Sod, and No Fertilizer

Rainfall Intensity [in/hr]	0.10	0.25
Total Solids [mg/L]	199.3	180.8
Alkalinity [mg/L]	101.3	84
pH	6.8*	6.8*

*Indicates average value adopted from previous study's corresponding soil/sod combination with no fertilizer.

The purpose for performing tests with no fertilizer applied is to determine the amount of nutrients that are inherent to the clean soil and fresh sod. Thus, Table 34 presents the measured masses of total nitrogen (TN) and total phosphorus (TP). The total nitrogen and phosphorus lost for this soil and sod combination is relatively low for both rainfall intensities.

Table 34: Distribution of Nutrient Loss between Runoff and Base flow on A-2-4 Soil, Pensacola Bahia Sod, and No Fertilizer

Rainfall Intensity [in/hr]	0.10	0.25
TN Mass (g)		
Base flow	0.23	1.09
Runoff	0.02	0.00
Total	0.25	1.09
Ratio of loss: runoff/total [%]	8.00	0.00
TP Mass (g)		
Base flow	0.001	0.008
Runoff	0.022	0.000
Total	0.024	0.008
Ratio of loss: runoff/total [%]	91.67	0.00

Figure 27 and Figure 28 show the losses of the mass of total nitrogen (TN) and total phosphorus (TP) in the runoff and base flow for both rainfall intensities. Base flow losses for TN for the soil type increased with increase in the rainfall intensity, from 0.10 to 0.25 in/hr because of possible residual fertilizer in the test bed. However, the total losses for TP decreased with increment to the rainfall intensity, from 0.10 to 0.25 in/hr due to the lack of runoff generated at these rainfall intensities. There was no runoff collected in the test with 0.25 in/hr. rainfall intensity as most of the rainfall infiltrated into the soil and either remained or exited the soil as base flow. Thus, the masses of TN and TP measured were from the base flow.

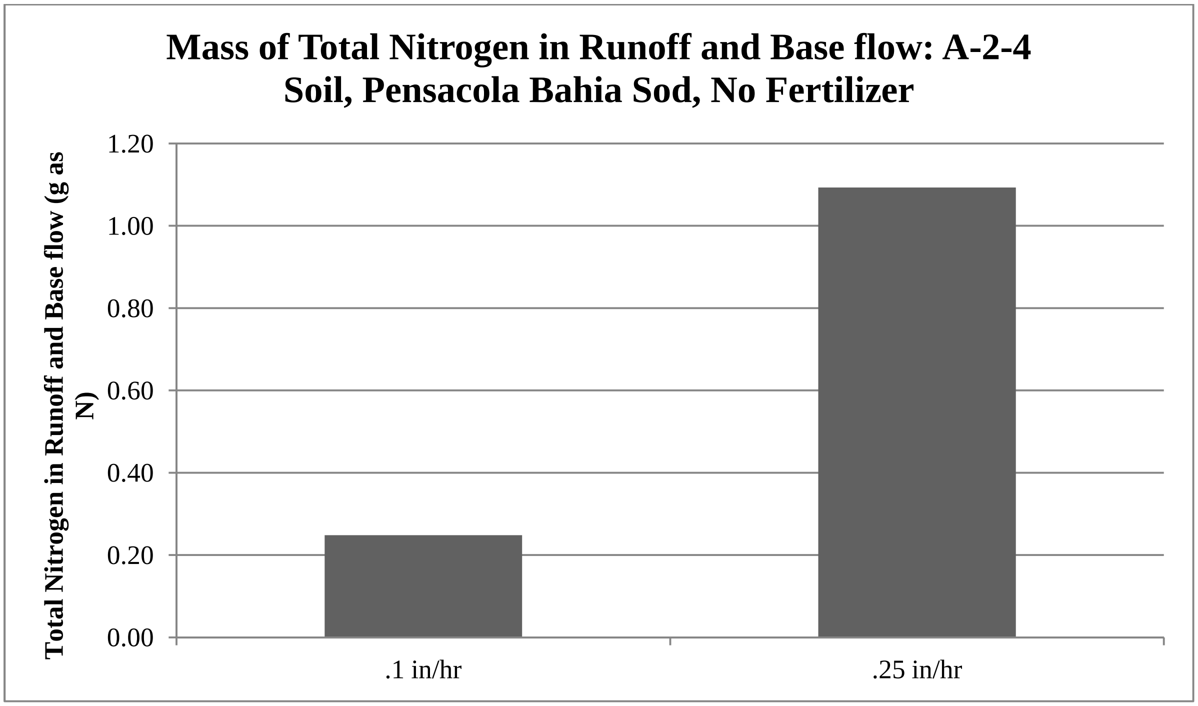

Figure 27: Mass of Total Nitrogen (TN) Collected – A-2-4 Soil, Pensacola Bahia Sod, and No Fertilizer

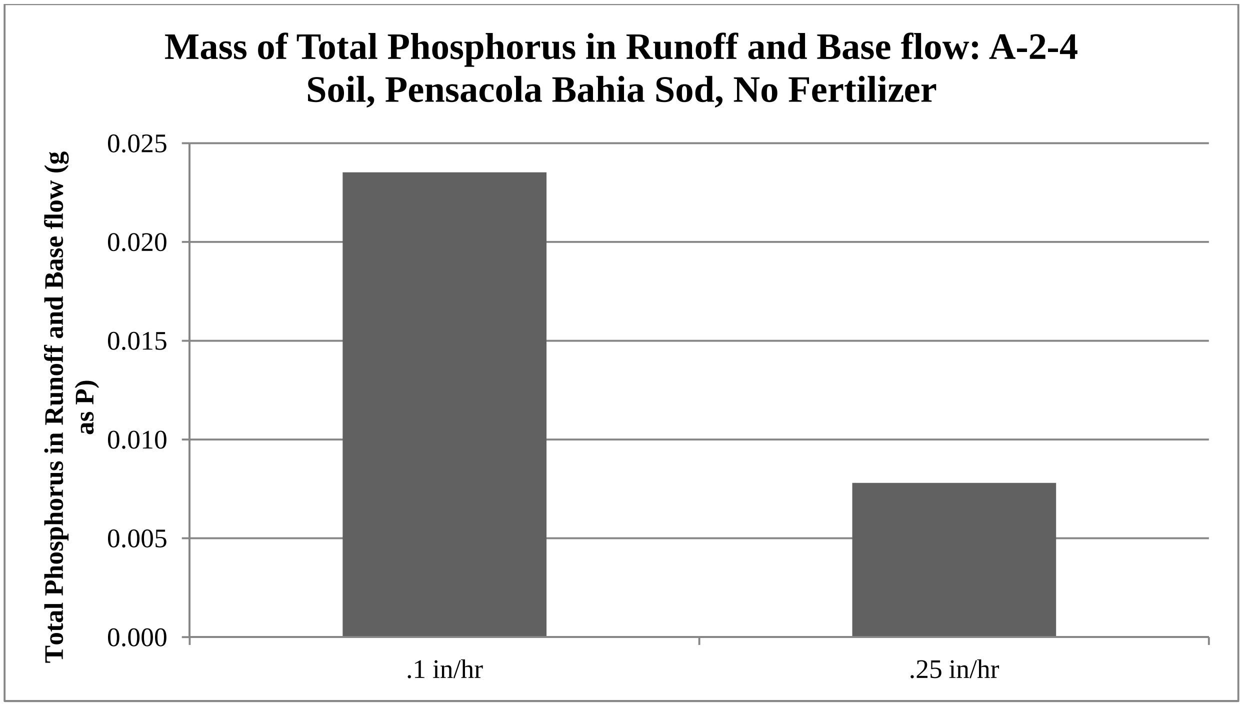

Figure 28: Mass of Total Phosphorus (TP) Collected – A-2-4 Soil, Pensacola Bahia Sod, and No Fertilizer

4.8.2 10-10-10 N-P-K Fertilization Practice @ 0.5 lb per 1000 ft^2 (One-Day Tests)

Table 35 presents the actual rainfall intensities applied to the test bed, along with corresponding applied water volumes, as well as respective volumes of collected runoff and base flow measured during the test. There was no runoff generated for the 0.10 in/hr rainfall intensity, but for the 0.25 in/hr rainfall intensity, the percentage of runoff to the total outflow volume was 53.6 percent. The difference in runoff volume for both rainfall intensities is due to the rainfall volumes and the antecedent moisture conditions at the commencement of testing.

Table 35: Volumes of Rainfall Applied, Runoff, and Base flow Collected on A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice

Intended intensity [in/hr]	**0.10**	**0.25**
Average actual intensity [in/hr]	0.11	0.27
Flow Volumes in Liters (L)		
Applied	196.8	454.0
Base flow Collected	26.8	122.28
Runoff Collected	0	141.2
Soil Moisture Content [%]	10.9	14.5
Runoff as Percentage of Total Collected [%]	0.0	53.6

Table 36 presents the average chemical parameters for all four tests, which include the total solids, alkalinity and pH for both base flow and runoff collected. The concentration of total solids ranged from 188 mg/L to 249 mg/L, and the alkalinity ranged from 83 to 122 mg/L as $CaCO_3$. As was the case in the previous tests with no fertilization, there was no measurement of the pH during this series of tests; rather, the pH value is adopted from the results in phase #1 that used the identical soil and sod combination (Table 22). The adopted pH value is 6.7, and the alkalinity ranged from 83 to 122 mg/L (as $CaCO_3$), which is indicative of the chemical neutrality of the system as was in phase #1 tests on the same soil and sod combination.

Table 36: Total Solids, Alkalinity, and pH in Tests on A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice

Rainfall Intensity [in/hr]	**0.10**	**0.25**
Total Solids [mg/L]	188	249
Alkalinity [mg/L]	83	122
pH	6.7*	6.7*

*Indicates average value adopted from previous study’s corresponding soil/sod combination with 10-10-10.

Prior to each test, 27.2 grams of 10-10-10 fertilizer was uniformly applied on the sodded portion of the test bed. Table 37 presents the total collected masses of TN and TP in the base flow and runoff. The masses of nitrogen and phosphorus collected at the 0.1 in/hr intensity were almost as low as the collected mass for the same soil and sod combination with no fertilizer.

However, there was significant increase in the masses of TN and TP with the increment of rainfall intensity. At the 0.25 in/hr rainfall intensity, the runoff generated contributed higher amount of nutrients collected from the test bed than the base flow. The percentage of collected TN to the runoff was 77.1% and for the collected TP it was 89%.

Table 37: Distribution of Nutrient Loss between Runoff and Base flow on A-2-4 Soil, Pensacola Bahia Sod with 10-10-10 Fertilization Practice

Rainfall Intensity [in/hr]	0.10	0.25
TN Mass (g)		
Base flow	0.29	1.15
Runoff	0.00	3.87
Total	0.29	5.02
Ratio of loss: runoff/total [%]	0.00	77.09
TP Mass (g)		
Base flow	0.012	0.21
Runoff	0.00	1.70
Total	0.012	1.91
Ratio of loss: runoff/total [%]	0.00	89.01

The graphical representation shown in Figure 29 and Figure 30 present the masses of TN and TP lost, respectively, from the combined base flow and runoff for all tests. Both graphs show that losses in the fertilizer TN and TP increases with increment in the rainfall intensity, which agrees with the results in phase #1 for the same soil and sod combination on the lowest slope evaluated (Figure 15 and Figure 16).

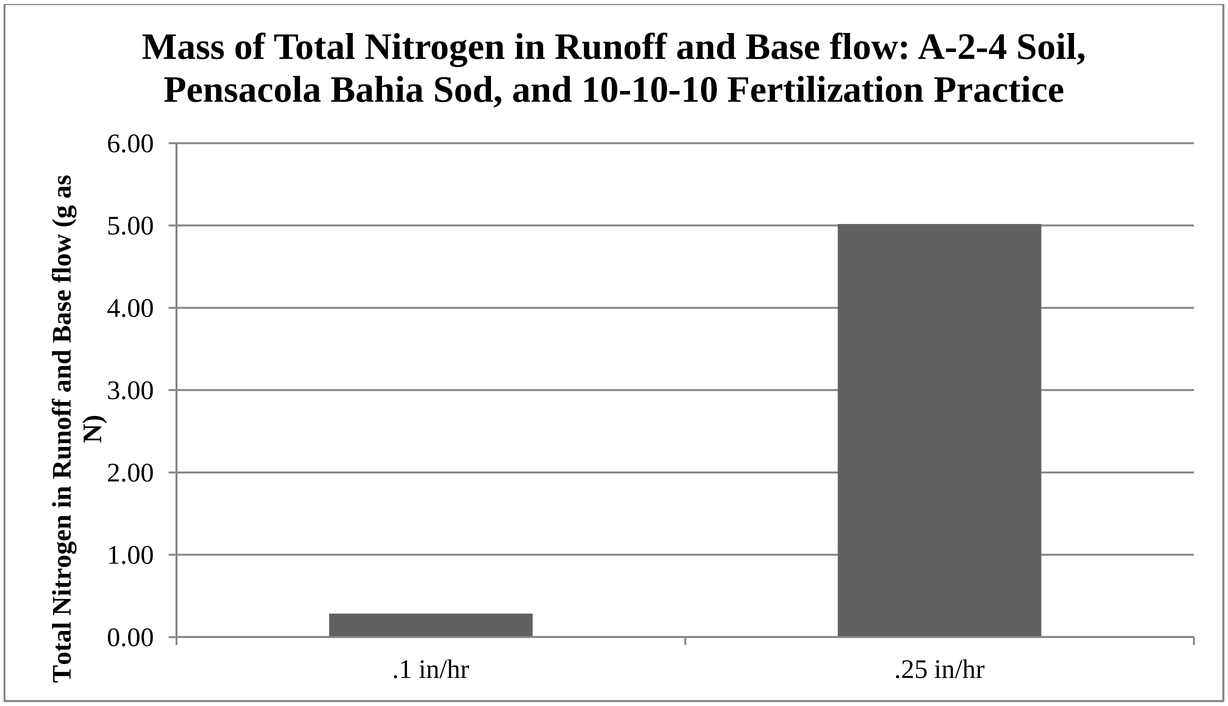

Figure 29: Mass of Total Nitrogen (TN) Collected – A-2-4 Soil and Pensacola Bahia Sod, and 10-10-10 Fertilization Practice

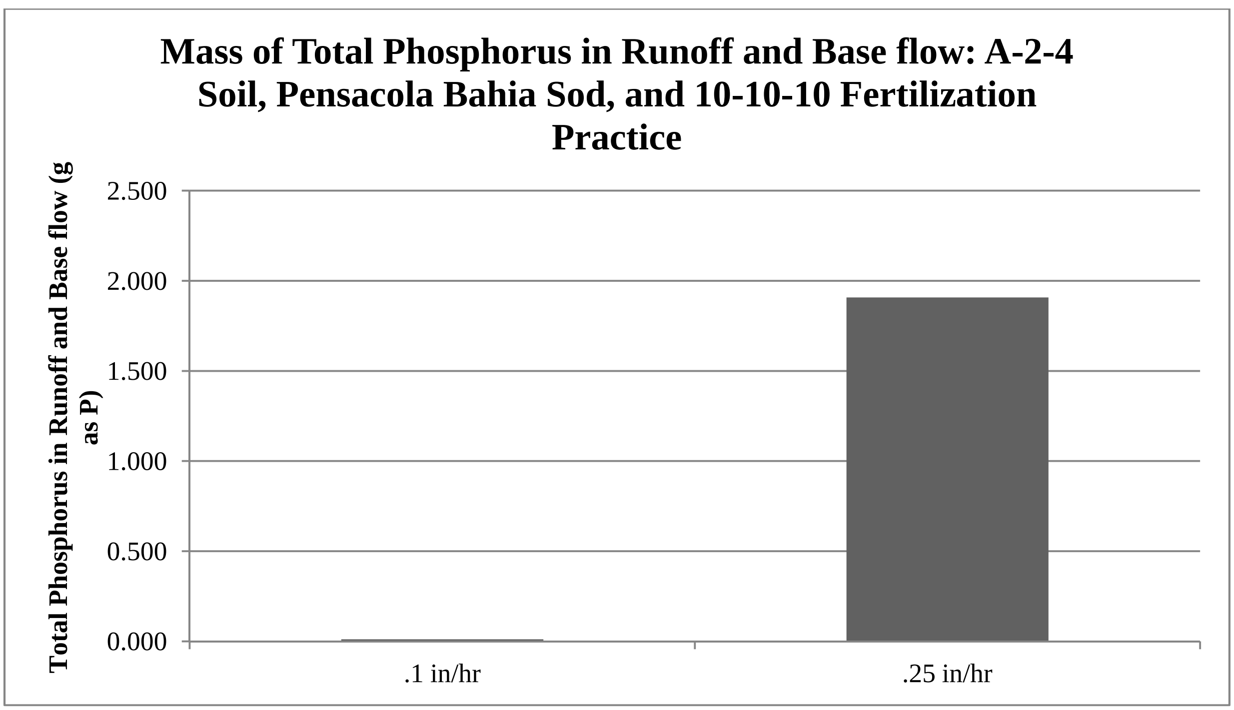

Figure 30: Mass of Total Phosphorus (TP) Collected – A-2-4 Soil and Pensacola Bahia Sod, and 10-10-10 Fertilization Practice

4.8.3 10-10-10 N-P-K Fertilization Practice @ 0.5 lb per 1000 ft² (Seven Day Test)

The two seven-day tests performed for each combination of soil and sod involved the application of fertilizer on test day one, no flush afterwards and another test performed on test day seven to evaluate the change occurring in the test bed over time. For the seven-day test, the rainfall intensity used was 0.25 in/hr.

Table 38 shows the actual rainfall intensities applied to the test bed, along with the corresponding applied water volumes, as well as the respective volumes of collected runoff and base flow for the different rainfall intensities. Runoff generated on day one of testing was due to the higher soil moisture content at the commencement of testing. On day one, the percentage of runoff collected to total outflow volume was 66.8%. There was no runoff generated on day seven because of the lower antecedent moisture content, which resulted in a much lower collected base flow volume when compared to day one base flow volume.

Table 38: Volumes of Rainfall Applied, Runoff, and Base flow Collected on A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

Intended Rainfall intensity [in/hr]	**0.25**	**0.25**
Test Day	**Day One**	**Day Seven**
Average actual intensity [in/hr]	0.28	0.26
Flow Volumes in Liters (L)		
Applied	467.2	443.6
Base flow Collected	111.7	24.9
Runoff Collected	225	0
Soil Moisture Content [%]	13.5	10.3
Runoff as Percentage of Total [%]	66.8	0.0

Table 39 presents the average chemical parameters measured in both tests, which are the concentration total solids, alkalinity and pH value in the outflow volumes (base flow and runoff). These parameters did not vary significantly from day one to day 7. The total solid concentration changed from 236 mg/L to 221 mg/L, alkalinity from 103 mg/L to 99.2 mg/L (as $CaCO_3$), and the pH value was 6.7 (adopted from phase #1 for the same soil and sod combinations – Table 25) for test day one and day 7, respectively.

Table 39: Total Solids, Alkalinity, and pH in Tests on A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

Rainfall Intensity [in/hr.]	**0.25**	**0.25**
Test Day	Day One	Day Seven
Total Solids [mg/L]	236	221
Alkalinity [mg/L]	103	99.2
pH	6.7*	6.7*

*Indicates average value adopted from previous study's corresponding soil/sod combination with 10-10-10.

The total mass of fertilizer (10-10-10 N P K) applied to the test bed before testing began on day one was 27.2 grams. Table 40 provides a summary of the total nitrogen and phosphorus mass collected on each day for base flow and runoff, if available. The percent of TN mass collected as runoff on day one was 75.8% of the total and the percent of TP mass collected as runoff on day one was 91.5%. On day 7, there was very little TN and TP mass collected. This is because the vast majority of nutrients lost were through runoff and the there was no runoff on day 7. The results indicate that runoff washes off most of the nutrients from the sod and soil while less nutrients move through the test bed soil for the seven-day test.

Table 40: Distribution of Nutrient Loss between Runoff and Base flow on A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

Rainfall Intensity [in/hr]	**0.25**	**0.25**
Test Day	**Day One**	**Day Seven**
TN Mass (g)		
Base flow	0.66	0.18
Runoff	2.04	0
Total	2.69	0.18
Ratio of loss: runoff/total [%]	75.84	0.00
TP Mass (g)		
Base flow	0.11	0.0006
Runoff	1.19	0
Total	1.30	0.0006
Ratio of loss: runoff/total [%]	91.54	0.00

The respective Figure 31 and Figure 32 present the loss of total nitrogen (TN in runoff + base flow) and phosphorus (TP in runoff + base flow) in the seven-day tests. The plots show significant losses of both TN and TP on day one compared to day 7. This is the expected trend because the applied nutrients in the fertilizer are washed off by the runoff, adsorbed into the soil in the test bed, or utilized by the sod. The result agrees with the findings in phase #1 of the study of the same soil and sod combinations, even though the rainfall intensity was higher in that phase of the study (Figure 17 and Figure 18).

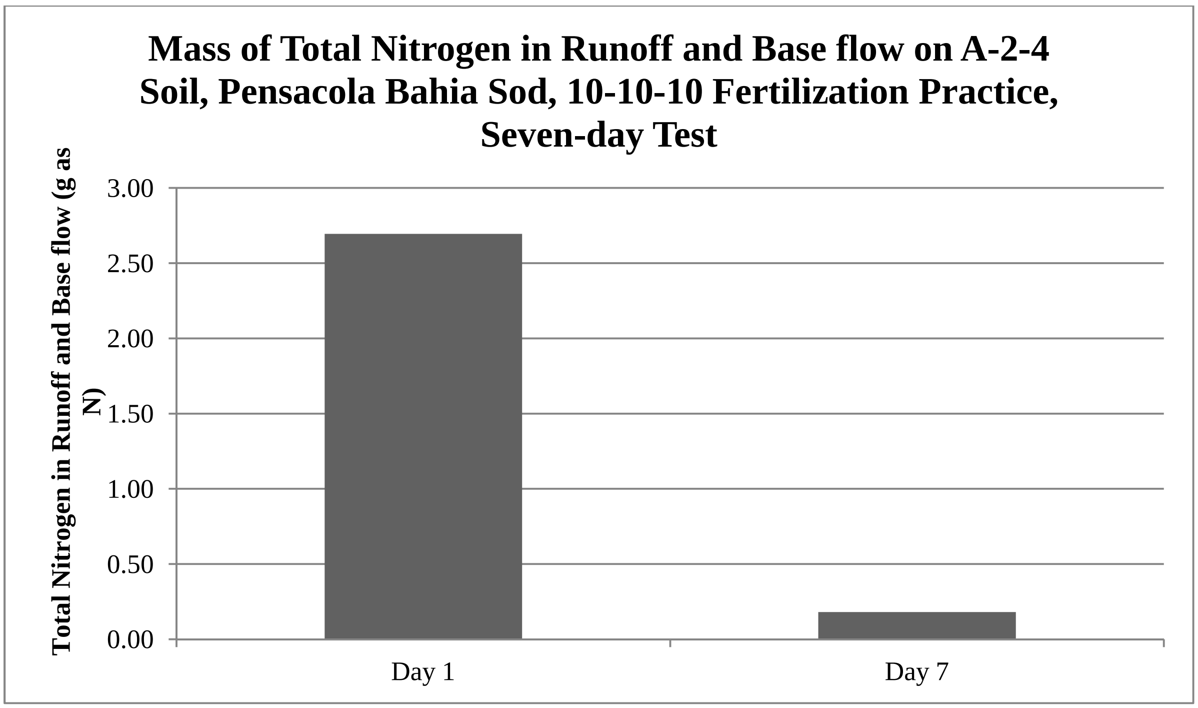

Figure 31: Mass of Total Nitrogen (TN) Collected – A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

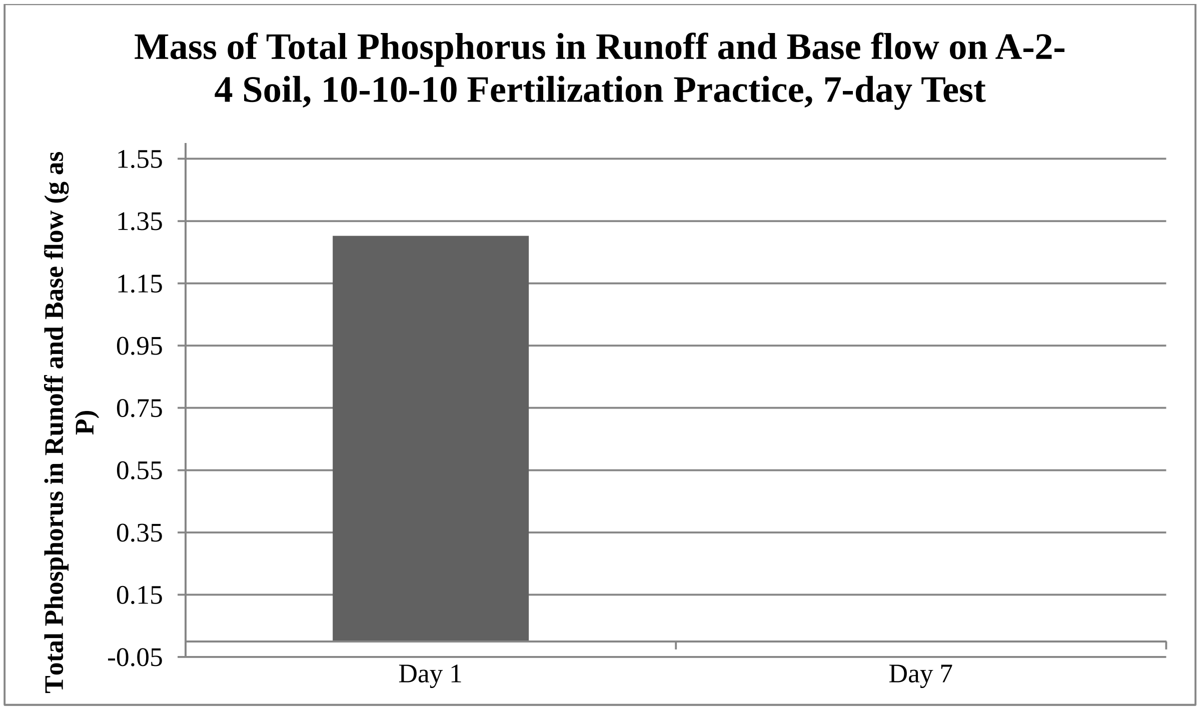

Figure 32: Mass of Total Phosphorus (TP) Collected – A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

4.8.4 16-0-8 N-P-K Fertilization Practice @ 0.5 lb of N per 1000 ft^2 (One-Day Test)

Following the 10-10-10 fertilizer testing series, the used soil and sod was removed from the test bed and replaced with fresh A-2-4 (silty sand) soil and new Pensacola Bahia sod. This was done to simulate pristine starting conditions that would be free of any contamination from the previous testing soil and sod combinations. Testing with a new fertilization practice (16-0-8 of N-P-K) started after the sod had developed a stable root system with the soil in the test bed. The rate of fertilizer application was 0.5 lb. N/1000 ft^2 on the new sod prior to each test. The total number of tests for the one-day test with fertilization was four.

Table 41 presents the actual rainfall intensities applied to the test bed, the corresponding volumes of applied rainfall, collected runoff and base flow during testing. There was no runoff generated at 0.10 in/hr rainfall intensity tests, and for the 0.25 in/hr rainfall intensity, the percentage of runoff to total outflow volume was 39.2% during the tests. As expected, the trend of runoff to total outflow volumes increased with the increase in rainfall intensity as was the trend in phase #1 testing on the same soil and sod combination (Table 27).

Table 41: Volumes of Rainfall Applied, Runoff, and Base flow Collected on A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 Fertilization Practice

Intended rainfall intensity [in/hr]	0.10	0.25
Average actual rainfall intensity [in/hr]	0.125	0.26
Flow Volumes in Liters (L)		
Applied	243.1	517.5
Base flow Collected	130.2	155.1
Runoff Collected	0.0	99.8
Soil Moisture Content [%]	15.1	16.1
Runoff as Percentage of Total [%]	0	39.2

Table 42 presents the average chemical parameters of the measured concentrations of total solids and alkalinity from both the runoff and base flow of all four tests, and the adopted pH values from phase #1 (Table 28). The concentration of total solids ranged from 270.2 mg/L to 350.5 mg/L and the alkalinity ranged from 115.9 to 119.95 mg/L as $CaCO_3$. The adopted pH value was 7.1 for the same soil and sod combination. Both the alkalinity and pH values are indicative of the chemical neutrality of the system.

Table 42: Total Solids, Alkalinity, and pH in Tests on A-2-4 Soil, Pensacola Bahia Sod, and 16-08-8 Fertilization Practice

Rainfall Intensity [in/hr]	0.10	0.25
Total Solids (mg/L)	350.5	270.17
Alkalinity (mg/L)	119.95	115.9
pH	7.1	7.1

The applied mass of total nitrogen was 27.2 g as N, and the total phosphate was zero (0.00) g as PO_4^3 for each test in the series. Table 43 presents the masses of total nitrogen and phosphorus collected from both the runoff and base flow. There was no TN loss in the runoff for 0.10 in/hr. rainfall intensity because there was no runoff from the test. The percentage of TN and

TP mass lost in runoff to the total lost in base flow and runoff for the 0.25 in/hr rainfall intensity was 35.5% and 75.0%, respectively; most of the TP lost were from the runoff. However, the total masses of nitrogen and phosphorus collected at both rainfall intensities were not significantly different; the TN and TP ranged from 2.91 to 2.93 mg/L and 0.02 to 0.08 mg/L, respectively. Since there was no phosphorus applied in the fertilizer, loss of TP from both base flow and runoff were low. The total phosphorus collected were slightly higher than what was collected during the no fertilizer trials in the previous testing series (Table 34 versus Table 43). This is indicative that the starting soil conditions may not have been identical for both testing series. On the other hand, it could be due to physiochemical differences in testing conditions such as temperature, moisture content, etc.

Table 43: Distribution of Nutrient Loss between Runoff and Base flow: A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 Fertilization Practice

Rainfall Intensity [in/hr]	**0.10**	**0.25**
TN Mass (g)		
Base flow	2.91	1.89
Runoff	0	1.04
Total	2.91	2.93
Ratio of loss: runoff/total [%]	0.00	35.50
TP Mass (g)		
Base flow	0.02	0.02
Runoff	0	0.06
Total	0.02	0.08
Ratio of loss: runoff/total [%]	0.00	75.00

Figure 33 and Figure 34 present the graphical presentation of total nitrogen and phosphorus losses from base flow and runoff in the four tests in this series. The graphs show that the losses in TN increases with increase in the rainfall intensity, which is similar to the results in Figure 19 of phase #1 study. The losses in TP were insignificant, as in Figure 20, because there was no phosphate in the applied fertilizer for the tests.

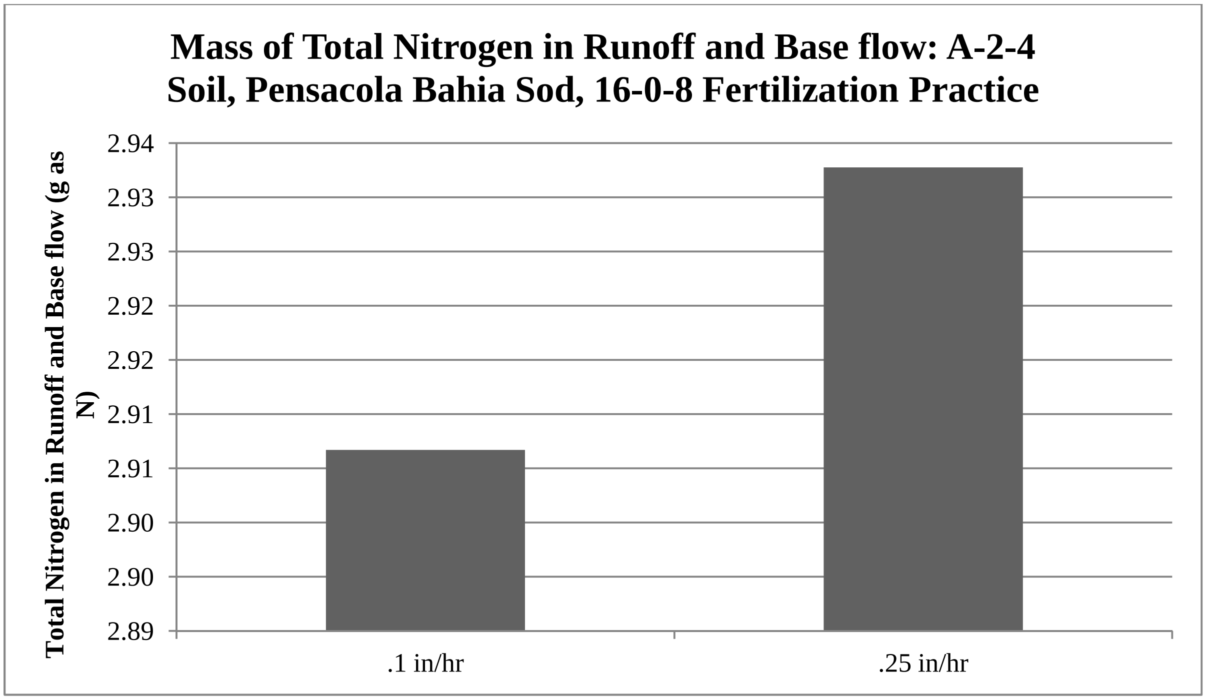

Figure 33: Mass of Total Nitrogen (TN) Collected – A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 Fertilization Practice

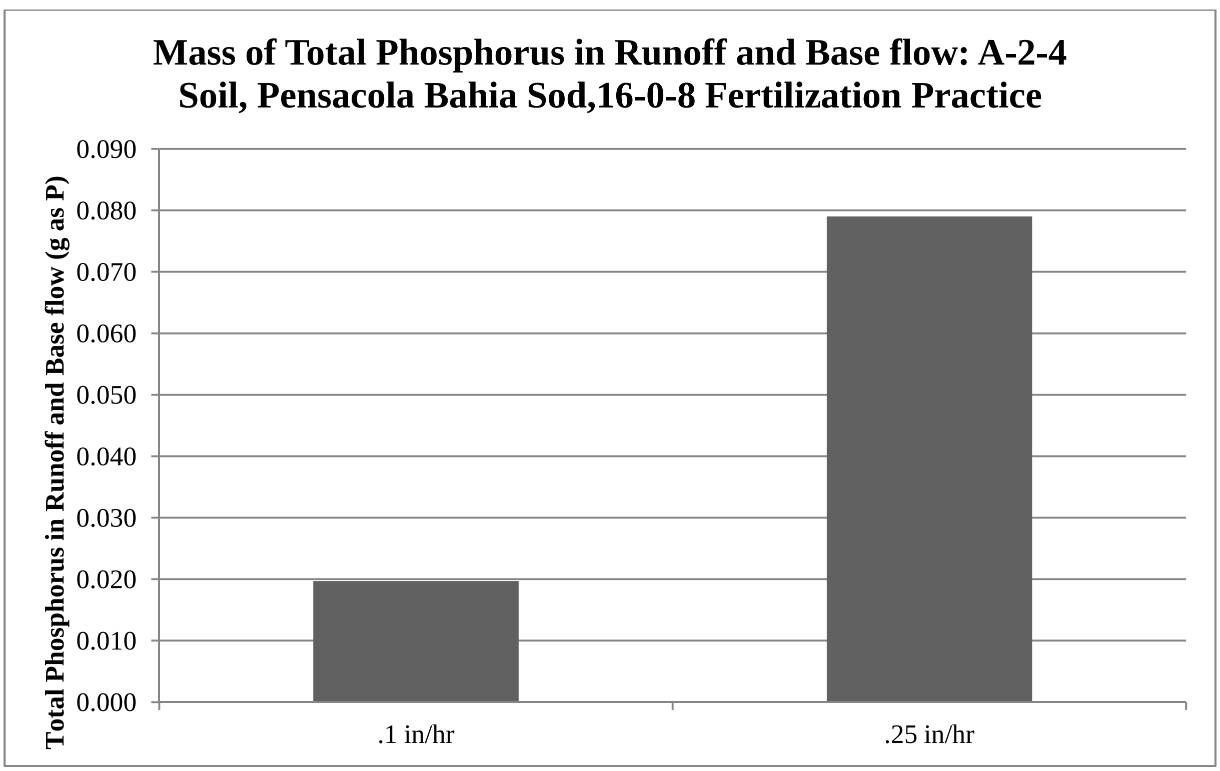

Figure 34: Mass of Total Phosphate (TP) Collected – A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 Fertilization Practice

4.8.5 16-0-8 N-P-K Fertilization Practice @ 0.5 lb of N per 1000 ft^2 (Seven-Day Test)

Table 44 shows the actual rainfall intensities applied to the test bed, the corresponding applied water volumes of rainfall, runoff and base flow. For both rainfall intensities considered there was runoff generated due to the high moisture content at commencement of testing on day one and day 7. However, the moisture content was slightly lower on day 7. The percentage of runoff volume to the total outflow volume was 66.4% and 28.6% for day one and day 7, respectively. Day 7 had more base flow but less runoff volume than Day one even though the applied rainfall volume was approximately equal, which is due to the antecedent moisture content of the soil. The higher moisture content resulted in more runoff volume because the soil was saturated and there was less infiltration.

Table 44: Volumes of Rainfall Applied, Runoff, and Base Flow Collected on A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 Fertilization Practice (Seven-Day Test)

Intended Rainfall Intensity [in/hr]	**0.25**	**0.25**
Test Day	**Day One**	**Day Seven**
Average Actual Intensity [in/hr]	0.28	0.27
Flow Volumes in Liters (L)		
Applied	483.7	457.8
Base flow Collected	52.1	149.5
Runoff Collected	103	60
Soil Moisture Content [%]	14.7	13.6
Runoff as Percentage of Total [%]	66.41	28.64

Table 45 presents the average chemical parameters total solids and alkalinity concentrations measured from the runoff and base flow in both tests, and the pH value adopted from the previous seven-day test. These parameters did not vary significantly from day one to day 7 testing. The concentration of total solids ranged from 372 mg/L to 395 mg/L and the alkalinity ranged from 92 to 133 mg/L as $CaCO_3$. The adopted pH value was 7.1 for the same soil and sod combination.

Table 45: Total Solids, pH, and Alkalinity in Tests on A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 Fertilization Practice (Seven-Day Test)

Rainfall Intensity [in/hr.]	0.25	0.25
Test Day	**Day One**	**Day Seven**
Total Solids [mg/L]	395	372
Alkalinity [mg/L]	133	92.0
pH	7.1	7.1

The applied mass of total nitrogen was 27.2 g as N and the total phosphate was zero (0.00) g as PO_4^3 for each test in the series. Table 46 presents the masses of total nitrogen and phosphorus collected from both the runoff and base flow. The mass of TN collected in the runoff and base flow ranged from 4.15 to 9.51 g and the TP collected on both days of testing was 0.11 g. On day one, the percentage of TN mass collected from runoff to the total was 41% and decreased to 25.5% on day 7, while the percentage of TP mass collected was 81.8% and 45.5 % on day one and day 7, respectively. However, the total mass of phosphorus collected on both days was equal, but the loss of TN on day 7 is indicative of the losses in runoff and base flow that occurred on day one, and soil adsorption and sod utilization between day one and day 7.

Table 46: Distribution of Nutrient Loss between Runoff and Base Flow on A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 Fertilization Practice (Seven-Day Test)

Rainfall Intensity [in/hr]	0.25	0.25
Test Day	**Day One**	**Day Seven**
TN Mass (g)		
Base flow	5.60	3.09
Runoff	3.91	1.06
Total	9.51	4.15
Ratio of loss: runoff/total [%]	41.11	25.54
TP Mass (g)		
Base flow	0.02	0.05
Runoff	0.09	0.05
Total	0.11	0.11
Ratio of loss: runoff/total [%]	81.82	45.45

Figure 35 and Figure 36 present the losses of total nitrogen and phosphorus from base flow and runoff on both test days, respectively. There was a decrease in the loss of TN from day one to day 7 but the loss of TP remained the same, which is the indicative of the mass of nitrogen and phosphate applied for the 16-0-8 fertilization practice. The applied mass of phosphate was zero so the losses measured may be from the residue in the soil and/or sod.

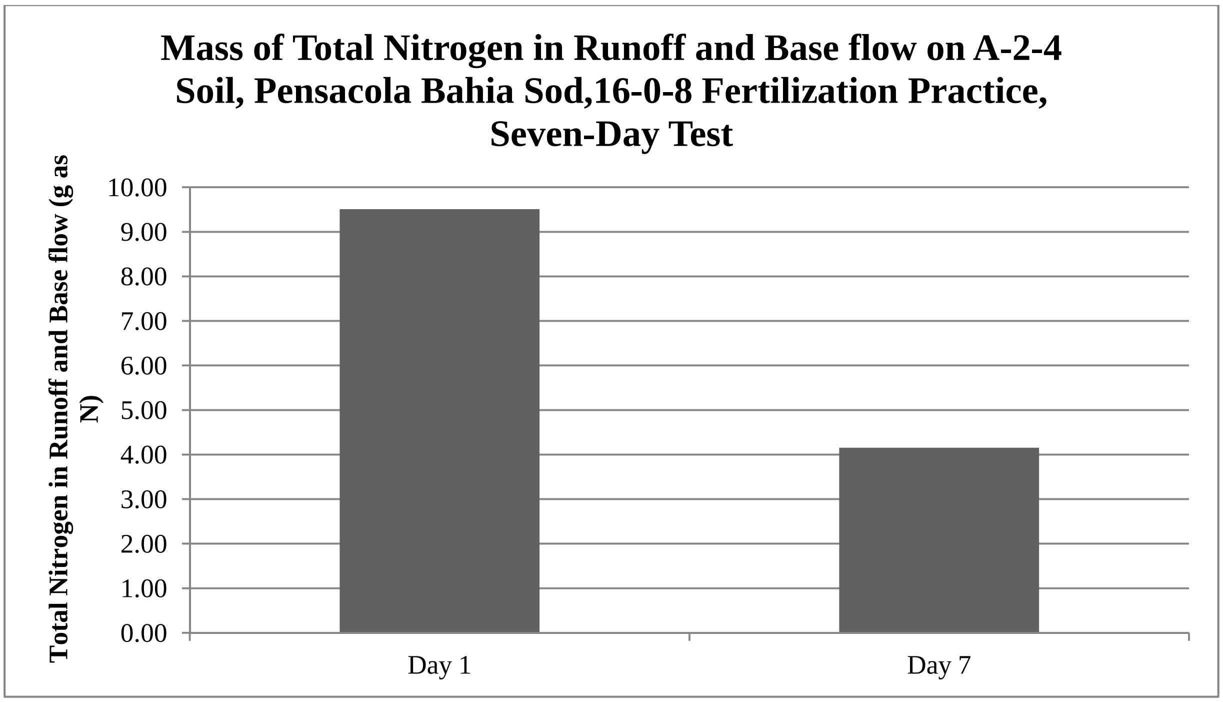

Figure 35: Mass of Total Nitrogen (TN) Collected – A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 Fertilization Practice (Seven-Day Test)

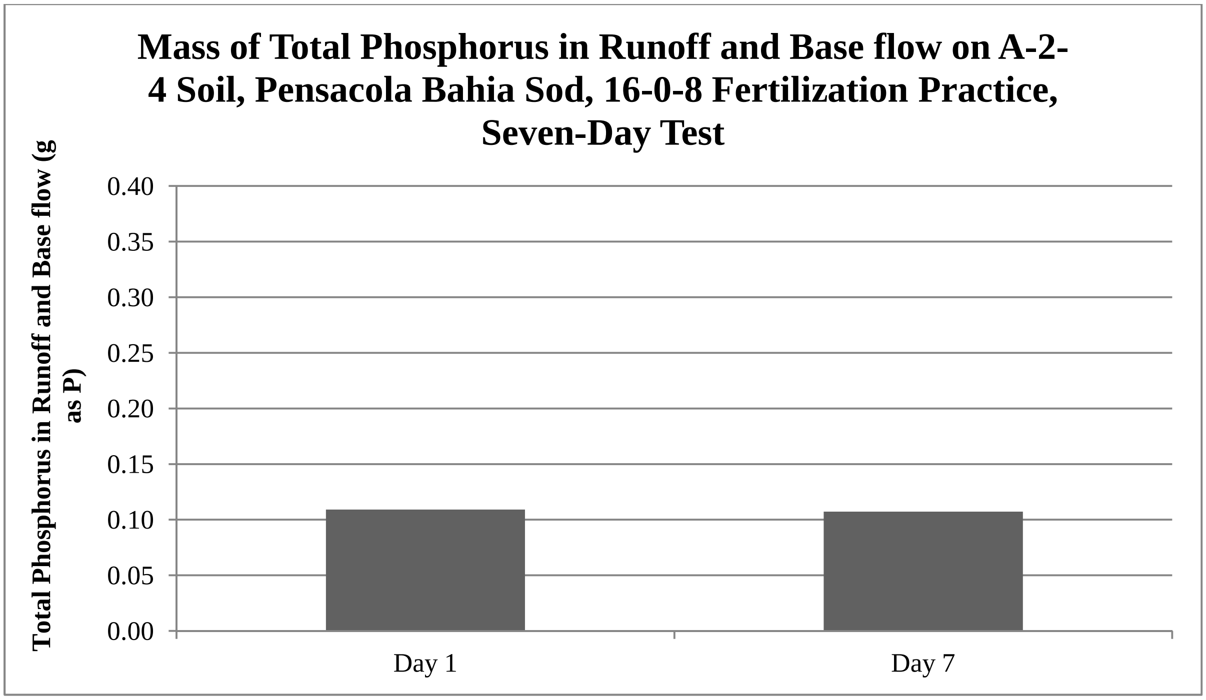

Figure 36: Mass of Total Phosphate (TP) Collected – A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 Fertilization Practice (Seven-Day Test)

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

In addition to effluent from the test bed, there was soil analyses on soil samples collected prior to tests with no fertilizer, and tests with the application of fertilizer – before and after testing – to determine the retention of total nitrogen, total phosphorus, and change in cationic exchange capacity (CEC). The sequence for testing was the 0.25 in/hr rainfall intensity tests and later the 0.10 in/hr rainfall intensity tests for samples obtained in the tests with fertilization practices. Presented in the following sections are the results and discussions on the soil analyses for the A-2-4 (silty sand) soil on the test bed during testing.

4.9.1 No Application of Fertilizer

Table 47 presents the average total nitrogen, total phosphorus, and cationic exchange capacity of A-2-4 soil prior to any fertilization practice for both rainfall intensities. The results presented are the average base values for the A-2-4 soil samples collected before each no fertilizer test. The average CEC of was approximately equal to 0.63 meq/g, which is indicative of a high cationic exchange capacity of the soil on the test bed prior to any type of fertilization practice.

Table 47: Total Nitrogen, Total Phosphorus, and CEC in Tests on A-2-4 Soil, Pensacola Bahia Sod, and No Fertilizer

Rainfall Intensity [in/hr]	0.10	0.25
Total Nitrogen [g]	216.7	305.5
Total Phosphorus [g]	328.4	277.3
CEC [meq/g]	0.63	0.64

4.9.2 10-10-10 N-P-K Fertilization Practice @ 0.5 lb per 1000 ft^2 (One-Day Tests)

Table 48 presents the average total nitrogen, total phosphorus, and CEC of A-2-4 soil during the 10-10-10 fertilization practice tests for both rainfall intensities. In the 10-10-10 fertilization practice, these were soils taken before and after fertilization for each test and after the simulated rainfall for both rainfall intensities. Due to the sequence of testing – 0.25 in/hr before 0.10 in/hr rainfall intensity tests, there was increase in the value of total nitrogen and phosphorus in the soil, which is indicative of a gradual build-up of nutrients in the test bed despite flush rainfall events. However, the cationic exchange capacity of the soil decreased significantly from the 0.25 to 0.10 in/hr rainfall intensity tests, which is indicative that the soil exchange capacity had been utilized by nutrients added to the soil in the test bed.

Table 48: Total Nitrogen, Total Phosphorus, and CEC in Tests on A-2-4 Soil and Pensacola Bahia Sod with 10-10-10 Fertilization Practice

Rainfall Intensity [in/hr]	0.10	0.25
Total Nitrogen Before Test [g]	1333	821
Total Nitrogen After Test [g]	1337	1847
Total Phosphorus Before Test [g]	1131	575
Total Phosphorus After Test [g]	950	758
CEC Before Test [meq/g]	0.38	0.61
CEC After Test [meq/g]	0.43	0.66

4.9.3 16-0-8 N-P-K Fertilization Practice @ 0.5 lb per 1000 ft^2 (One-Day Tests)

Table 49 presents the average total nitrogen, total phosphorus, and CEC of A-2-4 during the 10-10-10 fertilizer series for both rainfall intensities. Similar to the 10-10-10 fertilization practice tests, the increasing value of total nitrogen and phosphorus in the soil from the 0.25 in/hr series to the 0.10 in/hr series shows the gradual build-up of nutrients in the test bed, irrespective of the fertilization practice. Again, the cationic exchange capacity of the soil decreased because of the testing sequence of 0.25 in/hr before 0.10 in/hr test series, which confirms the utilization of the soil exchange by nutrients added.

Table 49: Total Nitrogen, Total Phosphorus, and CEC in Tests on A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 Fertilization Practice

Rainfall Intensity [in/hr]	0.1	0.25
Total Nitrogen Before Test [g]	2168	1046
Total Nitrogen After Test [g]	486	491
Total Phosphorus Before Test [g]	792	568
Total Phosphorus After Test [g]	552	509
CEC Before Test [meq/g]	0.49	0.52
CEC After Test [meq/g]	0.43	0.50

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

Figure 37 shows the plot of the chronological order between the cation exchange capacity of A-2-4 soil against the no-fertilization and 10-10-10 fertilization practice. The plot shows that the CEC was approximately constant for the no-fertilization practice and then initially had a slight increase and then dropped substantially for the remaining four tests with the 10-10-10 fertilizer. The testing with the 16-0-8 fertilization practice shown in Figure 38 also showed a slight increase in CEC followed by a substantial decrease. There was no test performed with no fertilizer for the batch of soil/sod combination used for 16-0-8 fertilization tests. Thus, a before and after fertilization trend could not be established for the 16-0-8 fertilization practice tests.

Regardless, the trend was similar, that is a decrease in A-2-4 soil CEC over time. The trend could be due to the utilization of the exchange sites by cations introduced to the soil via fertilizer or a decline in soil pH because of nitrification and the subsequent release of H^+ ions, which also decreases the soil CEC.

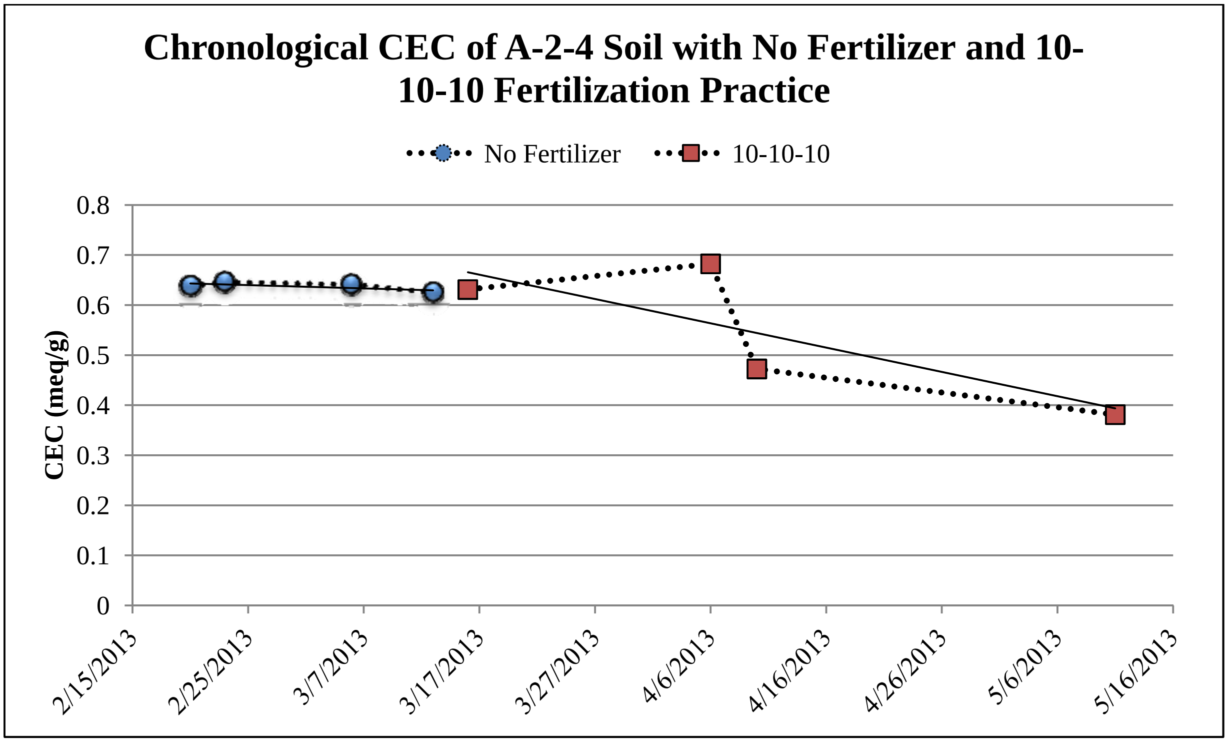

Figure 37: Chronological Sequence of CEC of A-2-4 Soil for No Fertilizer and 10-10-10 Fertilization Practices

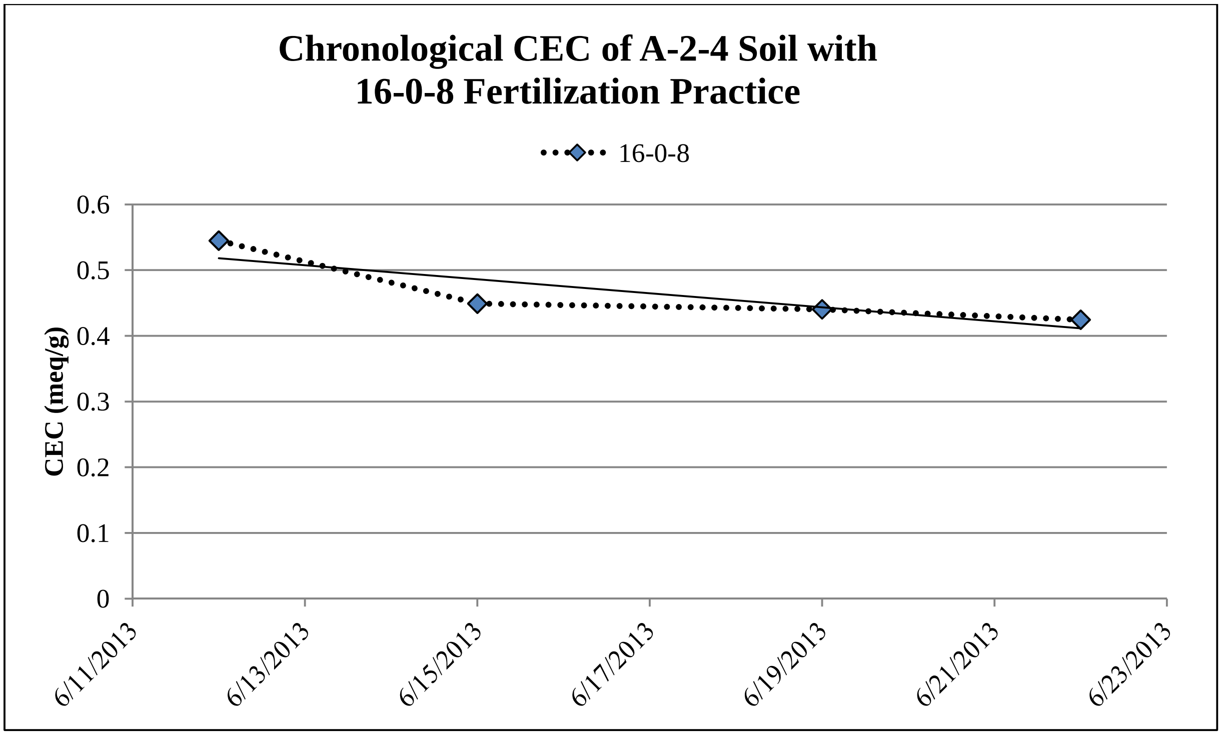

Figure 38: Chronological Sequence of CEC of A-2-4 Soil for 16-0-8 Fertilization Practice

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

Table 31 shows the chronological sequence of tests performed on A-3 (sandy) 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 fertilization practice, but not on the tests with 16-0-8 fertilization practice because of the assumption that the soil and sod conditions were similar. However, further analysis of tests showed that the assumption may not have been accurate, and that the virgin soil and, particularly, sod placed in the test bed prior to the 16-0-8 fertilization test series inherently had more nitrogen and phosphorus contents than was the condition with the virgin soil and sod placed prior to the 10-10-10 fertilization test series. Thus, for the A-3 and Argentine Bahia testing series, there was a no-fertilization test conducted prior to each of the 10-10-10 and 16-0-8 fertilization practices (after the replacement of soil and sod in the test bed).

It is important to note that for all of the tests on A-3 (sandy) soil, there was no runoff generated at both intensities, regardless of the soil antecedent moisture content due to the high infiltration capacity of the A-3 soil and the low volume of the simulated rainfall intensities.

4.10.1 No Application of Fertilizer

The second half of Table 31 shows there was eight tests performed with no fertilization, four tests for each soil and sod combination change, in order to establish a baseline for the soil/sod combination. The purpose of establishing a baseline is to determine the level of nutrients in the soil and the sod at the beginning of the test series. The highway slope and simulated rainfall intensities (0.25 and 0.10 in/hr) remained the same as was with the test series using A-2-4 soil.

4.10.1.1 No Fertilizer Prior to 10-10-10 Fertilization Practice

Table 50 presents the actual rainfall intensities applied to the test bed, the applied water volumes, and the base flow volume collected. There was no runoff generated for all tests on A-3 soil, so the total outflow volume was from the base flow.

Table 50: Volumes of Applied Rainfall, Runoff and Base flow in Tests Collected on A-3 Soil, Argentine Bahia Sod, and No Fertilizer prior to 10-10-10 Fertilization Practice

Intended rainfall intensity [in/hr]	**0.10**	**0.25**
Average actual intensity [in/hr.]	0.115	0.22
Flow Volumes in Liters (L)		
Applied	155.9	306.8
Base flow Collected	66.8	91.3
Runoff Collected	0.0	0.0
Soil Moisture Content [%]	11.50	8.65

Table 51 presents the average chemical parameters measured in all four tests such as total solids, alkalinity and pH. The concentrations of total solids ranged from 720.8 to 761.3 mg/L, alkalinity was from 328.5 and 329.5 mg/L (as $CaCO_3$), and the pH value was 7.3 for both rainfall intensities. These chemical parameters show chemical neutrality of the system and did not vary greatly between rainfall intensities.

Table 51: Total Solids, Alkalinity, and pH in Tests on A-3 Soil, Argentine Bahia Sod, and No Fertilizer prior to 10-10-10 Fertilization Practice

Rainfall Intensity [in/hr.]	**0.10**	**0.25**
Total Solids [mg/L]	720.8	761.3
Alkalinity [mg/L]	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, Table 52 presents the measured mass of total nitrogen (TN) and total phosphorus (TP) lost through base flow (no runoff). The TN and TP losses were slightly greater at the 0.25 in/hr rainfall intensity tests than the 0.10 in/hr rainfall intensity tests, but relatively low as expected (no fertilization). The higher rainfall intensity transported more nutrients through the soil into base flow because there was more rainfall volume available, approximately twice that of the lower rainfall intensity. All losses of TN and TP were in the base flow.

Table 52: Distribution of Nutrient Loss between Runoff and Base Flow on A-3 Soil, Argentine Bahia Sod, and No Fertilizer prior to 10-10-10 Fertilization Practice

Rainfall Intensity [in/hr.]	0.10	0.25
TN Mass [g]		
Base flow	1.09	1.93
Runoff	0.00	0.00
Total	1.09	1.93
TP Mass [g]		
Base flow	0.005	0.008
Runoff	0.000	0.000
Total	0.005	0.008

Both Figure 39 and Figure 40 present losses of total nitrogen (TN in runoff + base flow) and total phosphate (TP in runoff + base flow) for all the four test seriesTable 34. The mass of

TN increased at approximately100 percent from the 0.10 to 0.25 in/hr rainfall intensity due to the volume of rainfall applied on the tests bed and infiltrated through the soil. The mass of TP loss was relatively low but increased with rainfall intensity. There was no fertilization, so the explanation for the losses may be due to a host of bio-geochemical processes examined in detail in chapter 5.

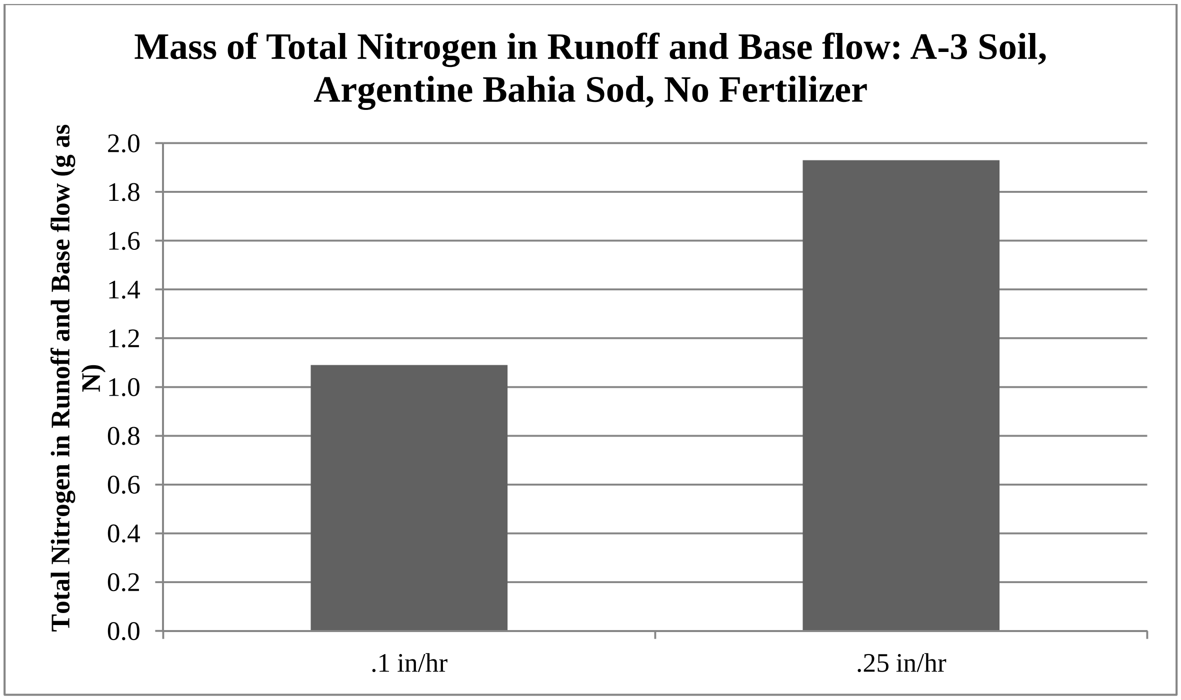

Figure 39: Mass of Total Nitrogen (TN) Collected – A-3 Soil, Argentine Bahia Sod, and No Fertilizer prior to 10-10-10 Fertilization Practice

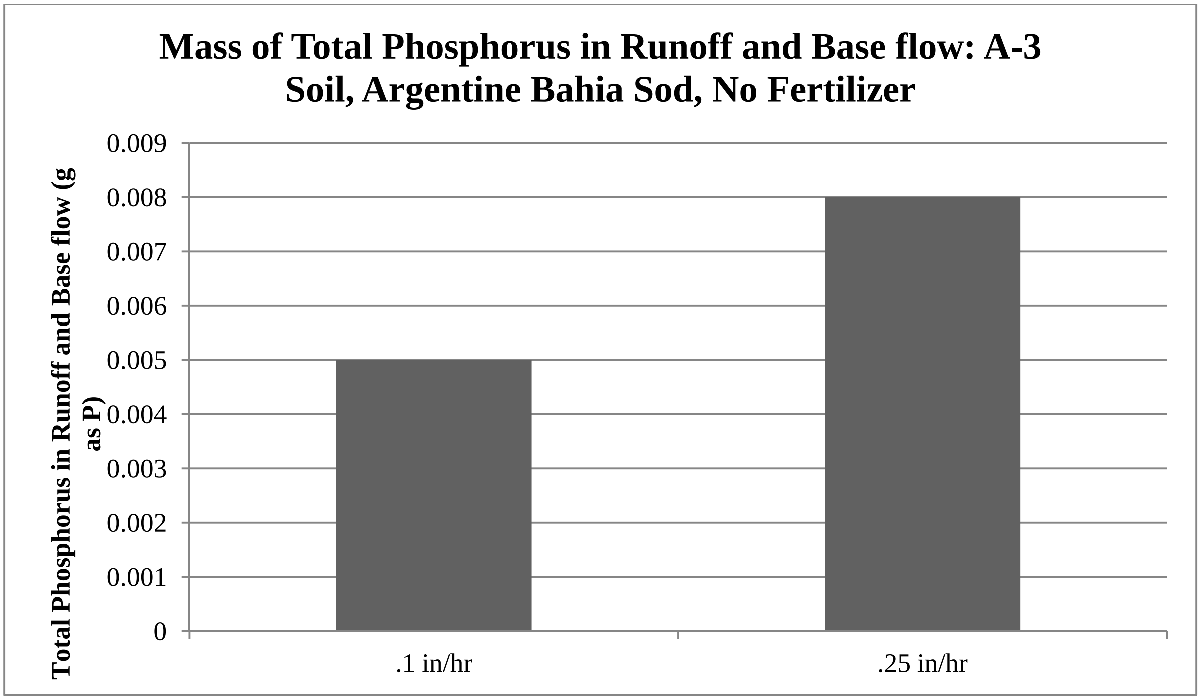

Figure 40: Mass of Total Phosphate (TP) Collected – A-3 Soil, Argentine Bahia Sod, and No Fertilizer prior to 10-10-10 Fertilization Practice

4.10.1.2 No Fertilizer Prior to 16-0-8 Application

Table 53 presents the actual rainfall intensities applied to the test bed, the corresponding applied volumes of rainfall and collected volumes of base flow. As was in the previous No-fertilizer test, there was no runoff for this test on A-3 soil. The applied rainfall volume was higher for the 0.25 in/hr rainfall intensity tests but the average collected base flow was less by approximately 50% due to the antecedent moisture content and the retention of water in the soil body.

Table 53: Volumes of Rainfall Applied, Runoff, and Base flow Collected on A-3 Soil, Argentine Bahia Sod, and No Fertilizer prior to 16-0-8 Fertilization Practice

Intended rainfall intensity [in/hr]	**0.10**	**0.25**
Average actual intensity [in/hr]	0.13	0.27
Flow Volumes in Liters (L)		
Applied	218.3	455.4
Base flow Collected	49.4	22.6
Runoff Collected	0.0	0.0
Soil Moisture Content [%]	10.40	8.75

Table 54 presents the average chemical parameters, the measured concentrations of total solids, alkalinity and the pH values in all four tests. Total solids ranged from 316.5 to 399.5 mg/L, alkalinity was from 220 and 242 mg/L (as $CaCO_3$), and the pH value was from 7.48 to 7.74. The variation of the chemical parameters between rainfall intensities was not significant.

Table 54: Total Solids, Alkalinity, and pH in Tests on A-3 Soil, Argentine Bahia Sod, and No Fertilizer prior to 16-0-8 Fertilization Practice

Rainfall Intensity [in/hr]	**0.10**	**0.25**
Total Solids (mg/L)	316.5	399.5
Alkalinity (mg/L)	220	242
pH	7.48	7.74

Table 55 presents the measured masses of total nitrogen (TN) and total phosphorus (TP) lost through base flow (no runoff). There were no significant differences in the masses of TN and TP losses between both rainfall intensity tests, the values are approximately equal. However, the masses of TN and TP were relatively low as expected (no fertilization), and all losses were in the base flow.

Table 55: Distribution of Nutrient Loss between Runoff and Base Flow on A-3 Soil, Argentine Bahia Sod, and No Fertilizer prior to 16-0-8 Fertilization Practice

Rainfall Intensity [in/hr]	0.10	0.25
TN Mass (g)		
Base flow	0.12	0.13
Runoff	0.00	0.00
Total	0.12	0.13
TP Mass (g)		
Base flow	0.002	0.001
Runoff	0.000	0.000
Total	0.002	0.001

Both Figure 41 and Figure 42 show graphically the difference in losses of total nitrogen (TN in base flow) and total phosphate (TP base flow) for all the four test series, respectivelyTable 34. The masses of TN and TP increased with the increment in the rainfall intensity from 0.10 to 0.25 in/hr. The values were low and the trend was may be due residual nutrients in the soil or other bio-geochemical processes in the soil.

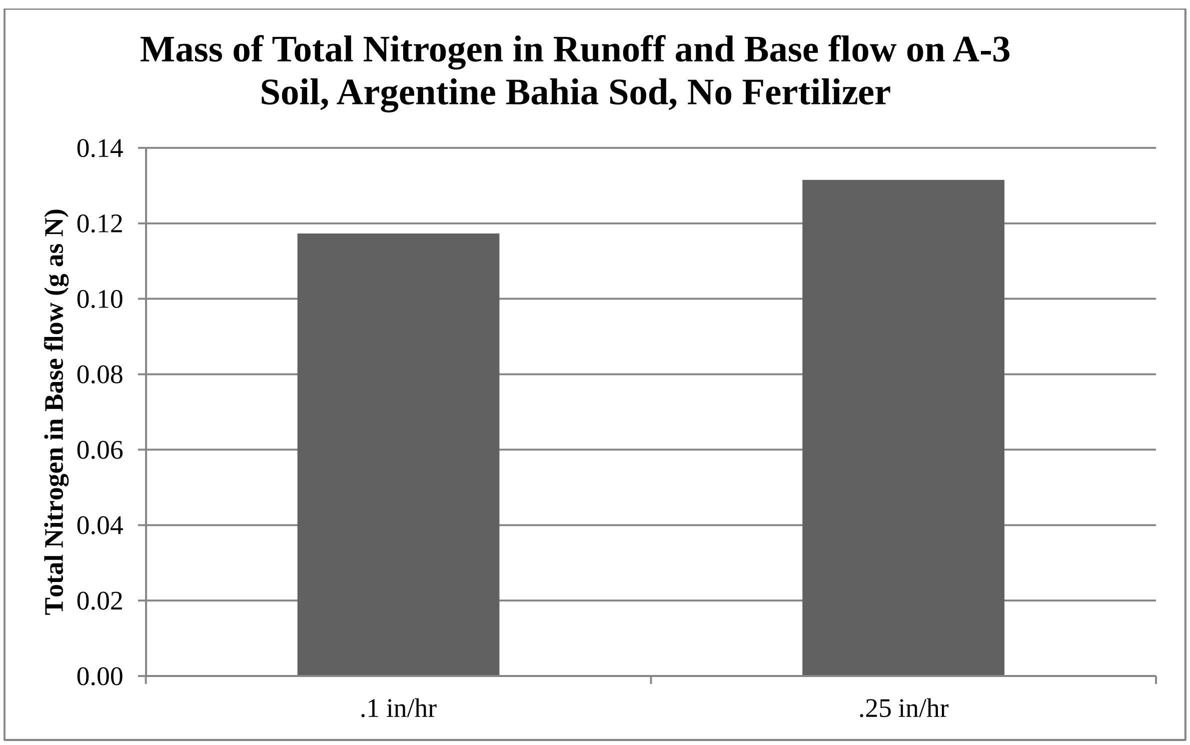

Figure 41: Mass of Total Nitrogen (TN) Collected – A-3 Soil, Argentine Bahia, and No Fertilizer prior to 16-0-8 Fertilization Practice

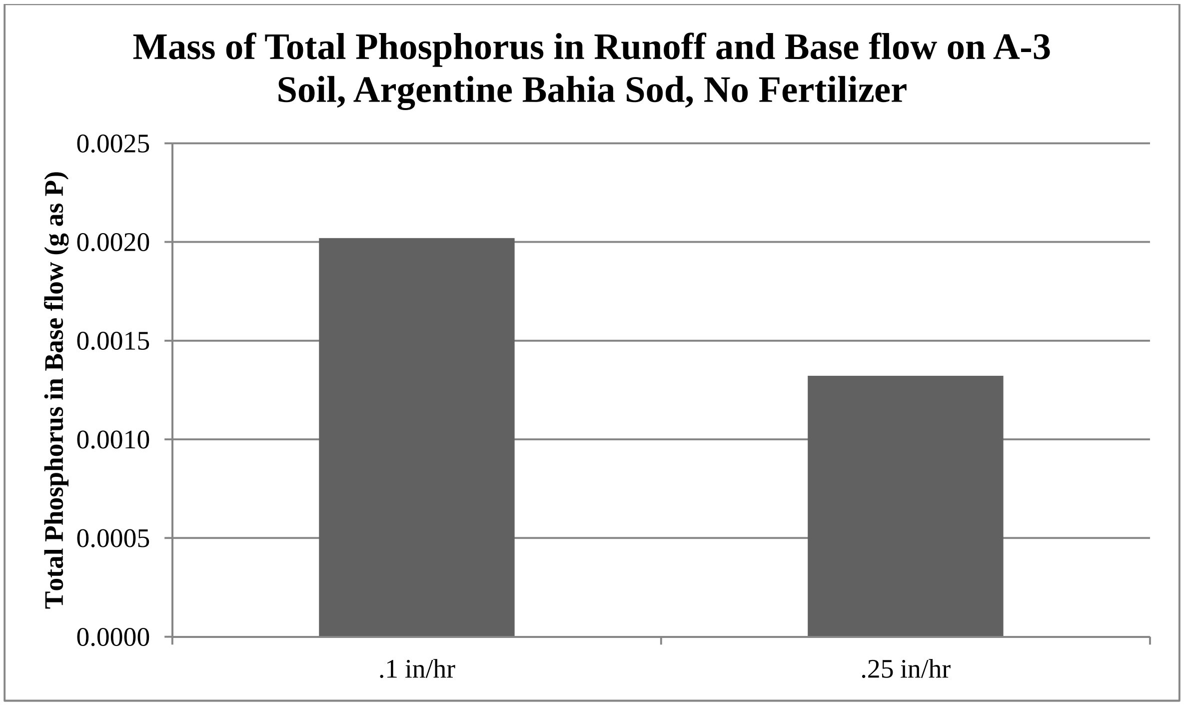

Figure 42: Mass of Total Phosphate (TP) Collected – A-3 Soil, Argentine Bahia Sod, and No Fertilizer prior to 16-0-8 Fertilization Practice

4.10.2 10-10-10 N-P-K Fertilization Practice @ 0.5 lb of N per 1000 ft^2 (One-Day Test)

There were four One-day tests performed on A-3 soil with Argentine Bahia sod with 10-10-10 fertilization practice. Table 56 presents the actual rainfall intensities applied to the test bed, the corresponding volumes of applied rainfall, volumes of collected base flow, and the antecedent moisture conditions for all the four tests. There was no runoff collected, accordingly, the total outflow volume was from the base flow and ranged from 86.4 to 115.1 L between both rainfall intensities.

Table 56: Volumes of Rainfall Applied, Runoff, and Base Flow Collected on A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

Intended rainfall intensity [in/hr]	**0.10**	**0.25**
Average actual intensity [in/hr]	0.125	0.26
Flow Volumes in Liters (L)		
Applied	206.5	296.1
Base flow Collected	86.4	115.11
Soil Moisture Content [%]	8.98	9.54

Table 57 presents the average chemical parameters, the measured concentrations of total solids, alkalinity and the pH values in all four tests. Total solids ranged from 502 to 563 mg/L, alkalinity ranged from 262 to 285 mg/L (as CaCO3), and the pH values ranged from 7.3 to 7.5, which are indicative of the chemical neutrality of the system. None of the chemical parameters varied greatly between rainfall intensities.

Table 57: Total Solids, Alkalinity, and pH in Tests on A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

Rainfall Intensity [in/hr]	0.10	0.25
Total Solids [mg/L]	502	563
Alkalinity [mg/L]	262	285
pH	7.5	7.3

The applied mass of total nitrogen was 27.2 g as N, and the mass of total phosphate was 27.2 g as PO_4^3. Table 58 presents the collected masses of TN and TP from base flow, there was no runoff. Thus, at the rainfall intensities, soil and sod types evaluated in phase #2 testing, the nutrient losses are by sod intake, soil adsorption and/or Base flow. The masses of TN and TP collected increased with increment in the rainfall intensity, but in the higher rainfall intensities evaluated in phase #1 of the study (Table 8), the collected masses were relatively constant for the all the rainfall intensities because of runoff generated. However, when compared to the no-fertilizer tests (Table 52), the TN was lower in spite of the addition of fertilizer, which is indicative of the fertilization of the sod placed on the test bed before the no-fertilizer tests. This shows that while not always the case, new sod can come with a significant amount of fertilizer already applied by the supplier.

Table 58: Distribution of Nutrient Loss between Runoff and Base Flow on A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

Rainfall Intensity [in/hr]	0.10	0.25
TN Mass (g)		
Base flow	0.29	0.71
Runoff	0.00	0.00
Total	0.29	0.71
TP Mass (g)		
Base flow	0.005	0.02
Runoff	0.000	0.000
Total	0.005	0.02

Both Figure 43 and Figure 44 presents the graphical representation of total nitrogen (TN in base flow) and total phosphate (TP in base flow) for all four tests, respectively. The loss of TN mass increases with an increase in rainfall intensity, which confirms the trend in phase #1 of the study (Figure 5). The loss of TP mass was very low but showed an incremental increase with an increase in rainfall intensity, but it may be due to a host of bio-geochemical processes discussed in chapter 5.

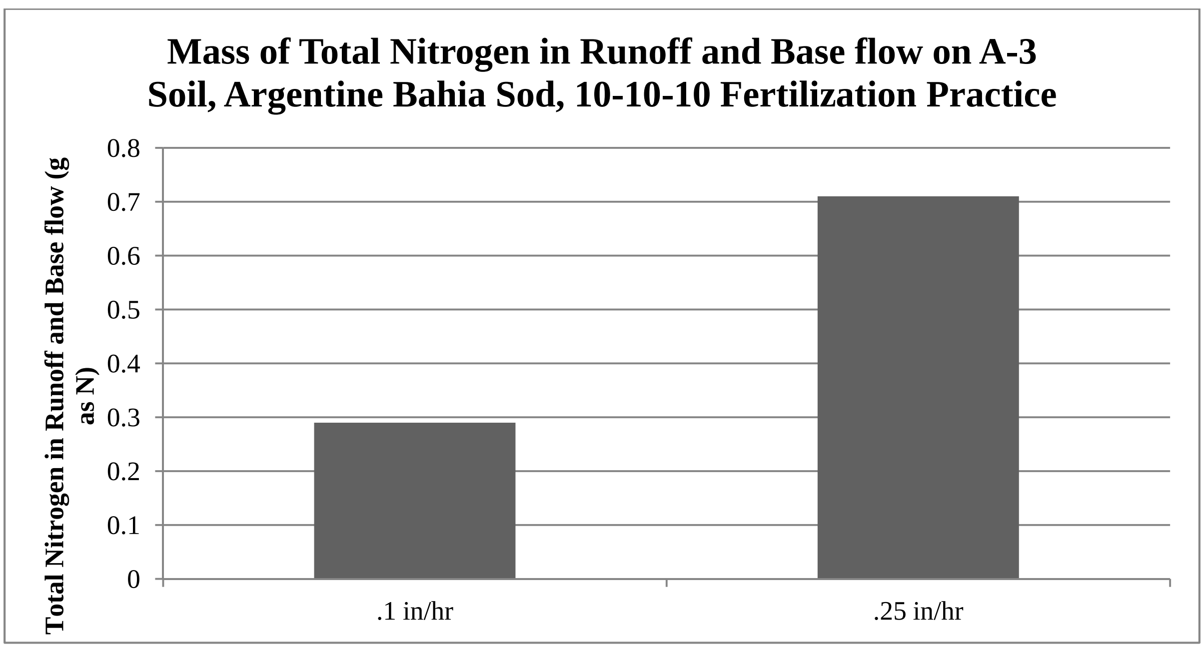

Figure 43: Mass of Total Nitrogen (TN) Collected – A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

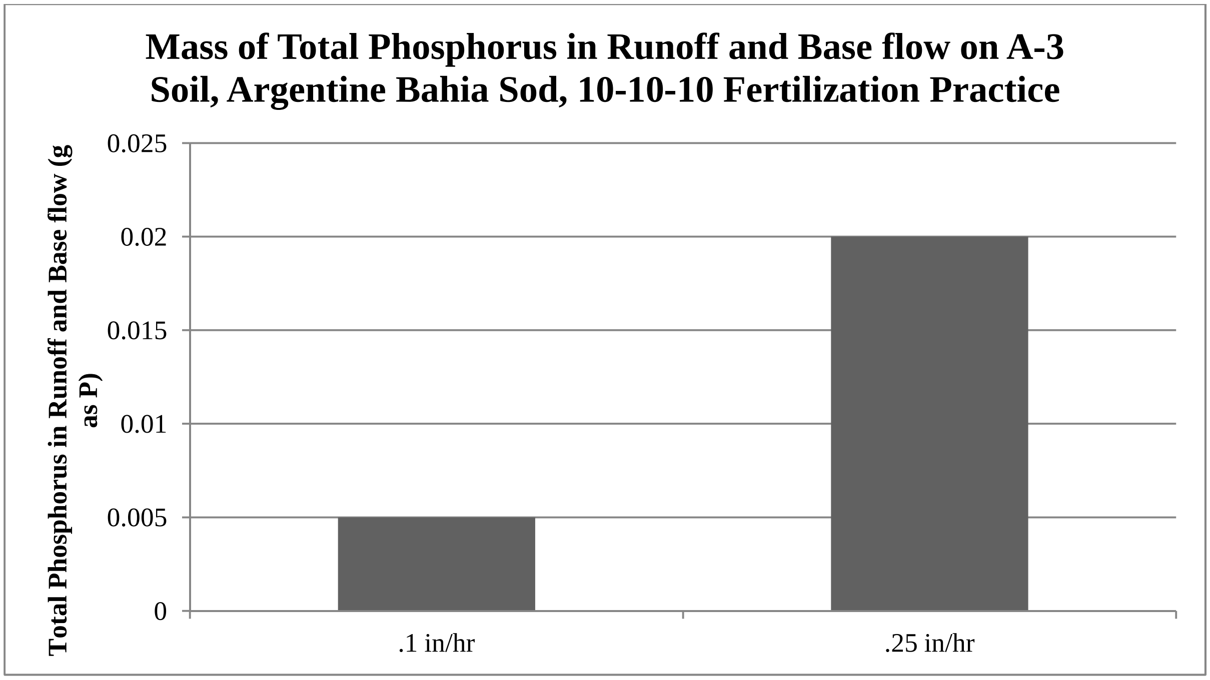

Figure 44: Mass of Total Phosphate (TP) Collected – A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

4.10.3 10-10-10 N-P-K Fertilization Practice @ 0.5 lb of N per 1000 ft^2 (Seven-Day Test)

There were two tests performed for the seven-day test for the A-3 soil and Argentine Bahia sod combination with 10-10-10 fertilization practice. The seven-day test involved the application of fertilizer on day one of testing, no flush rainfall event afterwards, and another test performed on day seven in order to evaluate the change occurring in the test bed soil over time. The simulated rainfall intensity for the seven-day test was 0.25 in/hr. Table 59 shows the actual rainfall intensities applied to the test bed, the corresponding volumes of applied rainfall, volumes of collected base flow, and the antecedent moisture conditions. The percentage of collected base flow to applied rainfall ranged between 26 to 29 percent; that means both the soil and sod retained and/or used up about 70 percent of the applied water since there was no runoff. The high percentage of retained water may be due to the low antecedent moisture contents of the soil.

Table 59: Volumes of Rainfall Applied, Runoff, and Base Flow Collected on A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

Intended rainfall intensity [in/hr]	**0.25**	**0.25**
Test Day	**Day One**	**Day Seven**
Average actual intensity [in/hr]	0.25	0.22
Flow Volumes in Liters (L)		
Applied	280.8	311.5
Base flow Collected	82.3	81.5
Soil Moisture Content [%]	9.68	8.31

Table 60 presents the average chemical parameters of the measured concentrations of total solids, alkalinity and pH values in both tests. The concentration of total solids ranged from 473 to 482 mg/L, alkalinity was from 265 to 268 mg/L (as $CaCO_3$), and pH values from 8.31 to 9.68, which are indicative of the basicity of the system. The total solids and alkalinity parameters did not vary significantly between both days.

Table 60: Total Solids, Alkalinity, and pH in Tests on A-3 Soil, Argentine Bahia, and 10-10-10 Fertilization Practice (Seven-Day Test)

Rainfall Intensity [in/hr]	**0.25**	**0.25**
Test Day	**Day One**	**Day Seven**
Total Solids [mg/L]	473	482
Alkalinity [mg/L]	268	265
pH	7.3	7.1

The applied mass of total nitrogen was 27.2 g as N, and that of total phosphate was 27.2 g as PO_4^{3-} for the day-one tests, only. Table 61 provides a summary of the total nitrogen (TN) and phosphate (TP) collected on each day of testing from base flow. The mass of TN collected on day 7 was about 27% more than what was collected on day one, which may be indicative of the conversion of ammonia to nitrate that then leached out through base flow on day 7. There was no significant change in the mass of TP collected and it may be due to adsorption of the nutrient in the soil body.

Table 61: Distribution of Nutrient Loss between Runoff and Base Flow on A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

Rainfall Intensity [in/hr]	0.25	0.25
Test Day	**Day One**	**Day Seven**
TN Mass (g)		
Base flow	0.27	0.37
Runoff	0.00	0.00
Total	0.27	0.37
TP Mass (g)		
Base flow	0.005	0.003
Runoff	0.000	0.000
Total	0.005	0.003

Both Figure 45 and Figure 46 present the graphical representation of the loss of total nitrogen (TN in base flow) and total phosphate (TP in base flow), respectively, between day one and day 7. The loss in TN increased with time because of the conversion of ammonia to nitrate, and the loss in TP decreased with time. These were the expected responses since there was no additional fertilization after the day one fertilizer application.

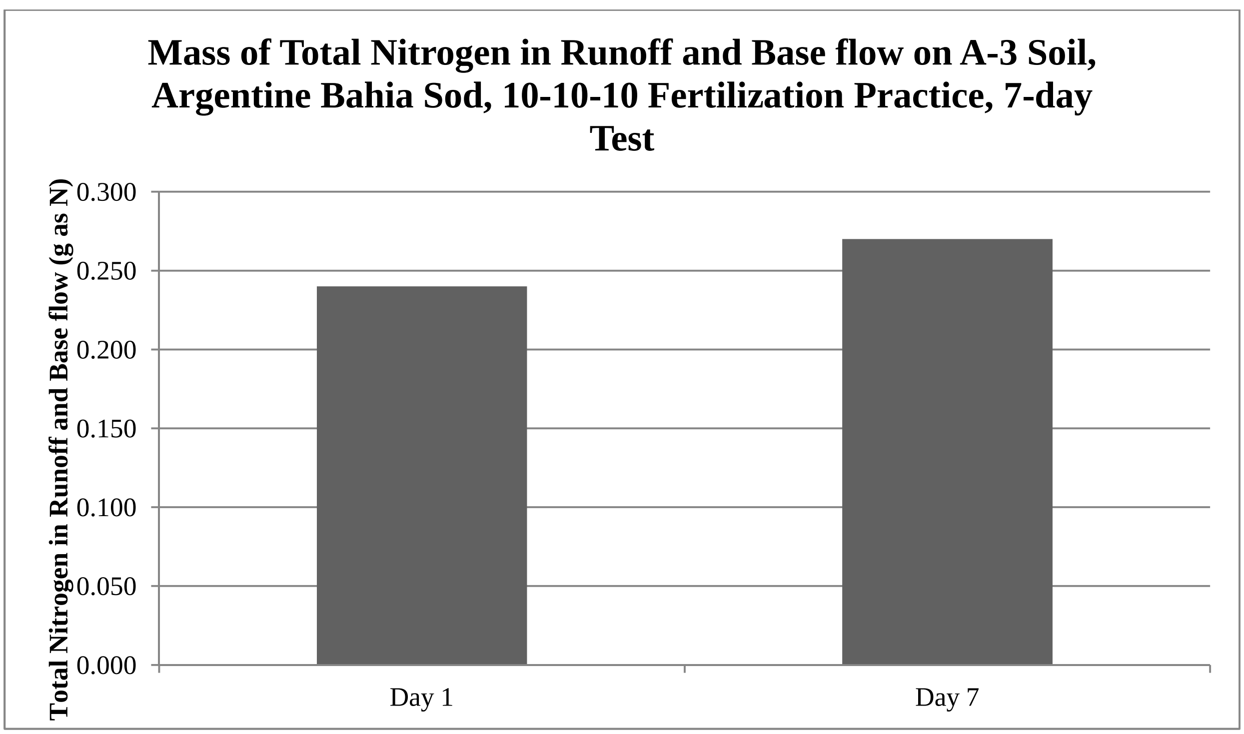

Figure 45: Mass of Total Nitrogen (TN) Collected – A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

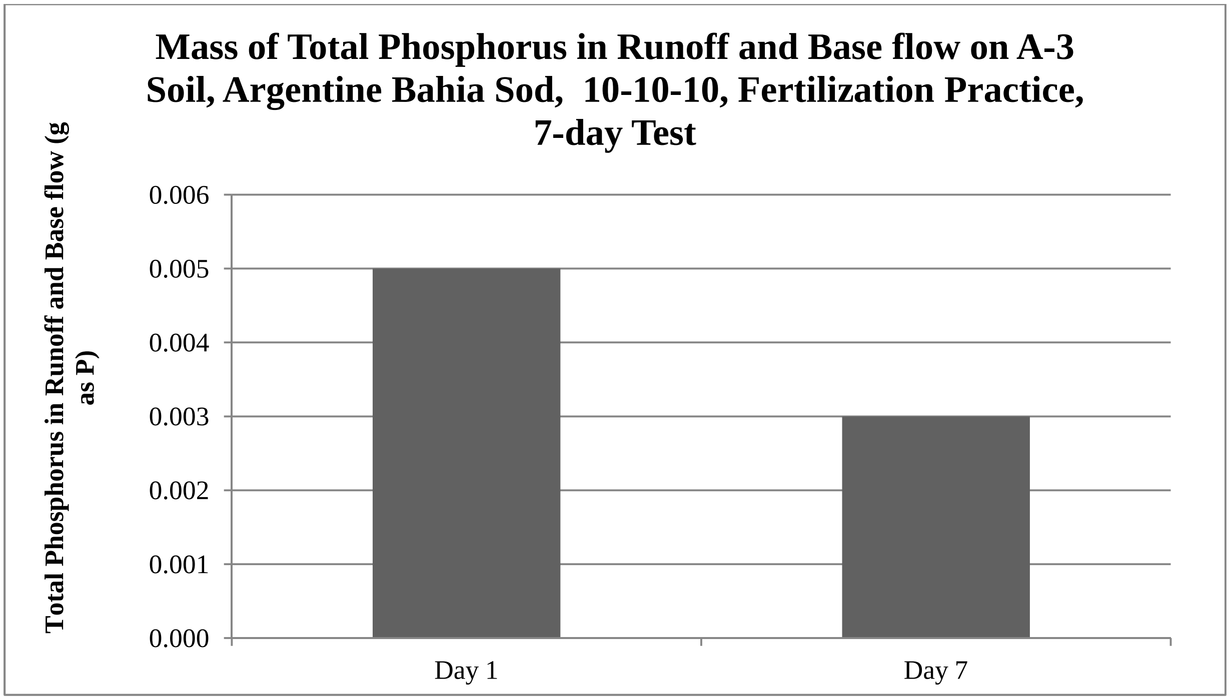

Figure 46: Mass of Total Phosphate (TP) Collected – A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice (Seven-Day Test)

4.10.4 16-0-8 (SR) N-P-K Fertilization Practice @ 0.5 lb of N per 1000 ft^2 (Seven-Day Test)

There were two tests performed for the seven-day tests and none for the one-day test because of equipment downtime. Thus, the discussions are only on the seven-day test results Table 62 shows the actual rainfall intensities applied to the test bed, the corresponding volumes of applied rainfall, volumes of collected base flow and antecedent moisture conditions. There was no runoff collected on both days of testing. The relatively low volume of collected base flow on day 7 was due the moisture content of the soil prior to testing and the soil infiltration rate.

Table 62: Volumes of Rainfall Applied, Runoff, and Base Flow Collected on A-3 Soil, Argentine Bahia Sod, and 16-0-8 Fertilization Practice (Seven-Day Test)

Intended rainfall intensity [in/hr]	**0.25**	**0.25**
Test Day	**Day One**	**Day Seven**
Average actual intensity [in/hr]	0.26	0.27
Flow Volumes in Liters (L)		
Applied	361.0	379.9
Base flow Collected	86.8	55.1
Soil Moisture Content [%]	13.5	8.96

Table 63 presents the average chemical parameters of the measured concentrations of total solids, alkalinity and pH values in both tests. The alkalinity was from 164 to 182 mg/L (as $CaCO_3$), and pH values from 7.3 to 7.4, which are indicative of the chemical neutrality of the system. The measurement of the concentration of total solids on day one of testing is missing due to experimental errors. Both alkalinity and pH parameters did not vary significantly between both days of testing.

Table 63: Total Solids, Alkalinity, and pH in Tests on A-3 Soil, Argentine Bahia, and 16-0-8 Fertilization Practice (Seven-Day Test)

Rainfall Intensity [in/hr]	**0.25**	**0.25**
Test Day	**Day One**	**Day Seven**
Total Solids (mg/L)	--	268
Alkalinity (mg/L)	182	164
pH	7.4	7.3

Table 64 provides a summary of the masses of total nitrogen (TN) and total phosphate (TP) collected in base flow on both days of testing. There was no change in phosphorus over the course of seven days because the fertilizer mix used contained no phosphorus, which resulted in the low TP masses collected. The mass of TN collected decreased from day one to day seven due to the low volume of base flow collected on day 7, soil adsorption, and sod utilization between day one and seven.

Table 64: Distribution of Nutrient Loss between Runoff and Base Flow on A-3 Soil, Argentine Bahia Sod, and 16-0-8 Fertilization Practice (Seven-Day Test)

Rainfall Intensity [in/hr]	0.25	0.25
Test Day	**Day One**	**Day Seven**
TN Mass (g)		
Base flow	0.80	0.19
Runoff	0.00	0.00
Total	0.80	0.19
TP Mass (g)		
Base flow	0.003	0.003
Runoff	0.000	0.000
Total	0.003	0.003

Figure 47 presents the graphical representation of the loss of total nitrogen (TN in base flow) between day one and day 7. The loss in TN mass decreased with time because of the low volume of base flow and no runoff collected. Furthermore, the trend may be due to local or temporal issues, such as unintended fertilizer concentration/dilution in the test bed, unintended sample concentration, or under/over estimation by laboratory equipment.

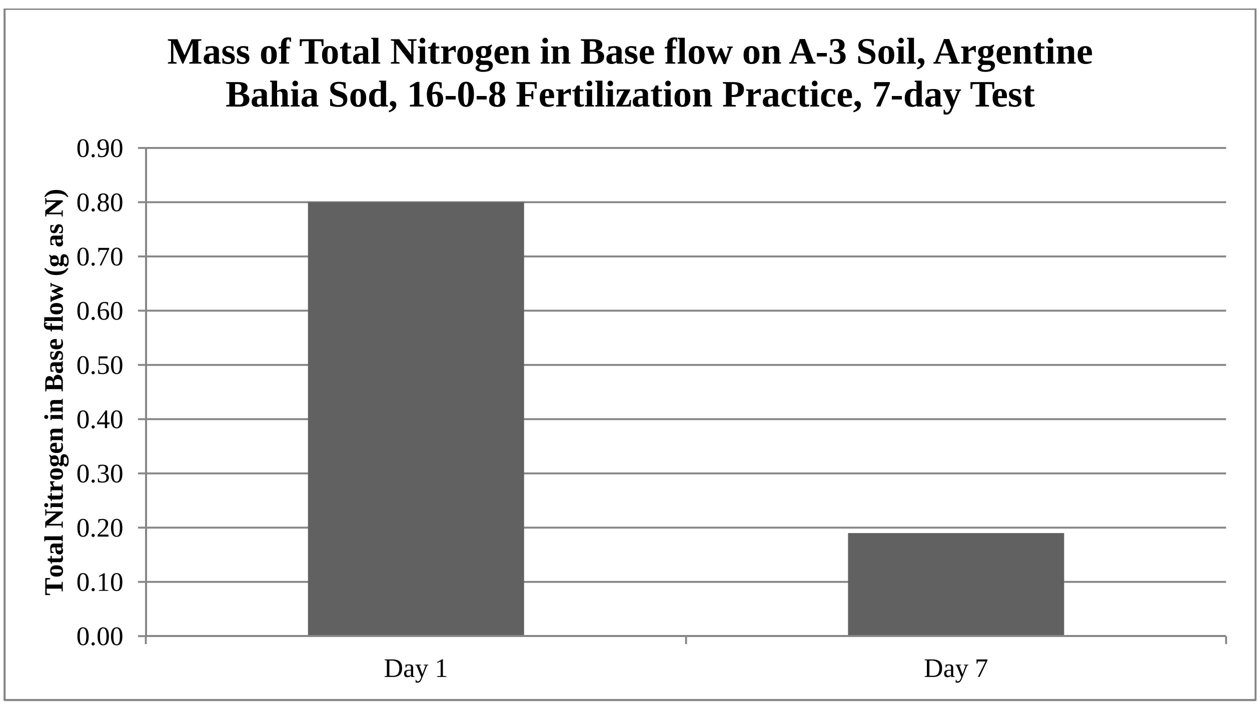

Figure 47: Mass of Total Nitrogen (TN) Collected – A-3 Soil, Argentine Bahia Sod, and 16-0-8 Fertilization Practice (Seven-Day Test)

4.11 AASHTO A-3 Soil with Argentine Bahia Sod –Soil Results

In addition to effluent from the test bed, the study evaluated soil samples collected from the test bed prior to testing for the no-fertilization practice and testing (before and after) for the fertilization practices. The analyses conducted were to determine the amount of total nitrogen and total phosphorus present, and the soil cation exchange capacity before and after fertilization. The subsequent sections present and discuss the results of the soil analyses for the no-fertilization and both fertilization practices (10-10-10 and 16-0-8). The chronological order of testing was such that the 0.25 in/hr intensity tests were performed before the 0.1 in/hr intensity tests.

4.11.1 No Application of Fertilizer

Table 65 presents the average mass of total nitrogen (TN) and total phosphate (TP) retained and the cation exchange capacity of A-3 (sandy) soil prior to the application of 10-10-10 fertilization for both rainfall intensities tested. The average values of all of these parameters did not vary significantly between intensities. However, the high values of TN and TP indicate that the soil and/or sod were preloaded with nutrients. The average CEC of the unfertilized A-3 soil, prior to the application of 10-10-10, was approximately 0.12 meq/g, which is indicative of high cation exchange capacity soil.

Table 65: Total Nitrogen, Total Phosphorus, and CEC in Tests on A-3 Soil, Argentine Bahia Sod, and No Fertilizer prior to 10-10-10 Fertilization Practice

Rainfall Intensity [in/hr]	0.10	0.25
Total Nitrogen [g]	6637	6650
Total Phosphorus [g]	2474	2279
CEC [meq/g]	0.121	0.121

On the other hand, Table 66 presents the average mass of total nitrogen (TN) and total phosphate (TP) retained and the cation exchange capacity of A-3 (sandy) soil prior to the application of 16-0-8 fertilization for both rainfall intensities tested. The high values of TN and TP is indicative of a soil and/or sod preloaded with nutrients. Based on the chronological order for testing, the assumption is that the nutrients leached off the test bed before any form fertilization. The cation exchange capacity was between 0.065 to 0.076 meq/g, which is indicative of high cation loading in this soil type.

Table 66: Total Nitrogen, Total Phosphorus, and CEC in Tests on A-3 Soil, Argentine Bahia Sod, and No Fertilizer (prior to 16-0-8 Fertilization Practice)

Rainfall Intensity [in/hr]	0.10	0.25
Total Nitrogen [g]	7668	9162
Total Phosphorus [g]	511	611
CEC [meq/g]	0.065	0.076

4.11.2 10-10-10 N-P-K Fertilization Practice @ 0.5 lb per 1000 ft^2 (One-Day Tests)

Table 67 presents the average mass of total nitrogen (TN) and total phosphate (TP) retained and the cation exchange capacity of A-3 (sandy) soil after the application of the 10-10-10 fertilizer and simulated rainfall testing for both rainfall intensities. The values of TN and TP were slightly higher for these testing conditions than measured in the no-fertilization tests for both rainfall intensities. The chronology of testing caused increase in the nutrient level of the soil. The increased level of nutrients at the 0.1 in/hr rainfall intensity shows fertilizer build-up in the soil due to the earlier 0.25 in/hr rainfall intensity tests and the reduced capacity to leach through the soil because of the low rainfall intensity of 0.1 in/hr. However, the masses of TN and TP decreased after testing except for TN in the 0.10 in/hr rainfall intensity tests that showed incremental increase. The CEC values remained approximately the same, before and after tests, for both rainfall intensities, which does not show any form of cation exchange capacity utilization.

Table 67: Total Nitrogen, Total Phosphorus, and CEC in Tests on A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

Rainfall Intensity [in/hr]	0.10	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

4.11.3 16-0-8 N-P-K Fertilization Practice @ 0.5 lb per 1000 ft^2 (One-Day Tests)

Table 68 presents the average mass of total nitrogen (TN) and total phosphate (TP) retained and the cation exchange capacity of A-3 (sandy) soil after the application of the 16-0-8 fertilization and simulated rainfall testing for the 0.25 in/hr rainfall intensity. The tests for the 0.10 in/hr rainfall intensity are inconclusive for the A-3 soil and argentine Bahia sod because of equipment downtime. The reduction in the masses of TN and TP in the soil, before and after testing, is indicative of the washing out of nutrients during tests. The cation exchange capacity is lower than the no-fertilization tests, which is indicative of a decline in exchangeable cations used up from the additional cations introduced into the soil during fertilization.

Table 68: Total Nitrogen, Total Phosphorus, and CEC in Tests on A-3 Soil, Argentine Bahia Sod, and 16-0-8 Fertilization Practice

Rainfall Intensity [in/hr]	0.10	0.25
Total Nitrogen Before Test [g]	n/a	9966
Total Nitrogen After Test [g]	n/a	8013
Total Phosphorus Before Test [g]	n/a	799
Total Phosphorus After Test [g]	n/a	690
CEC Before Test [meq/g]	n/a	0.05
CEC After Test [meq/g]	n/a	0.05

4.11.4 Cation Exchange Capacity of A-3 over Time

Figure 48 presents the cation exchange capacity of A-3 soil and Argentine Bahia sod with no fertilization and 10-10-10 fertilization practice. The changes observed in the CEC of the soil do not show a linear trend but varied with the tests. Generally, the CEC dropped with each 10-10-10 fertilization practice test. Figure 49 also showed the same decreasing trend with the 16-0-8 fertilization practice tests, which is indicative of the utilization of the additional cations in the soil by fertilization or decline in the pH of the soil because of nitrification and the subsequent release of H^+ ions, which also decreases CEC.

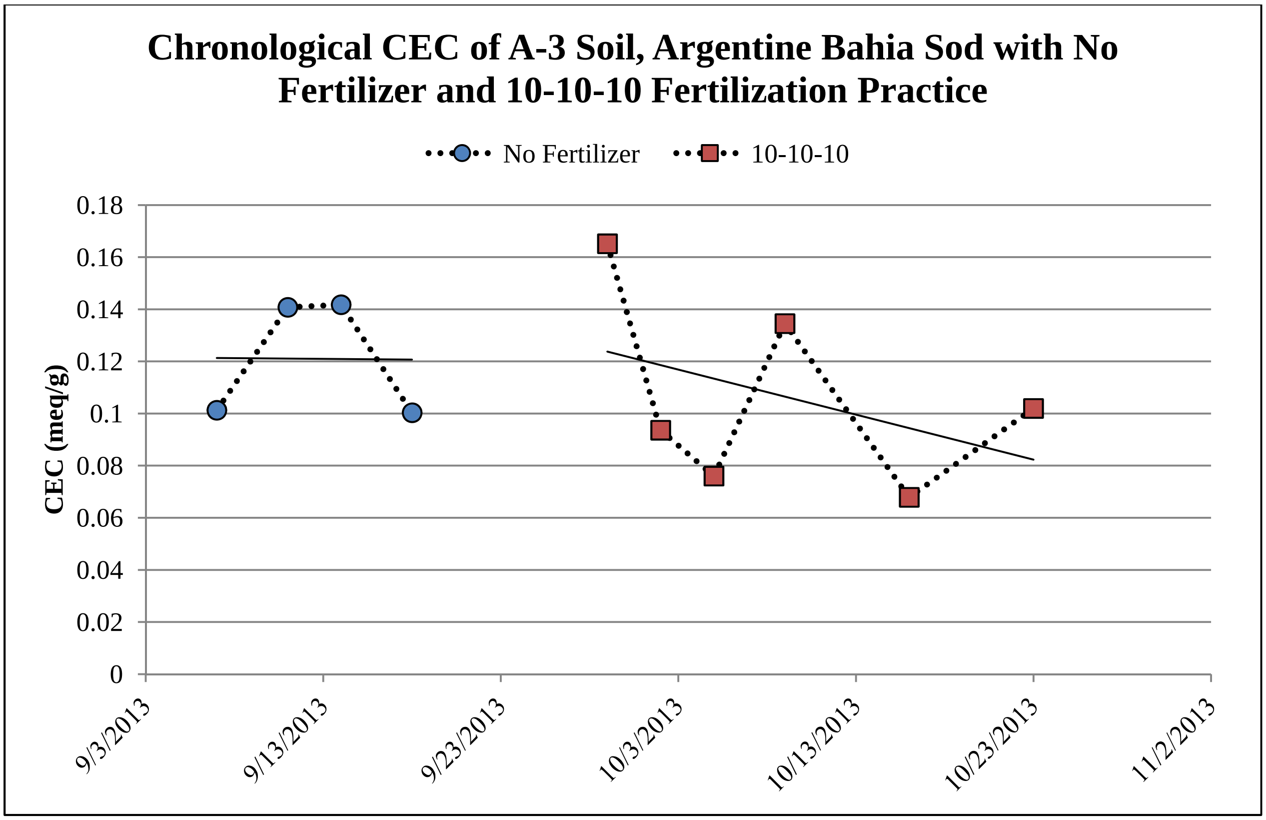

Figure 48: Chronological Sequence of CEC in Tests on A-3 Soil, Argentine Bahia Sod, and No Fertilizer and 10-10-10 Fertilization Practice

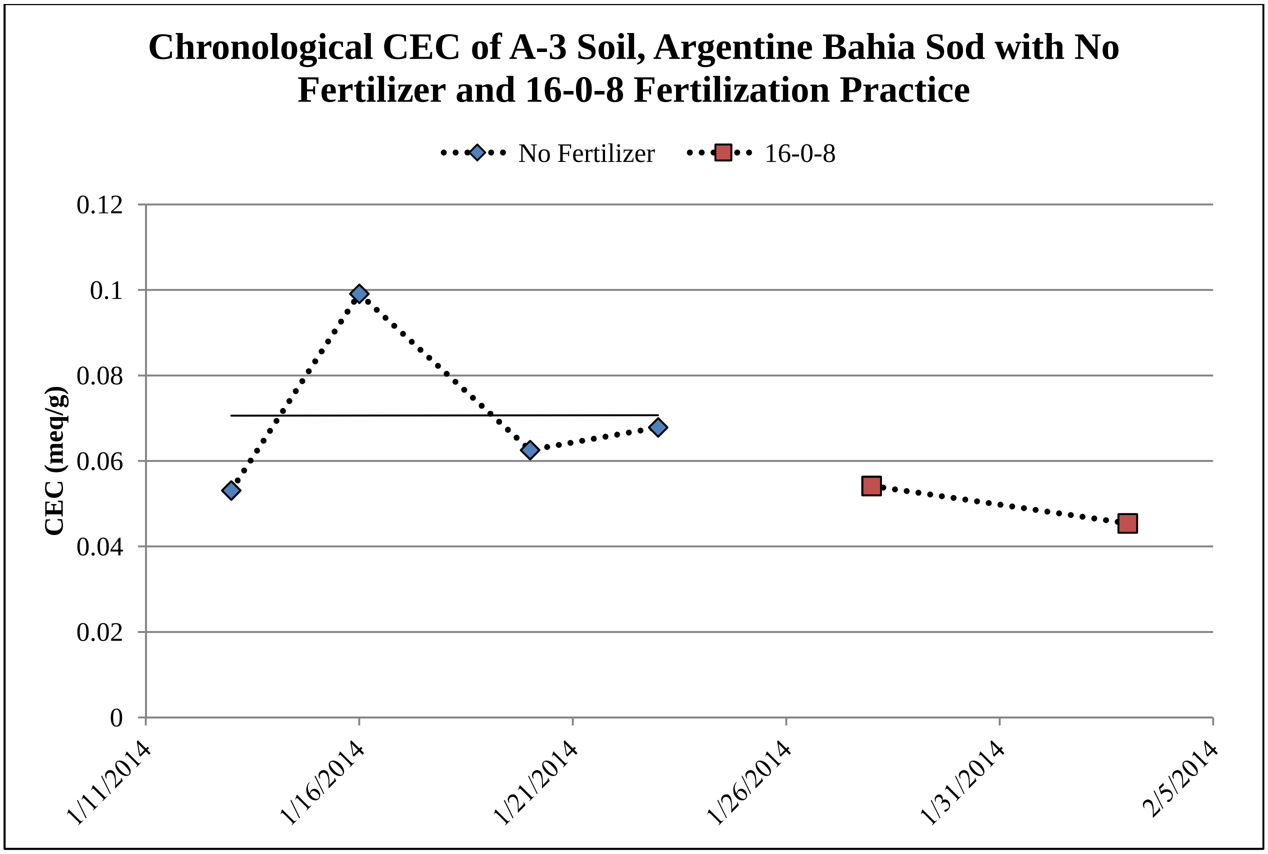

Figure 49: Chronological Sequence of CEC in Tests on A-3 Soil, Argentine Bahia Sod, and No Fertilizer and 16-0-8 Fertilization Practice

CHAPTER 5. MASS BALANCE OF NUTRIENTS

The applied fertilizer nutrients and naturally occurring nutrients continuously undergo several transformations by the physical, chemical, and biological processes in soil. These transformations make them exist in states between soluble or insoluble, fixed or free with respect to soil particles and intra-porous material. This results in changing their probability of being carried away by runoff or base flow. These factors are important to this study, as they have affected the availability of nutrients for wash out owing to the energy of runoff and base flow created by the simulated rainfalls.

The purpose of conducting moisture and nutrient mass balance analyses is to estimate the total nutrient available in the test bed at the commencement of each test. The mass of a particular nutrient washed out in any test, when expressed as a percentage of the estimated total available mass of that particular nutrient, shall serve as a rational basis for comparing the effects of fertilizer type, slope, soil gradation, and rainfall intensity.

5.1 Limitations of the Moisture and Nutrient Mass Balance Analyses

The mass balance analyses of the water content and nutrients in the test bed (for the four soil-turf combinations used in this study) are limited in quality by the empirical and mechanistic models available in the literature, a host of parametric values again borrowed from literature, and simplistic models that were proposed for this study as described in this chapter. The theoretical models in the literature were developed mostly based on studies conducted with quick release composite fertilizers, different soils, and for purposes other than highway fertilization, such as home lawns and golf courses with high-quality turfs and agricultural applications. In addition, the weather data used in this study are the average values obtained from the archival data of the nearest weather station. They may not truly represent the actual conditions at the test site.

A brief description of the transformation and transport processes of nitrogen (Hutson and Wagenet, 1991; Paramasivam, 2000; Singh and Sondhi, 2001; and Follett, 2008) and those of phosphorus (Greenwood et al., 2001a; Karpinets et al., 2004; and Vadas et al., 2008) was given in chapter 2. The transformations of nitrogen, that is, ammonia volatilization, nitrification, mineralization, and denitrification are greatly influenced by the temperature, soil aeration, pH, and microbial activity. The uptake of nutrients by the plants is subject to the age of the vegetation, the level of root establishment, seasonal parameters such as day light hours and temperature, and soil moisture.

Other important factors that governed the nutrient losses were the particle size distribution and solubility of the fertilizer in comparison to the corresponding characteristics of the soil-turf system, and the kinetic and impact energy of water. Some forms of nitrogen and phosphorus carry positive charges (cations) and get strongly attracted to the negatively charged soil surfaces. This issue did not considerably influence the results of this study as clean sand (A-3) and silty sand (A-2-4) were used, which did not contain considerable clay fractions. Table 69 presents a detailed description of the influencing parameters, which is followed by an explanation of how they were taken into account in this study.

The effect of wind speed was eliminated by measuring the actual rainfall on the test bed using twelve rain gauges, and using the average value in subsequent calculations and analysis. The test bed dimensions and test durations were kept constant for all the tests. The same A-3 soil and A-2-4 soil were used for all tests for keeping the gradation constant. Both soils contained negligible clay fraction, thus minimizing the mineralogical and surface area effects of nutrient adsorption. All the soils were compacted until unit weight measured using the nuclear density gauge was similar. Argentine and Pensacola Bahia sods were procured from the same source to maintain uniformity of species and nursing. In all the cases, the sod was established following the same method, and tests were conducted after a period of at least three weeks, thus allowing sufficient time for root penetration and decimation of any gap between sod and soil.

Table 69: Factors that Governed the Nutrient Balance in this Study

No.	Parameter	Influencing Mechanism
		Weather and Seasonal
1.	Higher Temperature	• Decreases vapor pressure; so low pressure water exiting the simulator may vaporize more easily; reduces the actual rainfall measured on the bed compared to intended rainfall • Increases evaporation from soil pores and grass • May enhance ammonia volatilization of fertilizers • May enhance other nitrogen transformations • Reduces water's viscosity, so increase permeability • Increase nutrient uptake by plants due to better photosynthesis
2.	Higher Wind Speed	• May splash outside the test bed; so reduces the actual rainfall measured on the bed compared to the intended rainfall • Increases evaporation
3.	Longer Daylight Hours	• Increases nutrient uptake by plants due to better photosynthesis
4.	Natural Precipitation	• Increases soil saturation • Increases nutrient loss in base flow and in runoff
		Soil Gradation and Compaction
5.	Coarser Gradation	• Increases permeability, ratio of base flow to run-off , and nutrient losses in base flow • Decreases the nutrient-soil interactions and increases nutrient loss • Increases ammonia volatilization • Increases root growth and nutrient uptake by plants
6.	Highway Compaction vs. Agricultural Tillage	• Compaction for improving strength and stiffness of highways, and no tillage of side slopes Result: less aeration of soils, lower root growth. • Reduced infiltration and fertilizer entry into soils. More loss of nutrients in increased run-off. • Anaerobic conditions → denitrification and gaseous N loss
7.	Higher Clay Content	• Increases CEC value, increasing adsorbed $NH_4$and P • Decreases permeability, thus decreasing the infiltration and loss of nutrients including nitrates

8.	Higher Soil Saturation	• Increases runoff and loss of nutrients • Creates anaerobic conditions for denitrification
Pore Water Conditions		
9.	pH	• Above 6, increases ammonia volatilization • Governs many soil-water processes
10.	Suspended Solids	• May adsorb nutrients (ammonium and phosphorus) and carry them with run-off and leachate
Simulated Rainfall		
11.	Higher Intensity	• Increases runoff and base flow volumes; also, flow velocities, and dissolution of nutrients
12.	Higher Duration	• Soil reaches saturation, and increases the run-off
Test Bed		
13.	Steeper Slope	• Increases run-off and energy for nutrient dissolution and transport
14.	Test bed Dimensions	• The 30 ft. length is a typical value of highway slopes; provides opportunities for re-capture of released nutrients and suspended solids • The one foot depth is too small for real world; vertical seepage from highways may have to travel several meters before reaching groundwater.

As the test beds were exposed to the atmosphere, the soil moisture and associated nutrient transformation and transport processes varied during the experimental investigations that took a few months for each soil-sod combination that was set up in the test bed. The soil moisture content depended on the evapotranspiration, natural rainfall between the test dates, and the simulated rainfall including the pre-irrigation and post-flush events. Figure 50 shows the schematic processes. As evapotranspiration and nutrient dynamics are highly influenced by the weather conditions, the daily values of mean temperature, day light duration in hours, and precipitation from archival weather data were obtained. These figures were obtained for all days on which the soil-sod combination existed in the test bed, i.e., including the days of the test. In this study, the soil moisture content of the test bed was considered uniform on any specific day, which is justified as our test bed is only one ft. (0.3 m) thick.

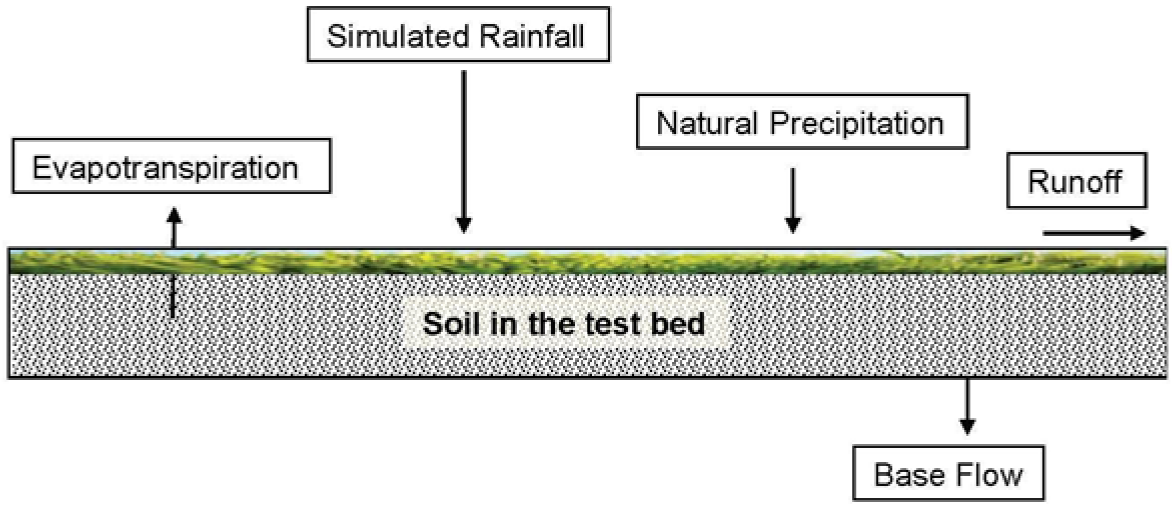

Figure 50: Mass Balance of Moisture in the Test Bed

Imrak et al. (2005) used modified Bellani plate gauges for measuring evapotranspiration (ET) from Bahia grass fields at the Plant Science Research and Education Unit of the University of Florida located in Citra, Florida. That location is close to Orlando, FL, where the current research study was conducted. As their mean temperature values, day light duration, grass type, and soil conditions are very similar, the observed range of ET data, viz., one to six mm per day has been adopted in this study. However, considering the mean temperatures and day light durations observed during the days of the experimental investigations, a mathematical function for estimating the ET on a given day was used in this study:

$$ET = a + k(T - T_{\min})^b (D - D_{\min})^c \quad \textbf{(5.1)}$$

where ET is evapotranspiration rate in mm per day, T is temperature in ^{o}F, D is day light duration in hours, and a, b, c, and k are empirical constants.

Based on archival weather data for Orlando, it is assumed that the mean annual maximum and minimum temperatures are 90^{o}F and 50^{o}F, respectively, and the mean annual maximum and minimum day light durations are 15 hours and 11 hours, respectively. For the observed range of

ET data, i.e., one to six mm per day, assuming linear relationship (b = c = 1), the values of "a" and "k" are worked out. This resulted in the final mathematical function for estimating the ET on a given day to become:

$$ET = 1 + 0.03125(T - 50)(D - 11) \qquad \textbf{(5.2)}$$

The actual average soil moisture content was measured at the commencement of each test, by collecting several soil samples, oven-drying, and taking the average to obtain the overall test bed value. The average moisture content on all other days was estimated by analyzing the moisture balance considering:

1) the actual average moisture contents determined before the commencement of each test;
2) the natural precipitation on all days;
3) the evapotranspiration on all days considering the daily mean temperature and day light duration; and
4) the volumes of water applied and collected during simulated rainfalls, including the pre-irrigation and post-flush events.

Based on the compacted soil density and saturated water content, this analysis has also yielded the cumulative seepage from the test bed during the period between the tests. Because the test bed was kept horizontal between tests and there was free board covered by turf grass, it was assumed that there was no runoff between the tests. The daily average moisture content was used to calculate the soil air content, which is important, as some of the nitrogen transformations are dependent on aerobic or anaerobic conditions.

5.2 Transformations and Transport of Nitrogen

Follett (2008) published a very comprehensive review of the various transformations governing the transport and fate of nitrogenous compounds in soil systems. Temperature, day light duration, pH, soil air content, moisture dynamics, soil's physic-chemical characteristics and the age and genetic characteristics of soil biota are the prime factors influencing these transformations. Hutson and Wagenet (1991) described a mechanistic mathematical model for quantifying the effects of these transformations and transport processes, viz., ammonia volatilization, nitrification, mineralization and immobilization, denitrification, adsorption by soil and intra-porous matter, plant uptake, consumption and excretion by the soil microbial community, and leaching through base flow and runoff. Figure 51 shows the schematic of the processes.

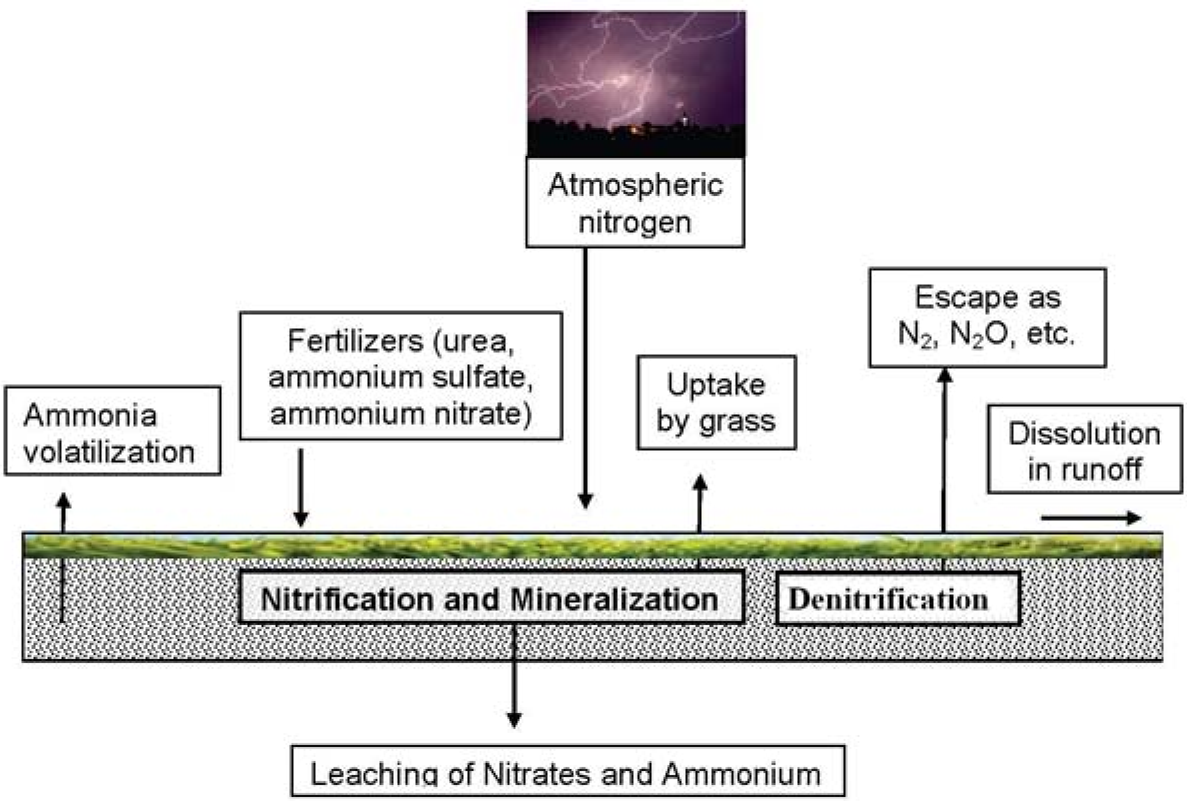

Figure 51: Mass Balance of Nitrogen in the Test Bed

The Leaching Estimation And Chemistry Models (LEACHM), originally proposed and developed by Hutson and Wagenet (1991) was successfully adopted in several subsequent research studies, including Paramasivam et al. (2000) and Singh and Sondhi (2001). Paramasivam et al. (2000) obtained satisfactory results by adopting this model for analyzing the concentrations of nitrogen at various depths in the sandy soil profile of a citrus plantation after applying liquid ammonium nitrate. Incidentally, the experimental site of Paramasivam et al. (2000) was in Lake Alfred, Florida, which is very close to Orlando, Florida. In another satisfactory application of LEACHM, Singh and Sondhi (2001) investigated the fate and transport of urea in a soil profile under winter wheat cultivation in Punjab, India. The soil and weather conditions there are also similar to the corresponding conditions in Florida.

The LEACHM is based on the solution of Richards' equation for moisture transport in the vadose zone, various transformations of nitrogen, and the transport of nitrogen by convection and diffusion. This rigorous solution is specifically advantageous for analyzing the transport and fate of fertilizers in applications where the vertical soil profile varies with depth and there are horizontal variations in the catchment or field scale setup. In this study, the test bed has limited horizontal dimensions, only 12 inches in thickness, and was provided with uniform soil and vegetation conditions. Therefore, an assumption was made that the moisture content, nutrient concentrations, and other physiochemical characteristics are uniform in the test bed. Based on this assumption, the mass balance of nutrients was analyzed for determining the mass of total nitrogen available at the beginning of each simulated rainfall event.

In this analysis, soil moisture and air contents, and the seepage quantity between the tests, as estimated in moisture balance were used. The seepage quantity between the tests was used to estimate the mass of nutrients lost from the test bed. The soil air content was used to modify the rate constants for nutrient transformation processes. Considering the similarity between the soil and weather conditions between Orlando and the project sites of Paramasivam et al. (2000) and Singh and Sondhi (2001), the range of nitrogen transformation parameters from their publications have been adopted. The range of adopted parameters, viz., ammonia volatilization constant (k_{volati}), nitrification constant (k_{nitri}), and denitrification constant ($k_{denitri}$), were adjusted for the weather data observed in Orlando.

Follett (2008) described that ammonia volatilization increases with increase in temperature and pH, with gaseous losses increasing by an order of magnitude for every unit of pH above 6.0. Based on data reported in the literature and experimental observations, a mathematical function for the ammonia volatilization constant (k_{volati}) was adopted as:

$$k_{volati} = \begin{cases} 0 & \text{for pH} \le 6 \\ 0.0001(pH-6)^2(T-50) & \text{for pH} > 6 \end{cases} \quad \textbf{(5.3)}$$

where T is the daily mean temperature (^oF) with its minimum being 50 ^oF, below which the ammonia volatilization ceases.

Nitrification, being an aerobic process, and denitrification, being an anaerobic process, are essentially dependent on soil aeration, which is, in turn, dependent on soil gradation, compaction, moisture content, etc. In a way similar to that of ammonia volatilization constant (k_{volati}), simple mathematical functions for the nitrification constant (k_{nitri}) and the denitrification constant ($k_{denitri}$) were developed as:

$$k_{nitri} = \alpha\theta_{air}^{n} \quad \textbf{(5.4)}$$

$$k_{denitri} = \beta(1-\theta_{air})^{d} \quad \textbf{(5.5)}$$

In the literature, data for the nitrogen uptake rates by Bahia grass in sandy soils for Florida specific variations of day light durations and weather parameters was not found.

Bowman et al. (2002) studied the nutrient uptake by six warm-season turf grasses in sandy soils near Raleigh, North Carolina. Considering the proximity and similarities between North Carolina and Florida, the nutrient uptake by Bahia grass in Florida was assumed based on their data for the Centipede grass. Based on the facts that grasses become dormant in winter, and the Florida's daylight durations vary in a range of 11 to 15 hours, a simple mathematical function was adopted for the total nitrogen uptake by Bahia grass in Florida:

$$U_{TN-Bahia} = 0.555(D - D_{\min}) \quad \textbf{(5.6)}$$

where $U_{TN\text{-}Bahia}$ is the total nitrogen uptake by Bahia grass per test bed (22.2 m^2 area) per day, D is the day light duration in hours, D_{min} = 11 hours for Orlando (on winter solstice). These equations were used for analyzing the mass balance of total nitrogen on daily basis for each soil-sod combination.

5.3 Transformations and Transport of Phosphate

There are several relevant publications on the plant uptake of phosphorus, soil-phosphorus interactions, and leaching of phosphorus (Nye and Tinker 1977, Barber 1984, Chen and Barber 1990, Sharpley 1995, Pote et al. 1996, Greenwood et al. 2001a, Greenwood et al. 2001b, Karpinets et al. 2004, Roose and Fowler 2004, Erickson et al. 2005, Davison et al. 2008, Vadas et al. 2008, and Erickson et al. 2010). Unlike soil nitrogen, the soil phosphorus is not subject to volatilization under atmospheric conditions. However, it may remain in slowly dissolvable suspended mineral particulate form or are strongly adsorbed to soil surfaces depending on the pore water chemistry and soil's physicochemical characteristics. The analysis presented in this report is largely based on the model described by Karpinets et al. (2004), which considers three pools of soil phosphorus, viz., extractable phosphorus (X) that is readily available for plant uptake or leaching, non-extractable phosphorus (Y) that is strongly adsorbed on soil surfaces, and mineral phosphorus that provides solubility-product type buffering of X (P_{buffer}). It is assumed that the applied fertilizer phosphorus is partitioned between X and Y with most of it going to the X pool. The model assumes that the uptake by grass, as well as the leaching and runoff losses, is from the X pool. Figure 52 shows the schematic of the interactions between these three pools and the environment.

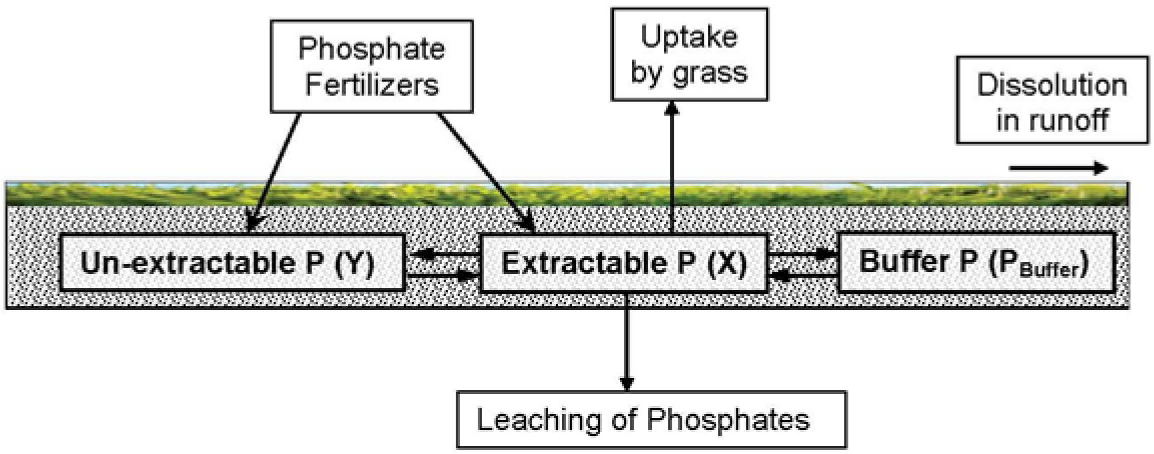

Figure 52: Mass Balance of Phosphate in the Test Bed

Karpinets et al. (2004) validated their model by comparing their model predictions with the data observed in four countries, spread across three continents. One of the field data set was from an experimental study conducted in loamy sand soil in Norfolk, North Carolina. Considering the similarities of this site with the test bed in Orlando, with respect to soil, vegetation, and weather, the rate constants for interactions between different pools of soil phosphorus were adopted. Also, their conclusion that the partitioning of applied fertilizer phosphorus between X and Y pools is in the ratio of X and Y to their total, respectively were followed.

The phosphorus uptake by plants is reported to be much less than that for nitrogen uptake (Nye and Tinker, 1977; Barber, 1984; Chen and Barber, 1990, and Shimozono, 2008). In this study, the total phosphorus uptake by Bahia grass was taken as 20% of the total nitrogen uptake. Based on the facts that grasses become dormant in winter, and the Florida's daylight durations vary in a range of 11 to 15 hours, a simple mathematical function for the total phosphorus uptake by Bahia grass in Florida was adopted:

$$U_{TP-Bahia} = 0.111(D - D_{\min}) \tag{5.7}$$

where $U_{TP\text{-}Bahia}$ is the total phosphorus uptake by Bahia grass per test bed (22.2 m^2 area) per day and D is the day light duration in hours, D_{min} = 11 hours for Orlando (on winter solstice). The phosphorus rate constants, results of the moisture balance analysis, and this equation for TP uptake were used in a spreadsheet for analyzing the mass balance of total phosphorus on a daily basis for each soil-sod combination.

The three mass balance analyses discussed in this sub-section, together with further analysis of mass of nutrients lost in runoff and base flow, are presented in the next sub-sections for all soil-sod combinations that were set up in the test bed.

5.4 AASHTO A-3 Soil with Argentine Bahia Moisture and Nutrient Analyses

5.4.1 Phase #1 Soil-Sod Combination 1 for 10-10-10 Fertilization Practice

The seven tests that were conducted on the soil-sod combination 1 are reproduced from Table 2 and are listed in Table 70. As described before, the moisture balance of this combination was analyzed and is presented in Table 93. The mass balance of total nitrogen (TN) and total phosphate (TP) are also presented in Table 94 and Table 95, respectively.

Table 70: Chronological Sequence of Tests on Soil-Sod Combination 1 – Phase #1

Test #	Soil	Bahia Sod	Fertilizer	Slope	in/hr	Date
1	A-3	Argentine	10-10-10	25%	0.5	5/27/2009
2	A-3	Argentine	10-10-10	25%	1	6/3/2009
3	A-3	Argentine	10-10-10	25%	3	6/10/2009
4	A-3	Argentine	10-10-10	33%	0.5	6/22/2009
5	A-3	Argentine	10-10-10	33%	1	6/29/2009
6	A-3	Argentine	10-10-10	50%	0.5	7/2/2009
7	A-3	Argentine	10-10-10	50%	1	7/6/2009

The total nitrogen mass balance and Figure 53 revealed a few trends about the nitrogen in the system and its fate. The figure shows that TN mass builds up in the soil but can also be released, depending on the conditions. The general trend, however, is for the TN to build up in the system with time and fertilizer application.

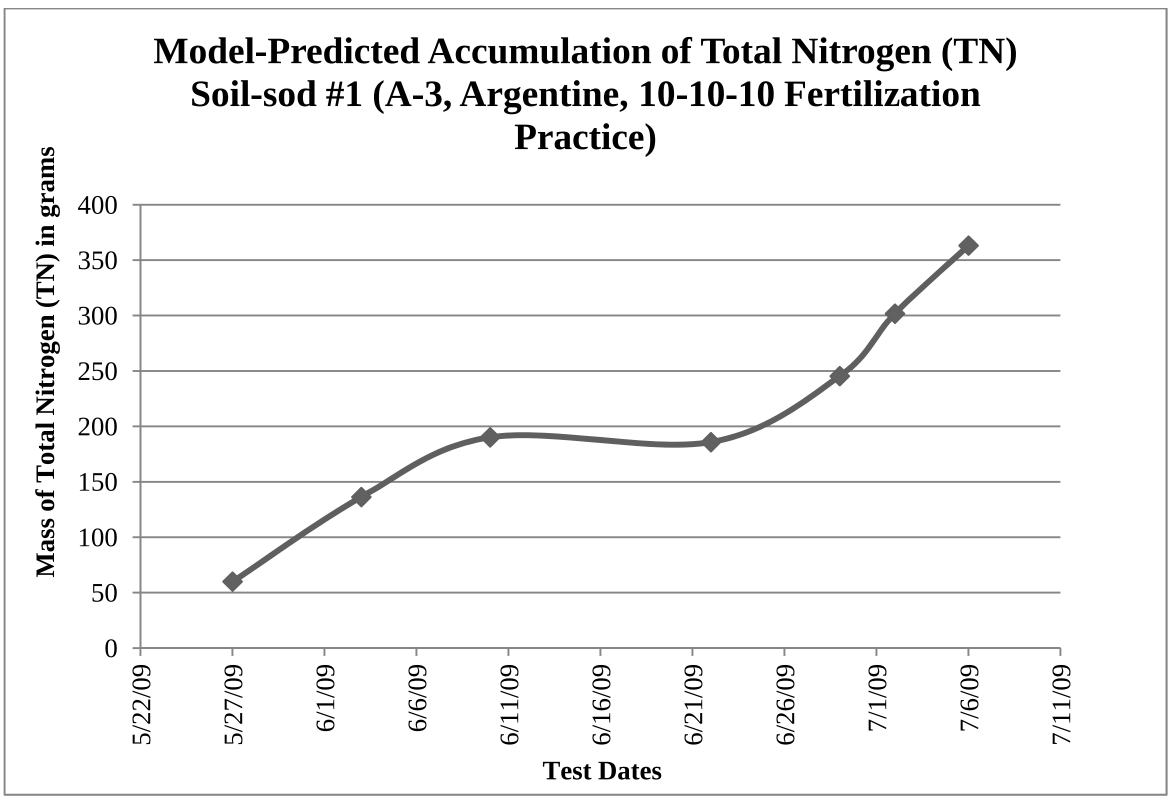

Figure 53: Model-Predicted Accumulation of TN in Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice)

Examination of Figure 54 shows the model prediction of the fate of TN in the system. It can be seen from this figure that denitrification and seepage since the previous test were minor factors in nitrogen loss from the system, accounting for only 2% of the total applied. Ammonia volatilization was shown to be a significant form of mass loss from the system, accounting for about 6% of the total applied. The variables that effect ammonia volatilization are ammonia availability, temperature, and pH.

Nitrogen uptake by grass was also shown to be significant, accounting for 10% of the total applied. Uptake by grass was dependent on number of daylight hours or season. The mass of total nitrogen in the soil generally increased with time and fertilizer application. The mass lost in the flush events after the simulated rain event was also significant, accounting for 9% of the total applied. The total nitrogen mass lost was during the simulated rain event was the most significant, accounting for about 19% of the total applied. This shows that about 53% of the total TN applied remained in the soil. Figure 55 shows the percentage of TN mass lost to the total available. The mass of TN lost from the system increases with rainfall intensity. There was no observable trend with TN mass loss and soil slope.

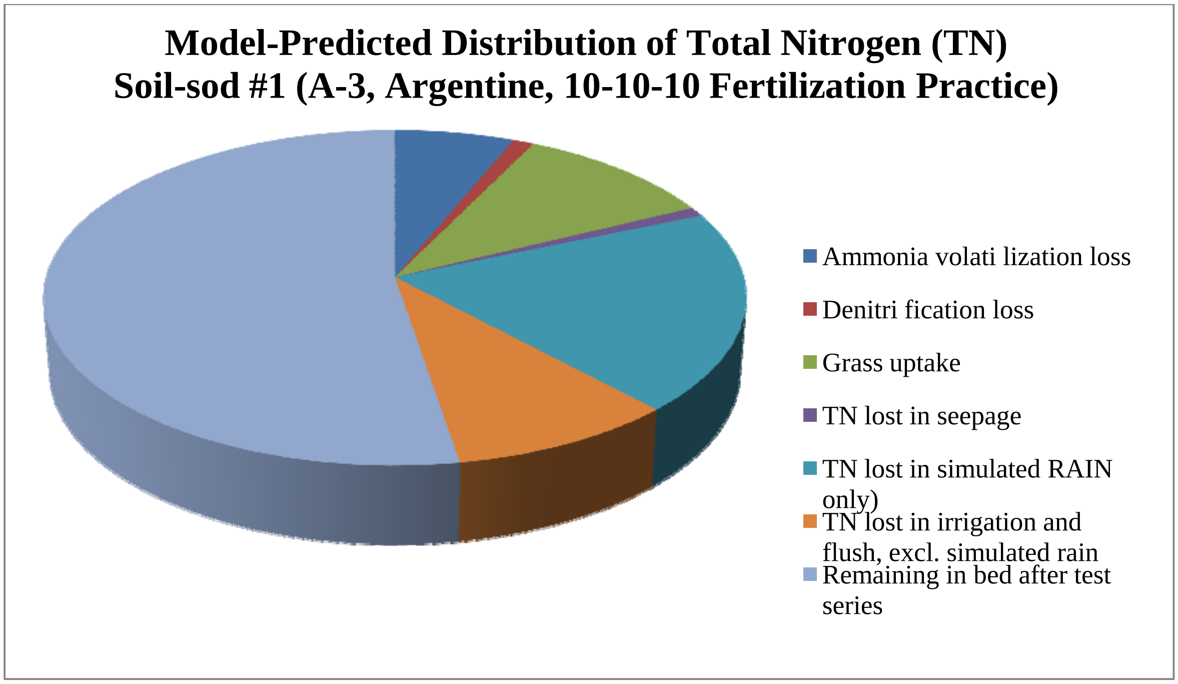

Figure 54: Model-Predicted Distribution of TN for Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice)

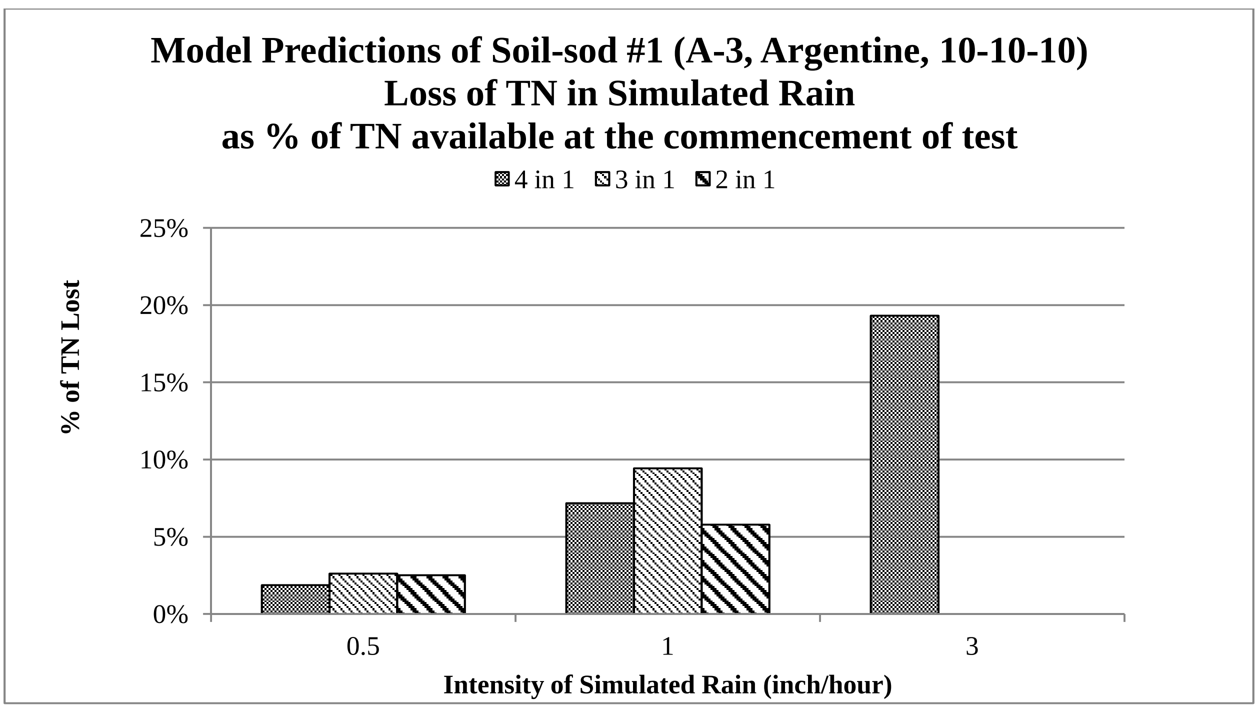

Figure 55: Model Predictions of Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice) Loss of TN in Simulated Rain as a Percentage of TN Available at the Commencement of the Test

The following observations can be made from Figure 56, Figure 57, and Figure 58, about the fate and transport of phosphate in the soil during the test series. The mass of phosphate in the soils built up over time as tests were run and fertilizer was applied (Figure 56). The phosphorus lost via sod uptake, seepage since the previous test, and from the flush events that occurred after the simulated rain event was insignificant and played only a minor role in the mass lost from the system accounting for only about 8% of the total applied (Figure 57). Similar to the total nitrogen mass balance, the mass of phosphate lost during the simulated rain event was a significant accounting for about 15% of the total applied. This resulted in about 78% of the applied TP remaining in the soil. Figure 58 shows that as rainfall intensity increases, the loss of TP from the system also tends to increase. The effect from slope did not show any obvious trends.

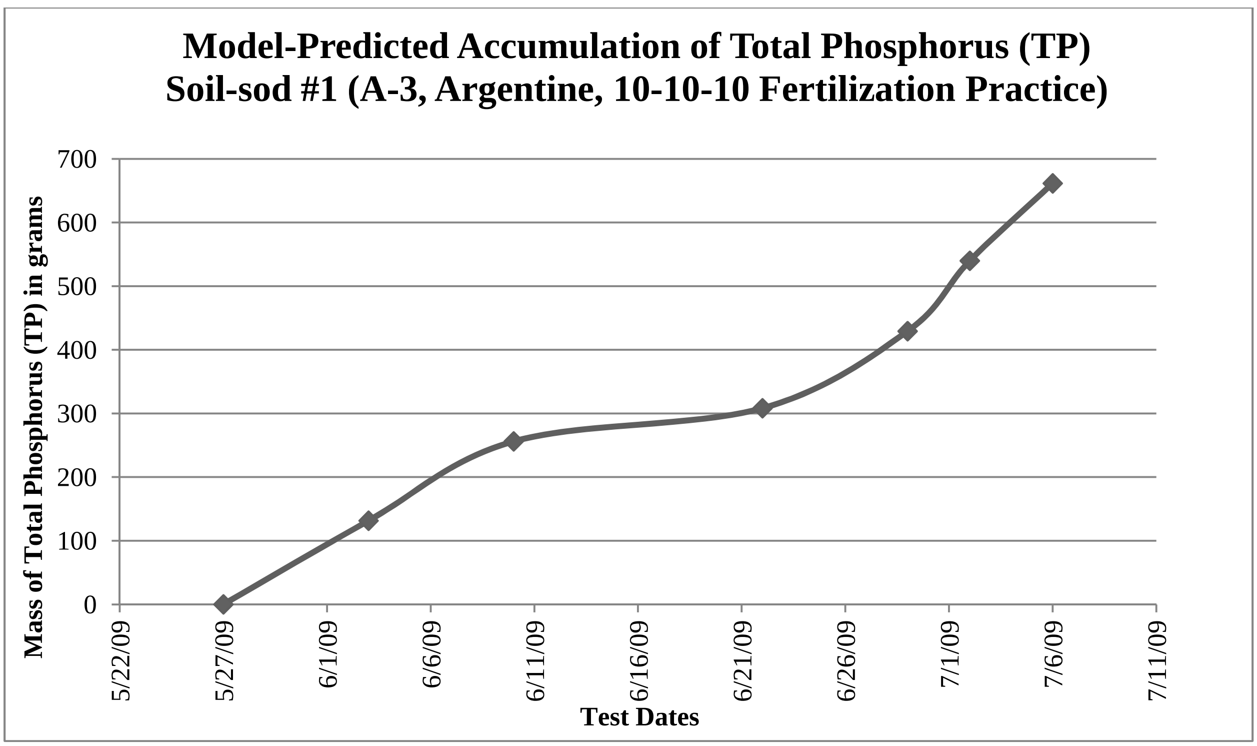

Figure 56: Model-Predicted Accumulation of Total Phosphate (TP) Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice)

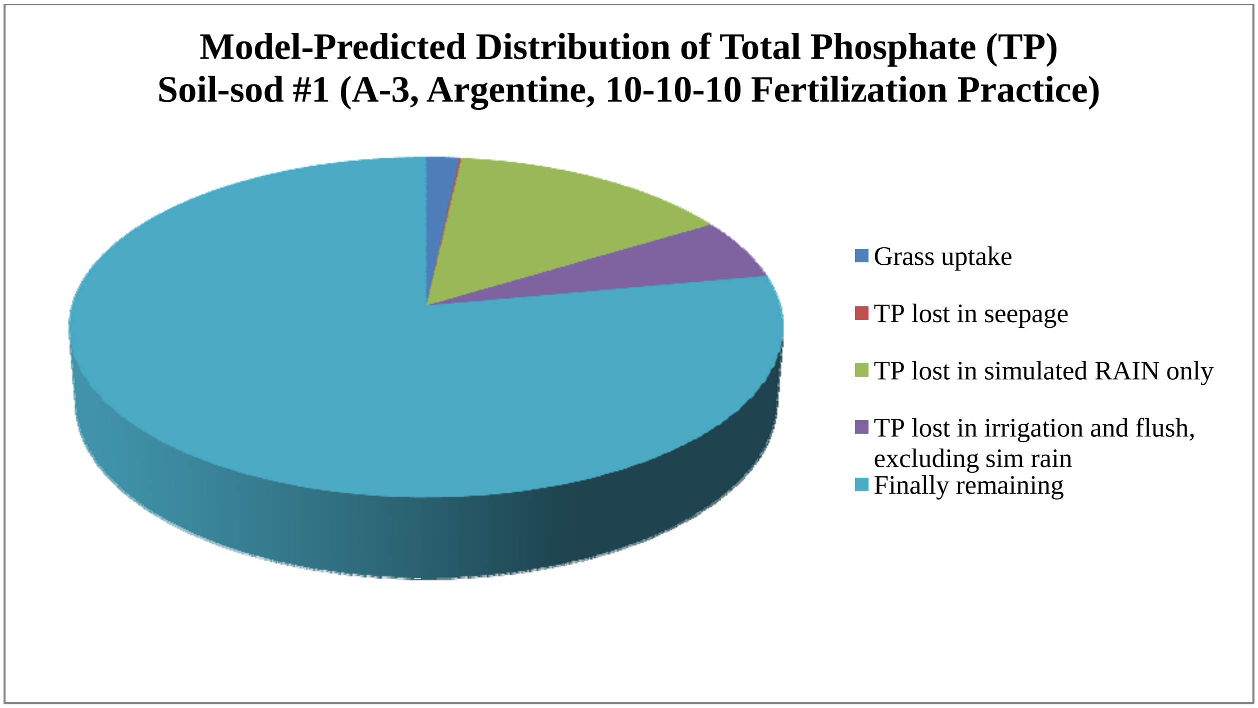

Figure 57: Model-Predicted Distribution of Total Phosphate (TP) for Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

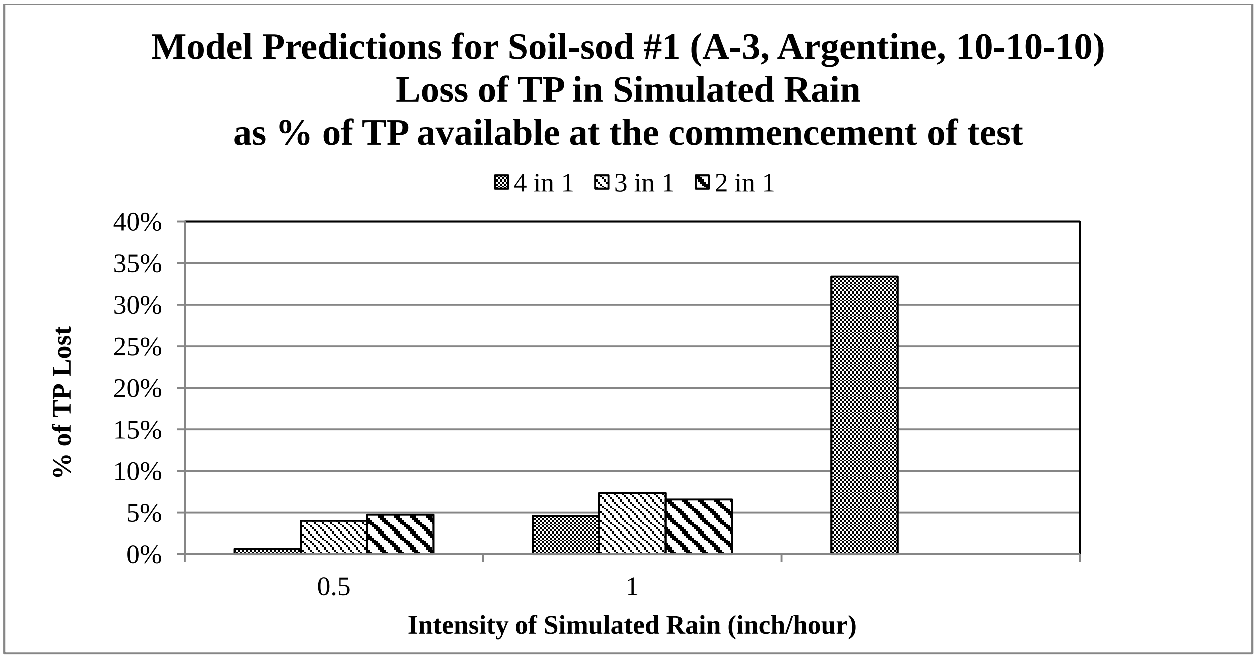

Figure 58: Model Predictions for Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice) Loss of TP in Simulated Rain as a Percentage of TP Available at the Commencement of Test

5.4.2 Phase #2 Soil-Sod Combination 1 for No-Fertilizer and 10-10-10 Fertilization Practice

The 10 tests that were conducted on the soil-sod combination 1 for phase #2 of this study are reproduced from Table 31: Chronological Sequence of Tests and are listed in Table 71. As described before, the moisture balance of this combination was analyzed and is presented in Table 101. The mass balance of total nitrogen (TN) and total phosphate (TP) are also presented in Table 102.

Table 71: Chronological Sequence of Tests on Soil-Sod Combination 1 – Phaes #2

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

The total nitrogen mass balance and Figure 59 revealed a few trends about the nitrogen in the system and its fate. This figure shows that TN mass is slowly released from the soil but stays relatively stable. Additionally, a comparison to measured TN mass values is compared to the values predicted by the model. This shows that while the modeled values give a decent representation of the measured values, the measured values show much more variability. Examination of Figure 60 shows the model prediction of the fate of TN in the system. It can be seen from this figure that grass uptake and TN mass loss in simulated rainfall were minor factors in nitrogen loss from the system accounting for only 6% of the total lost from the test bed. The TN mass loss from irrigation and the flush (excluding the simulated rain event) was shown to be a significant form of mass loss from the system accounting for about 12% of the total lost from the test bed.

TN mass loss due to denitrification was also shown to be significant accounting for about 14% of the total mass lost from the test bed. The most significant pathways for TN mass loss for this test series was through TN mass loss through seepage between tests and ammonia volatilization accounting for 27% and 41% of the TN lost from the test bed. The variables that effect ammonia volatilization are ammonia availability, temperature, and pH.

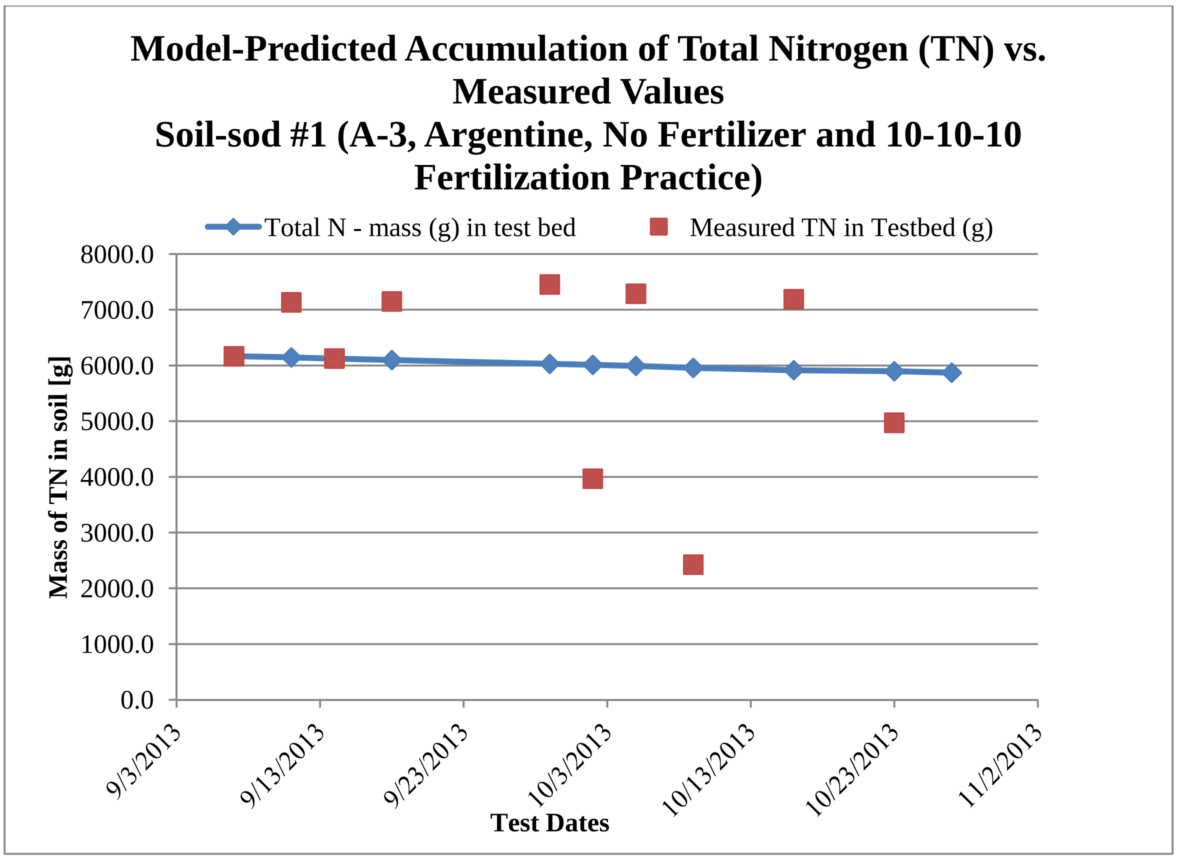

Figure 59: Phase #2 Model-Predicted Accumulation of TN vs. Measured Values in Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, No Fertilizer and 10-10-10 Fertilization Practice)

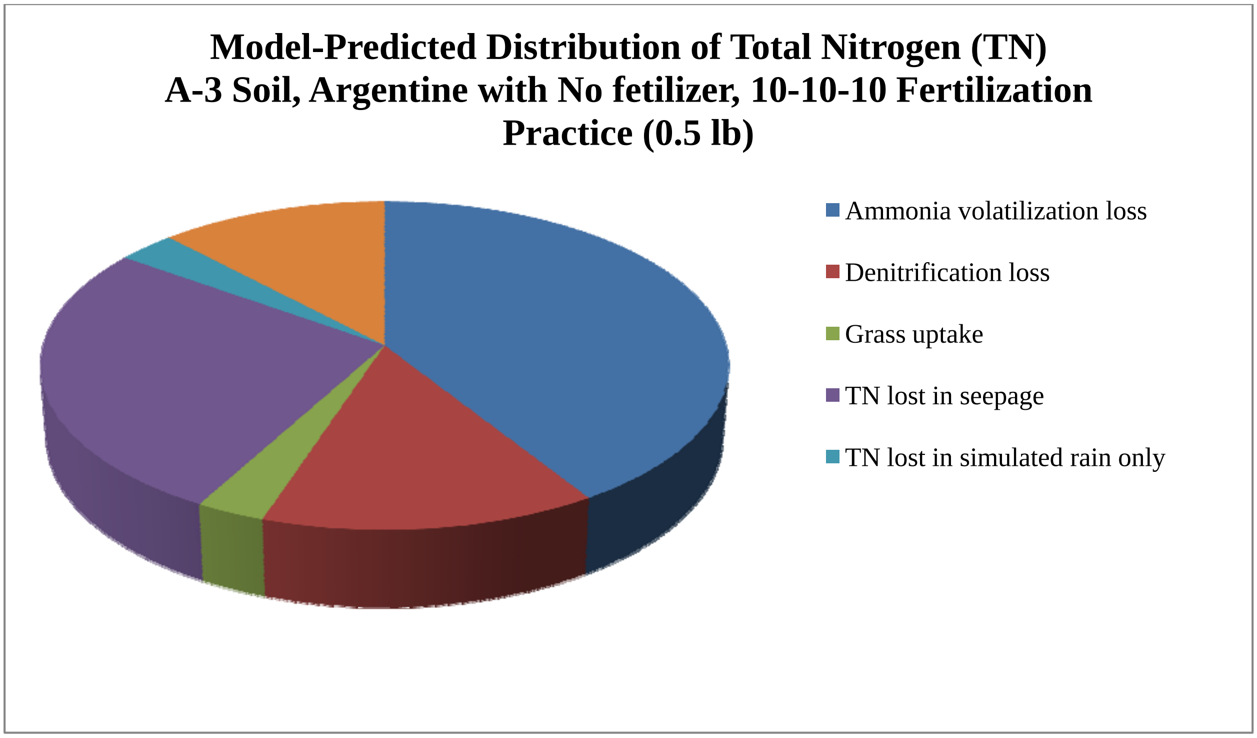

Figure 60: Phase #2 Model-Predicted Distribution of TN for Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, No Fertilizer and 10-10-10 Fertilization Practice)

The following observations can be made from Figure 61 and Figure 62 about the fate and transport of phosphate in the soil during the test series. The mass of phosphate in the soils built up over time as tests were run and fertilizer was applied (Figure 61). Additionally, measured TP mass values from soils analysis were compared to the modeled values and show good agreement as in the overall trend is for TP mass to build up in the soil. It should be noted that the measured values for soil TP mass were more variable than the modeled ones. The phosphorus lost via sod uptake, seepage since the previous test, from the flush events that occurred after the simulated rain event, and the mass of TP lost during the simulated rain event were significant and played a major role in the mass lost from the system (Figure 62). It should be noted that a significant amount of TP remained in the soil during the test series.

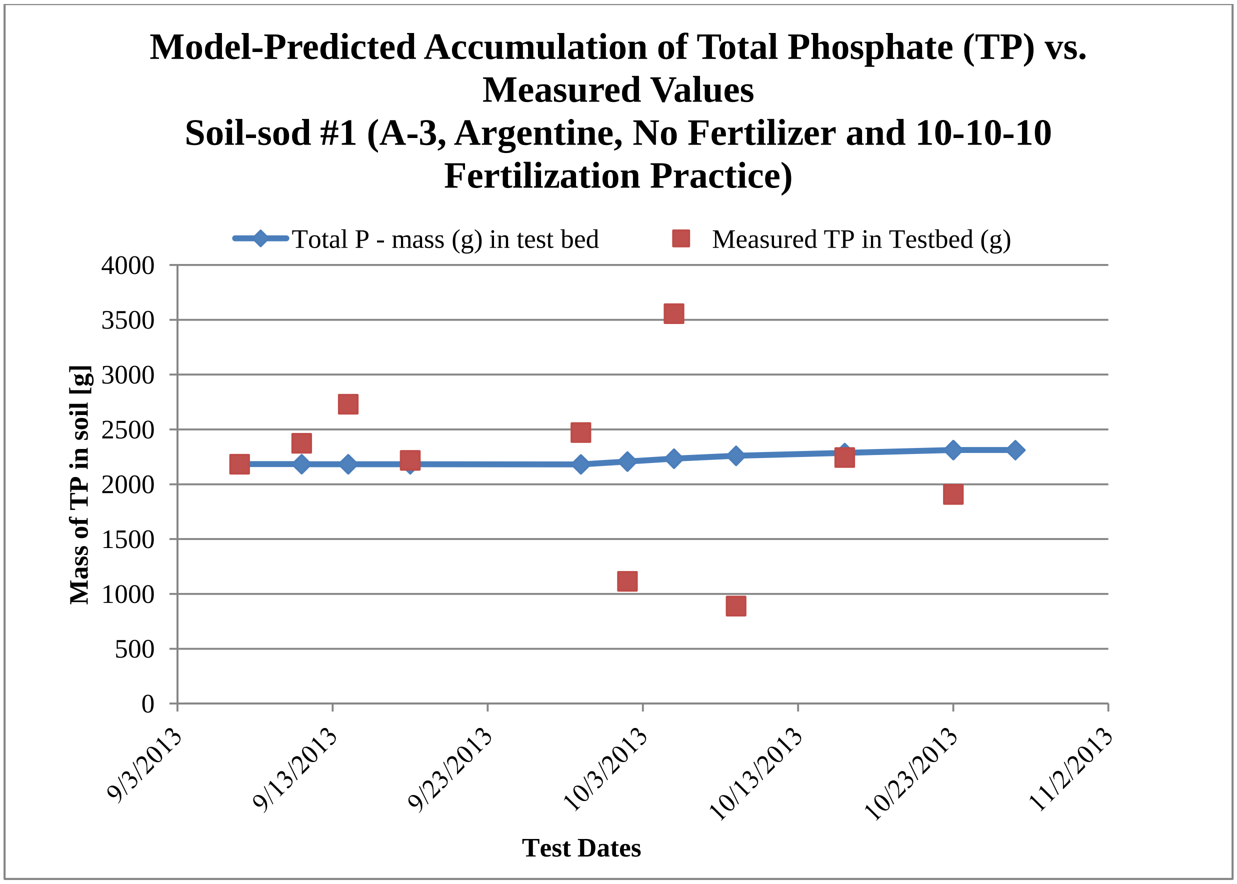

Figure 61: Phase #2 Model-Predicted Accumulation of Total Phosphate (TP) vs. Measured Values Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, No Fertilizer and 10-10-10 Fertilization Practice)

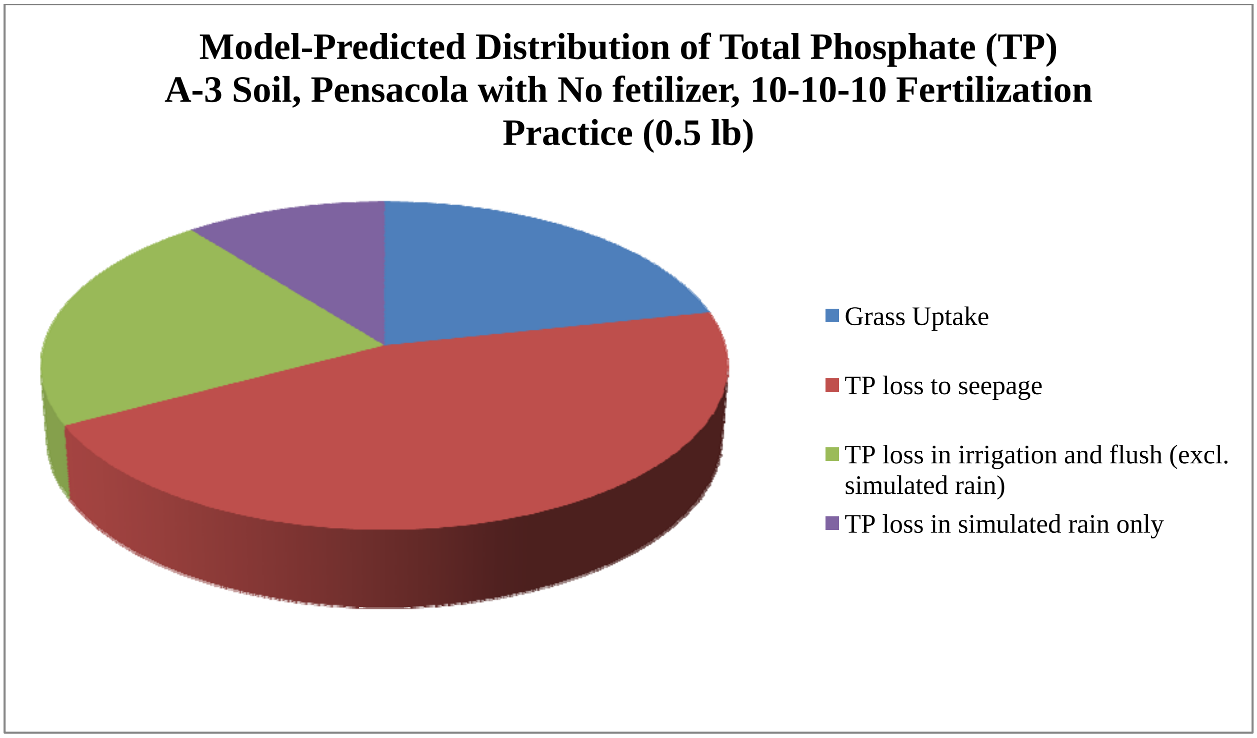

Figure 62: Phase #2 Model-Predicted Distribution of Total Phosphate (TP) for Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, No Fertilizer and 10-10-10 Fertilization Practice)

5.4.3 Phase #1 Soil-Sod Combination 2 for No-Fertilizer, 16-0-8 (SR) and 10-10-10 Fertilization Practices (Seven-Day Test)

The 18 tests that were conducted on the soil-sod combination 2 are reproduced from Table 2 and are listed in Table 72. The moisture balance of this combination was analyzed as per models described before and using a spreadsheet and presented in Table 96. The mass balance of total nitrogen (TN) is also presented in Table 97. Figure 29 through Figure 36 show a summary of the results of this mass balance. Figure 63 shows a few general trends with how nitrogen builds up and is released from the system. Generally, it can be seen that as fertilizer is applied the mass of TN in the system increases, while if no fertilizer is added the TN mass tends to decrease.

Table 72: Chronological Sequence of Tests on Soil-Sod Combination 2 – Phase #1

Test #	Soil	Bahia Sod	Fertilizer	Slope	in/hr	Date
1	A-3	Argentine	None	25%	0.5	8/17/2009
2	A-3	Argentine	None	25%	1.0	8/20/2009
3	A-3	Argentine	None	25%	3.0	8/24/2009
4	A-3	Argentine	16-0-8	25%	3.0	8/27/2009
5	A-3	Argentine	16-0-8	25%	0.5	8/31/2009
6	A-3	Argentine	16-0-8	25%	1.0	9/3/2009
7	A-3	Argentine	16-0-8	33%	1.0	9/10/2009
8	A-3	Argentine	16-0-8	33%	0.5	9/14/2009
9	A-3	Argentine	16-0-8	50%	1.0	9/17/2009
10	A-3	Argentine	16-0-8	50%	0.5	9/21/2009
11	A-3	Argentine	10-10-10	33%	3.0	10/13/2009
12	A-3	Argentine	16-0-8 (half)	25%	1.0	10/26/2009
13	A-3	Argentine	16-0-8 (half)	25%	3.0	10/29/2009
14	A-3	Argentine	16-0-8 (half)	25%	0.5	11/5/2009
15	A-3	Argentine	16-0-8 (half)	50%	0.5	11/12/2009
16	A-3	Argentine	16-0-8 (half)	50%	1.0	11/17/2009
17	A-3	Argentine	16-0-8 (half)	33%	0.5	11/19/2009
18	A-3	Argentine	16-0-8 (half)	33%	1.0	11/23/2009

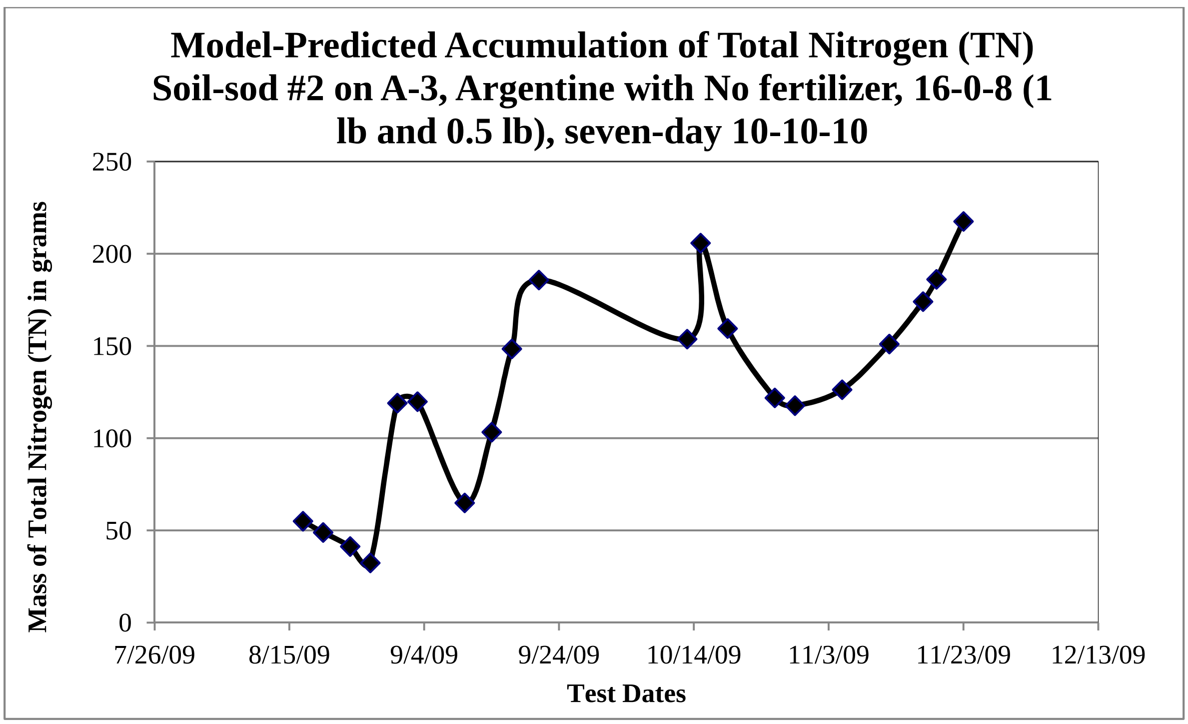

Figure 63: Model-Predicted Accumulation of Total Nitrogen (TN) on Soil-Sod Combination #2 (A-3 Soil, Argentine Bahia Sod with No Fertilizer, 16-0-8 (SR) Fertilization Practice at 1 lb and 0.5 lb, Seven-Day Test with 10-10-10 Fertilization Practice)

Figure 64 shows the different pathways for nitrogen in the system. From this figure, it is apparent that the primary path for nitrogen loss is in the flush after the simulated rain events. This accounts for about 42% of the nitrogen lost from the system. The majority of the TN mass is lost during the flush events as opposed to the simulated rain event, suggesting that the slow release may be reducing the rate of TN loss during the simulated rain events. Denitrification and ammonia volatilization were insignificant for these test series' accounting for about 5% of the nitrogen lost per the total applied. The nitrogen lost was more significant for grass uptake, seepage loss between tests, and the simulated rain event, accounting for about 7%, 12%, and 15% respectively. The nitrogen remaining in the system accounted for about 19% of the total applied.

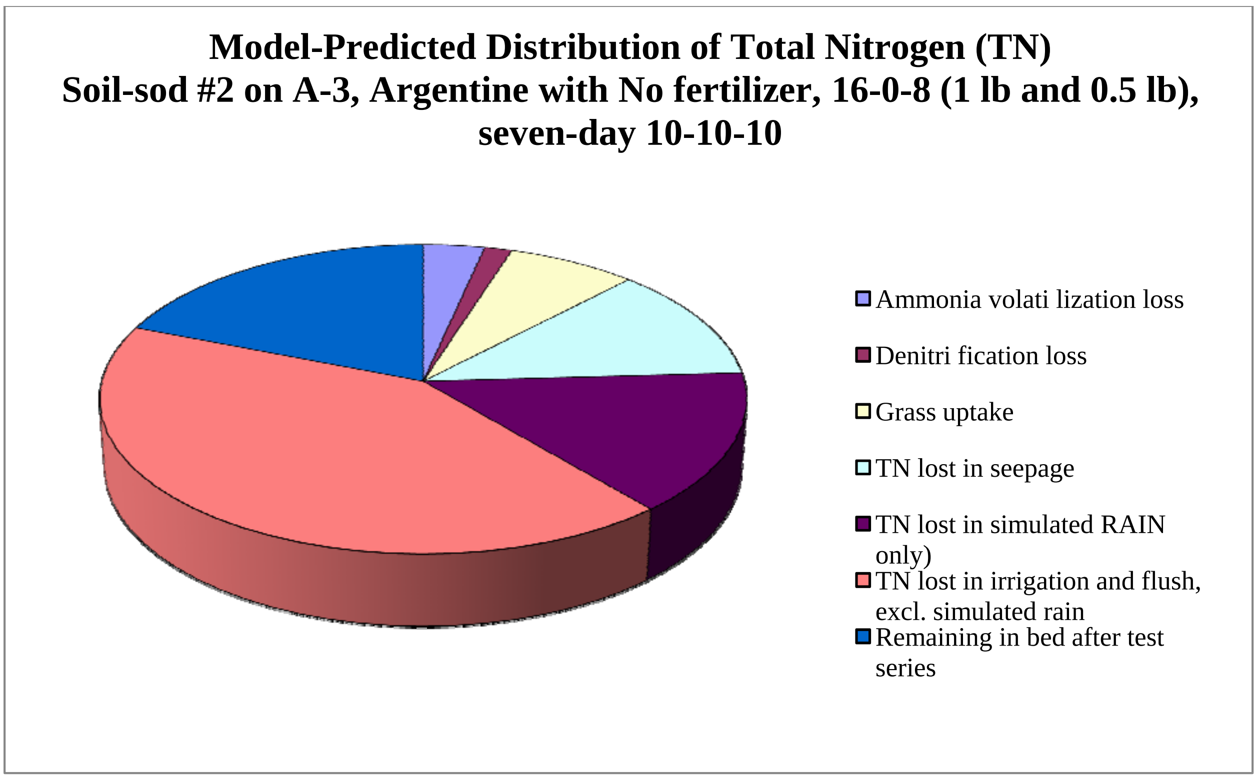

Figure 64: Model-Predicted Distribution of Total Nitrogen (TN) on Soil-Sod Combination #2 (A-3 Soil, Argentine Bahia Sod with No Fertilizer, 16-0-8 (SR) Fertilization Practice applied at 1 lb and 0.5 lb, Seven-Day Test with 10-10-10 Fertilization Practice)

Figure 65 shows the percent of TN lost in the simulated rain event with respect to what is available for the no-fertilizer test series. The no-fertilizer tests indicated no real trend with respect to TN mass lost except it is insignificant. This is because no fertilizer was added to the system, making sod uptake the dominant form of TN mass loss.

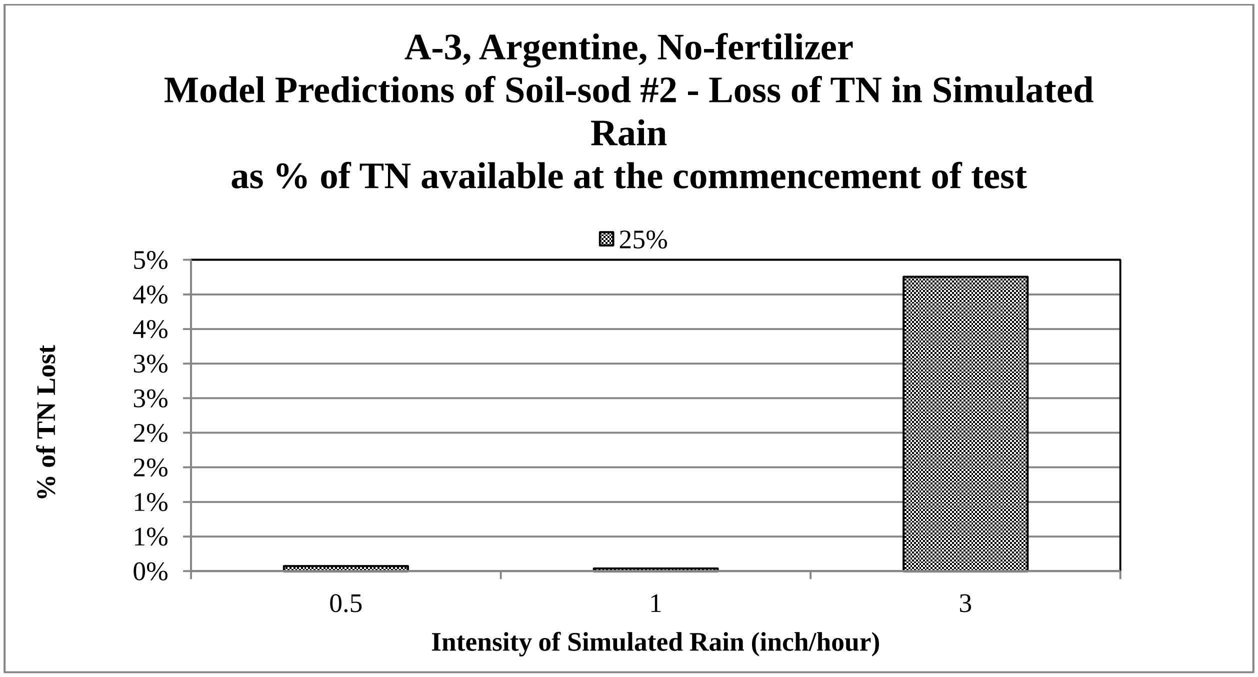

Figure 65: A-3 Soil, Argentine Bahia Sod, No Fertilizer Model Predictions of Soil-Sod Combination #2 – Loss of TN in Simulated Rain as a Percentage of TN Available at the Commencement of Test

Figure 66 illustrates this same comparison but with the 16-0-8 (SR) fertilizer applied at 1 lb of N per 1000 ft^2. This analysis shows that in general the TN mass loss increases with increasing rainfall intensity; however, the nitrogen available in the soil also plays a role. This can be seen in the 3 in/hr rainfall intensity test which was run right after the no-fertilizer test thus having lower nitrogen levels in the soil and lower nitrogen lost from the system.

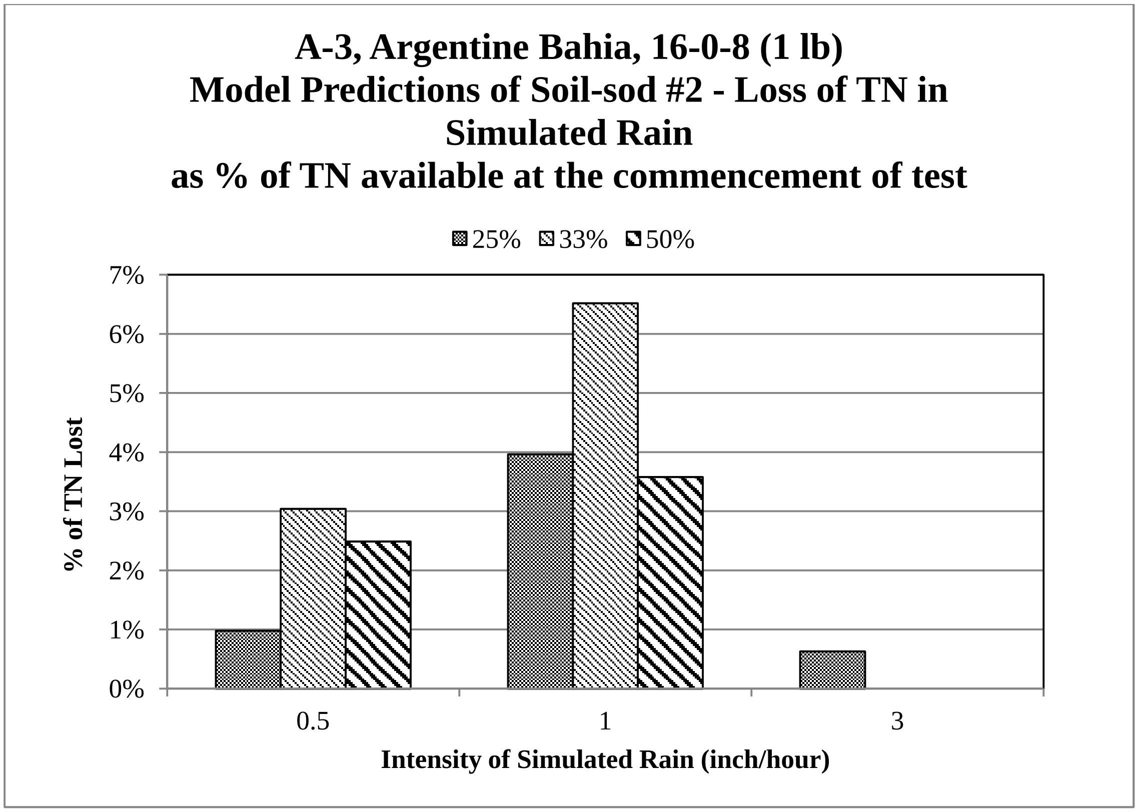

Figure 66: A-3 Soil, Argentine Bahia Sod, 16-0-8 Fertilization Practice (1 lb) Model Predictions of Soil-Sod Combination #2 – Loss of TN in Simulated Rain as a Percentage of TN Available at the Commencement of Test

Figure 67 shows this comparison for the 10-10-10 fertilizer seven-day test. The tests for the 10-10-10 fertilizer seven-day test showed a general decrease of nutrient losses with time after the initial fertilizer application. This is expected as fertilizer was only applied on the first day of the test.

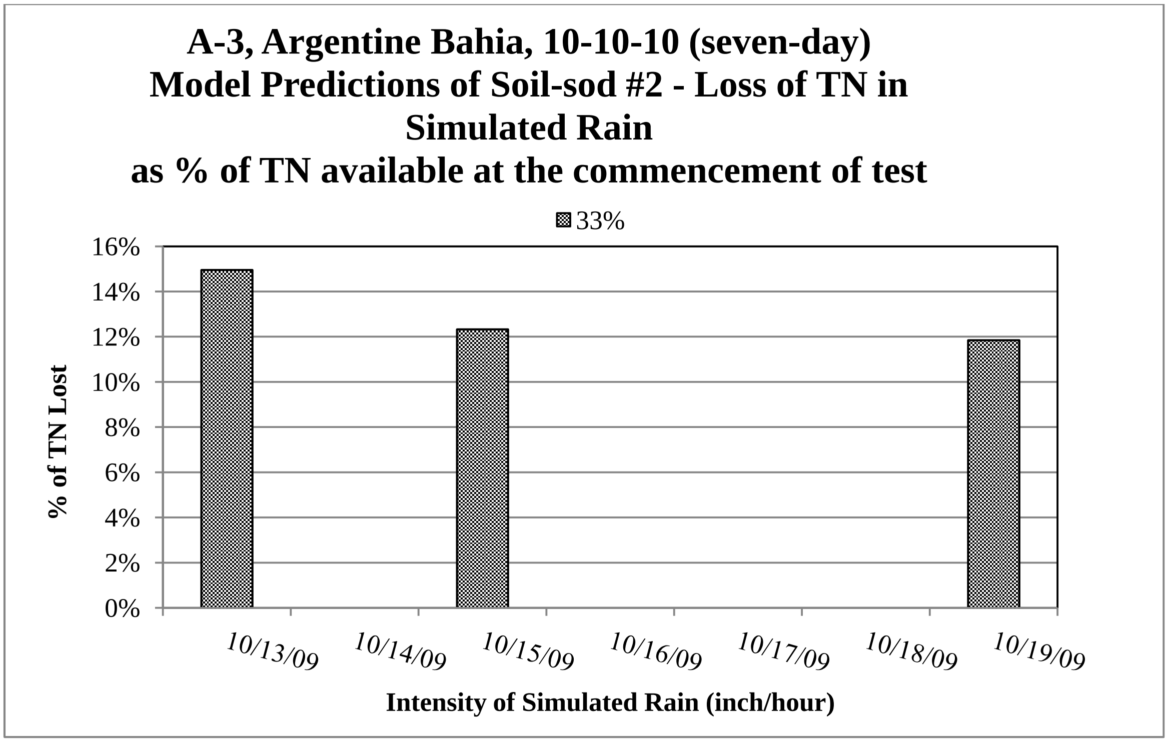

Figure 67: A-3 Soil, Argentine Bahia Sod, 10-10-10 Fertilization Practice (Seven-Day Test) Model Predictions of Soil-Sod Combination #2 – Loss of TN in Simulated Rain as a Percentage of TN Available at the Commencement of Test

In Figure 68, the percent of TN lost in the simulated rain event is shown and compared to the total available at the time of the test for the 16-0-8 (SR) fertilizer applied at 0.5 lb of N per 1000 ft^2. The TN lost is insignificant, and there are no obvious trends. It should be noted that the 1-to-4 slope, 1 in/hr rainfall test seemed to be high relative to the rest of the data in this test series.

Comparing the mass lost from the 10-10-10 fertilizer and two application rates of the 16-0-8 (SR) fertilizer for the simulated rain event, the mass of TN lost was higher for the 10-10-10 fertilizer. This implies a benefit of using the slow release fertilizer and further benefit of using a 0.5lb per $1000ft^2$ application rate as opposed to a 1lb application rate.

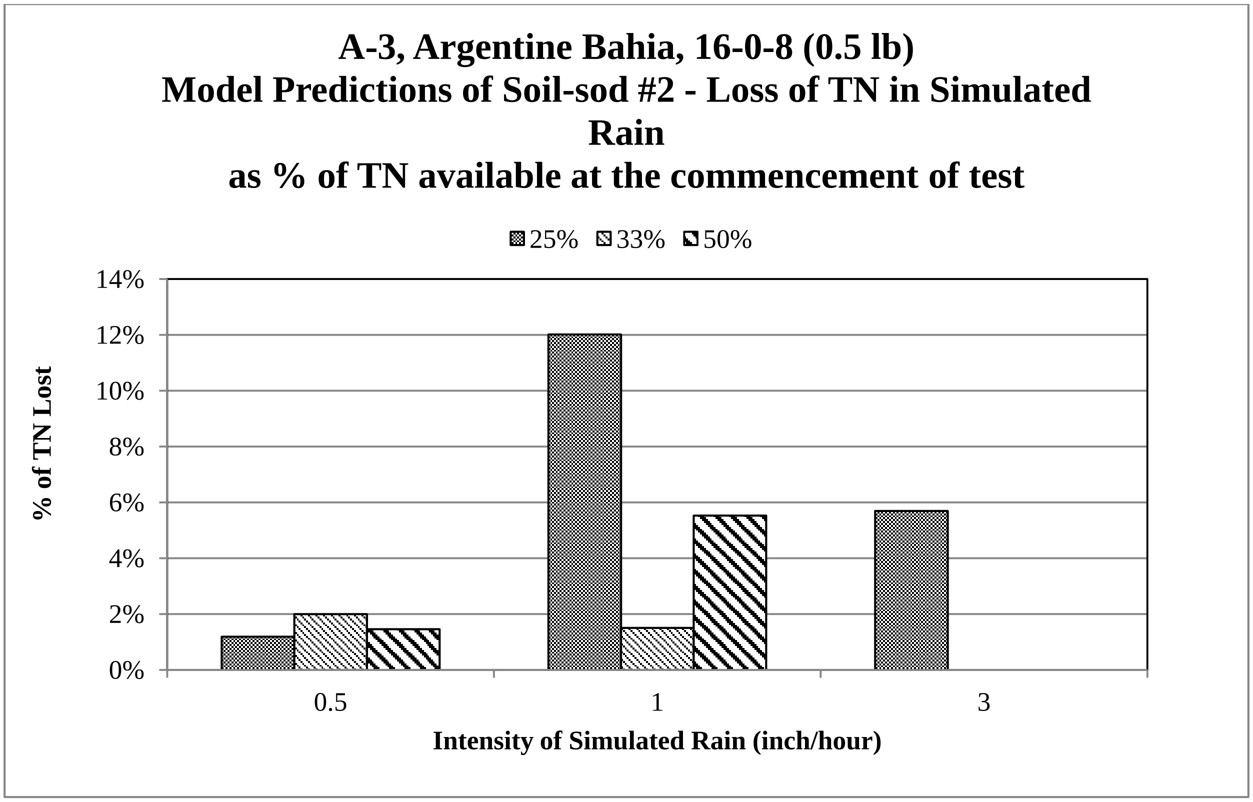

Figure 68: A-3 Soil, Argentine Bahia Sod, 16-0-8 Fertilization Practice (0.5 lb) Model Predictions of Soil-Sod Combination #2 – Loss of TN in Simulated Rain as a Percentage of TN Available at the Commencement of Test

5.4.4 Phase #2 Soil-Sod Combination 2 for No-Fertilizer, 16-0-8 (SR) Fertilization Practice

The 10 tests that were conducted on the soil-sod combination 1 for phase #2 of this study are reproduced from Table 31 and are listed in Table 73. As described before, the moisture balance of this combination was analyzed and is presented in Table 106. The mass balance of total nitrogen (TN) is also presented in Table 107.

Table 73: Chronological Sequence of Tests on Soil-Sod Combination 2 – Phase #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
9	A-3	Argentine	16-0-8	0.1	NA
10	A-3	Argentine	16-0-8	0.1	NA

* indicates a Seven-Day test

The total nitrogen mass balance and Figure 69 revealed a few trends about the nitrogen in the system and its fate. This figure shows that TN mass is slowly released from the soil but stays relatively stable. Additionally, a comparison to measured TN mass values is compared to the values predicted by the model. This shows that while the modeled values give a decent representation of the measured values, the measured values show much more variability.

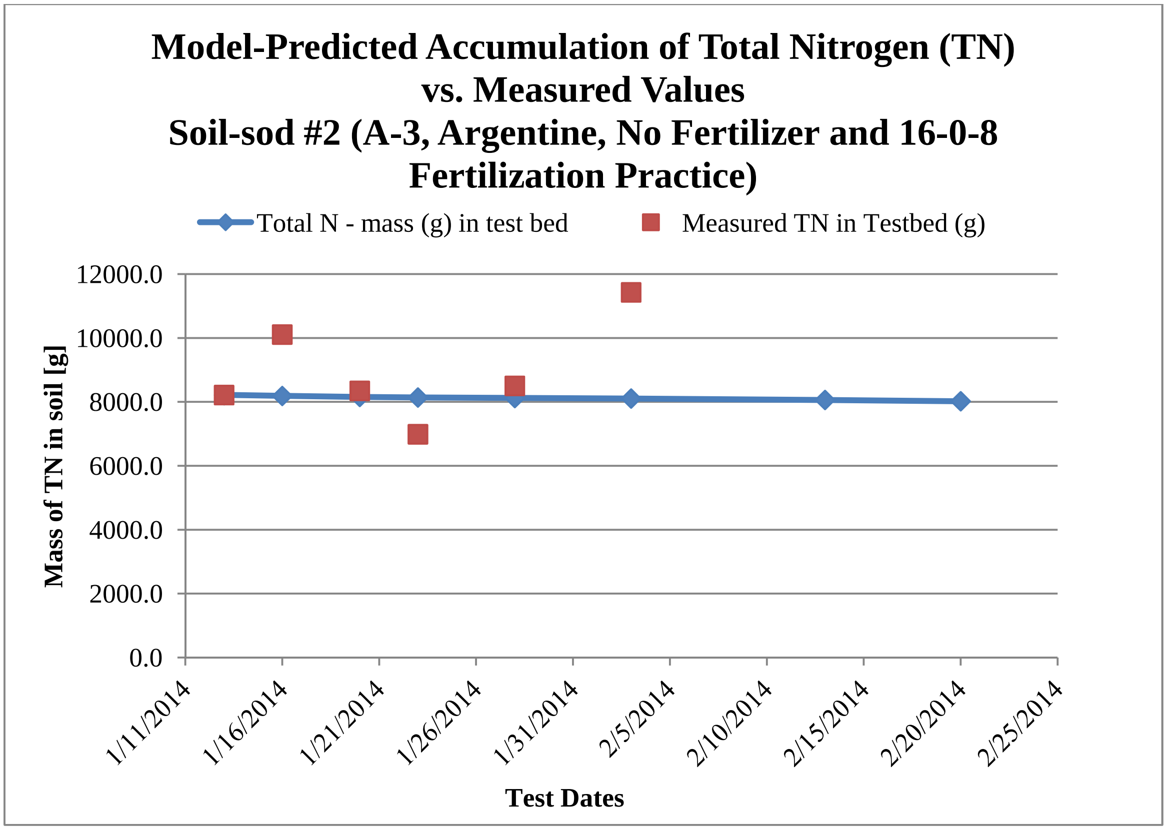

Figure 69: Phase #2 Model-Predicted Accumulation of TN vs Measured Values in Soil-Sod Combination #2 (A-3 Soil, Argentine Bahia Sod, No Fertilizer and 16-0-8 Fertilization Practice)

Examination of Figure 70 shows the model prediction of the fate of TN in the system. It can be seen from this figure that grass uptake and TN mass loss in simulated rainfall were minor factors in nitrogen loss from the system accounting for only 1% of the total lost from the test bed. The TN mass loss from irrigation and the flush (excluding the simulated rain event) was shown to be a significant form of mass loss from the system accounting for about 12% of the total lost from the test bed.

The most significant pathways for TN mass loss for this test series was through TN mass loss through seepage between tests, ammonia volatilization, and TN mass loss due to denitrification accounting for 26%, 28%, and 33%, respectively, of the TN lost from the test bed. The variables that effect ammonia volatilization are ammonia availability, temperature, and pH.

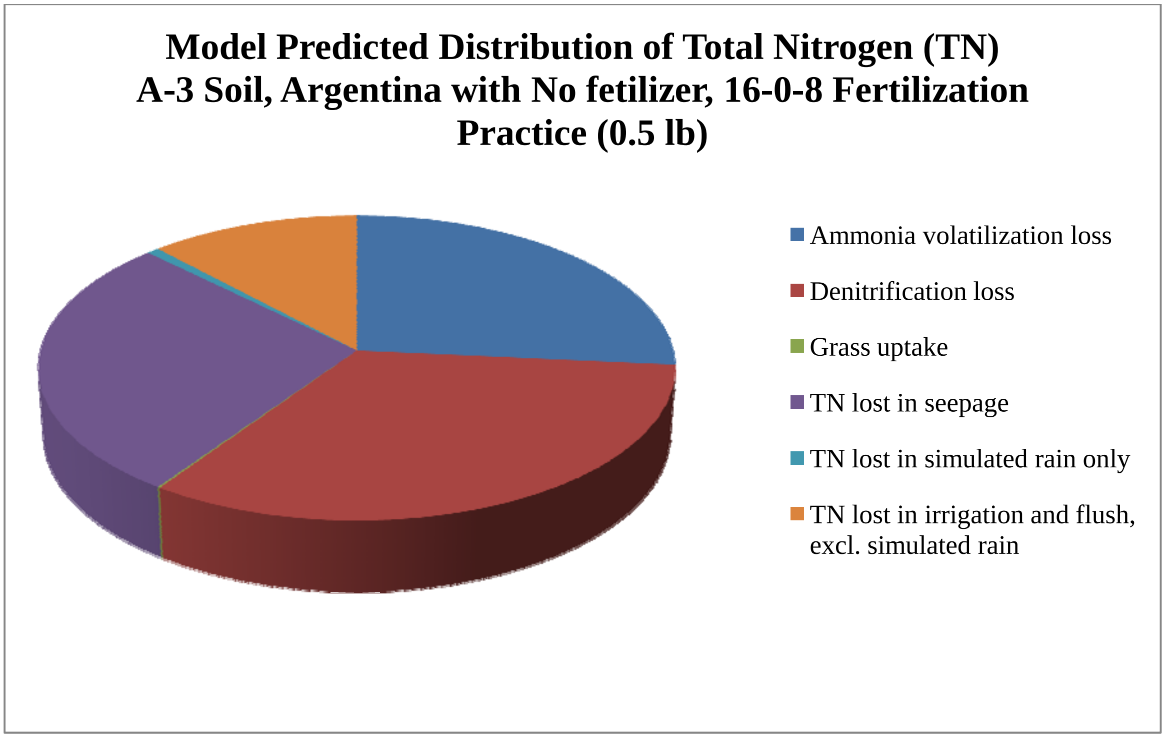

Figure 70: Phase #2 Model Predicted Distribution of TN for Soil-Sod Combination #2 (A-3 Soil, Argentine Bahia Sod, No Fertilizer and 16-0-8 Fertilization Practice)

5.5 AASHTO A-2-4 Soil with Pensacola Bahia

5.5.1 Phase #1 Soil-Sod Combination 3 for No-Fertilizer and 10-10-10 Fertilization Practice (One-Day and Seven-Day)

The 16 tests that were conducted on the soil-sod combination 3 are reproduced from Table 2 and are listed in Table 74. The moisture balance of this combination was analyzed as per models described before and is presented in Table 98. The mass balance of total nitrogen (TN) and total phosphorus (TP) is presented in Table 99 and Table 100, respectively.

Table 74: Chronological Sequence of Tests on Soil-Sod Combination 3 – Phase #1

Test #	Soil	Bahia Sod	Fertilizer	Slope	in/hr	Date
1	A-2-4	Pensacola	None	25%	0.5	1/14/2010
2	A-2-4	Pensacola	None	25%	1	1/21/2010
3	A-2-4	Pensacola	None	25%	3	1/28/2010
4	A-2-4	Pensacola	10-10-10	25%	0.5	2/1/2010
5	A-2-4	Pensacola	10-10-10	25%	3	2/4/2010
6	A-2-4	Pensacola	10-10-10	25%	1	2/8/2010
7	A-2-4	Pensacola	10-10-10	33%	0.5	2/11/2010
8	A-2-4	Pensacola	10-10-10	33%	1	3/4/2010
9	A-2-4	Pensacola	10-10-10	50%	0.5	3/8/2010
10	A-2-4	Pensacola	10-10-10	50%	1	3/15/2010
11	A-2-4	Pensacola	10-10-10, 7-day test	33%	3	3/23/2010
14	A-2-4	Pensacola	10-10-10	25%	0.5	4/1/2010
15	A-2-4	Pensacola	10-10-10	25%	1	4/5/2010
16	A-2-4	Pensacola	10-10-10	25%	3	4/8/2010

Figure 71 shows the accumulation of TN in the test bed. It can be seen from the figure that as fertilizer is added the TN mass in the system increases and decreases when none is added. As expected, the mass of TN decreased with time for all tests where fertilizer was not added, i.e. all six of the no fertilizer tests and day three and day seven of the seven-day test. Nitrogen uptake by sod was also shown to vary significantly depending on time of year (from Table 99 in Appendix C). This can be observed by comparing the grass uptake for the first run no-fertilizer tests with the second run no-fertilizer tests, which were run about three months apart.

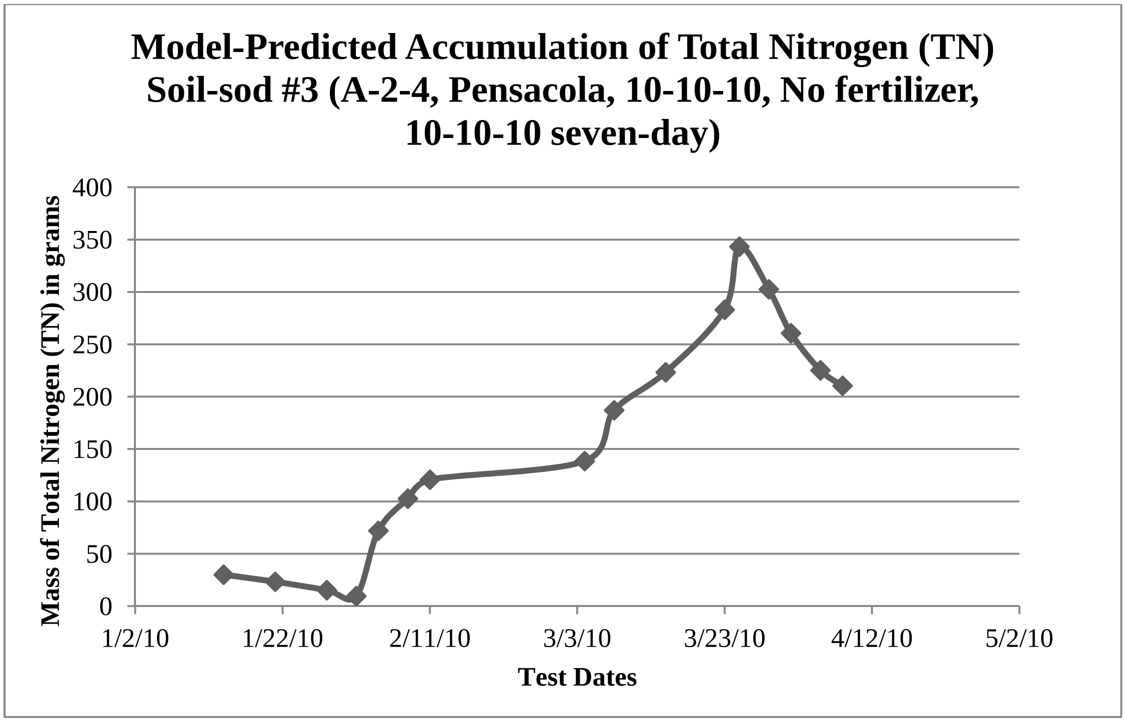

Figure 71: Model-Predicted Accumulation of Total Nitrogen (TN) for Soil-Sod Combination #3 (A-2-4 Soil, Pensacola Bahia Sod, 10-10-10 Fertilization Practice, No-Fertilizer, Seven-Day Test with 10-10-10 Fertilization Practice)

Figure 72 show the distribution of TN mass pathways in the system. The denitrification and ammonia volatilization were insignificant accounting for only 2% of the mass applied to the system. The grass uptake was also insignificant accounting for only 6% of the mass applied to the system. The mass lost in seepage between tests, the flush events after the simulated rain events, and the simulated rain events were the most significant pathways accounting for 17%, 24%, and 29% respectively. The mass remaining in the system after the simulated rain event was about 23% of the total applied. This indicates that about 77% of the TN mass applied left the system.

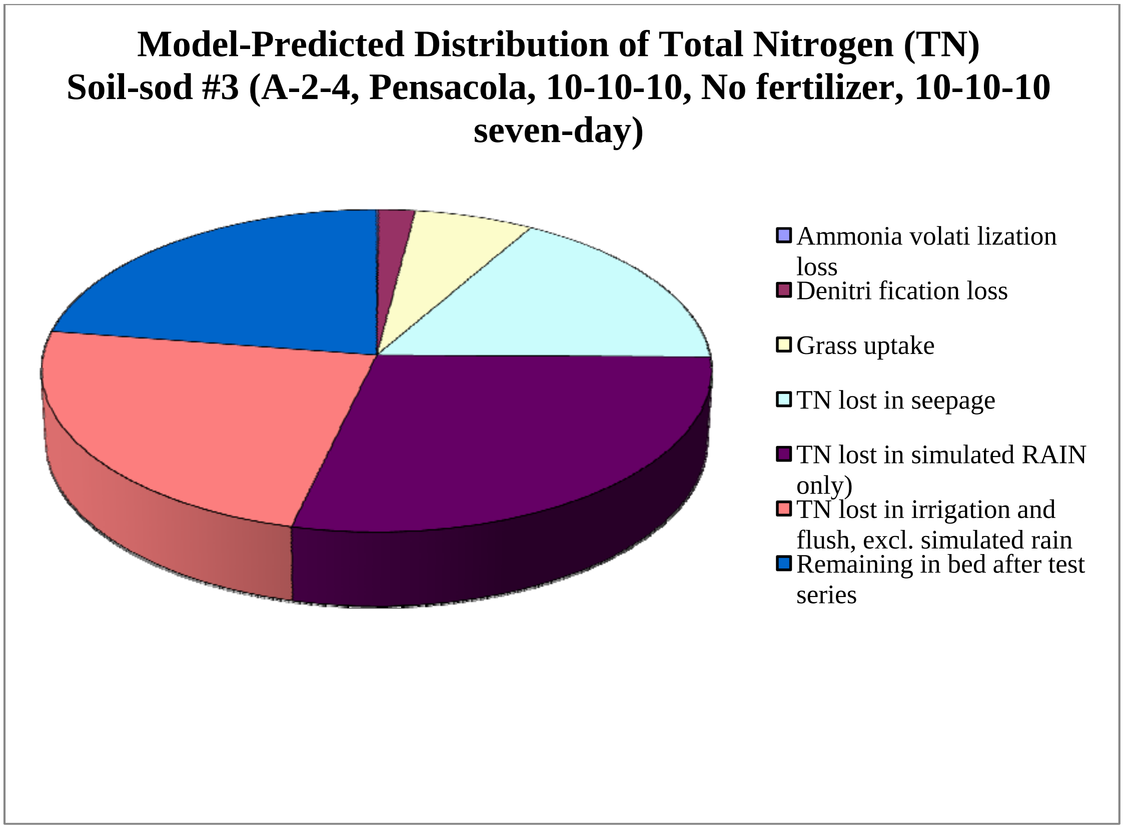

Figure 72: Model-Predicted Distribution of Total Nitrogen (TN) for Soil-Sod Combination #3 (A-2-4 Soil, Pensacola Bahia Sod, 10-10-10, No-Fertilizer, Seven-Day Test with 10-10-10 Fertilization Practices)

In Figure 73, the percent of TN lost in the simulated rain events to the total available at the time the test was run for the no-fertilizer tests is shown. The TN loss is insignificant but does tend to increase with increasing rainfall intensity. This is likely due to higher rainfall intensities creating higher volumes of water leaving the system and thus more mass of TN.

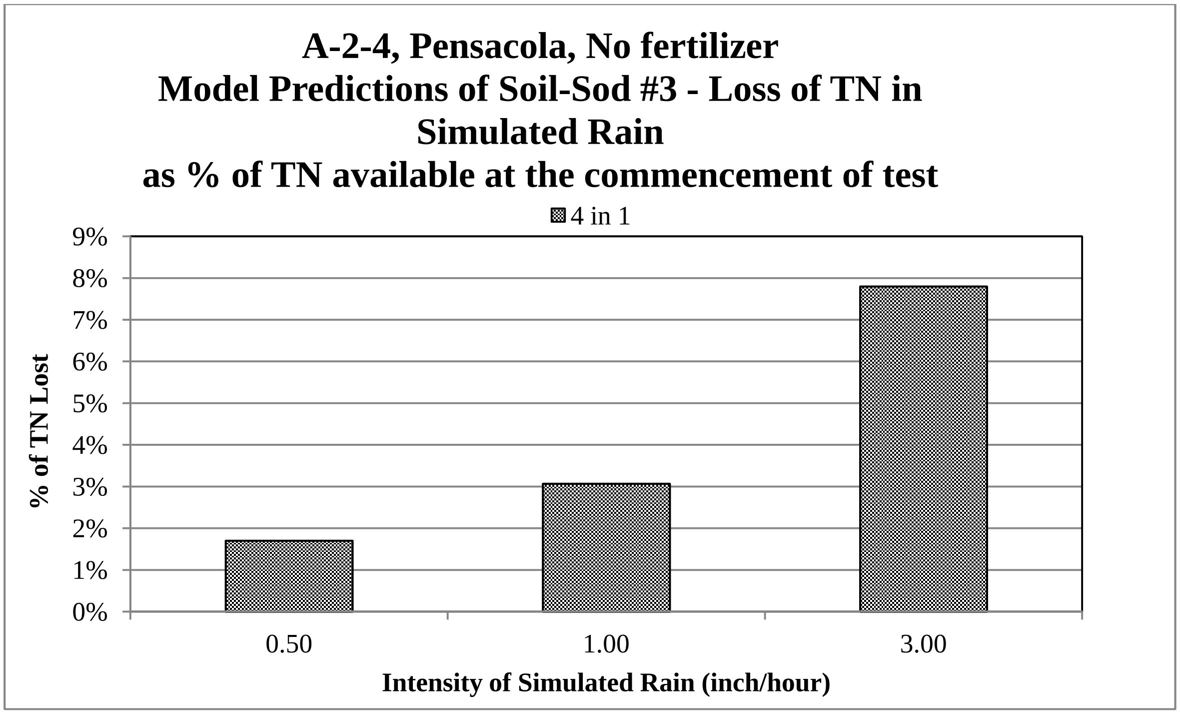

Figure 73: A-2-4 Soil, Pensacola Bahia Sod, No-Fertilizer Model Predictions of Soil-Sod Combination #3 – Loss of TN in Simulated Rain as a Percentage of TN Available at the Commencement of Test

Figure 74 shows this comparison for the 10-10-10 fertilizer tests. Again, the TN mass loss is significant for almost all the tests run, except for the test run on a 1 to 2 slope at 1 in/hr (suspiciously low). However, there were no observable trends with this data.

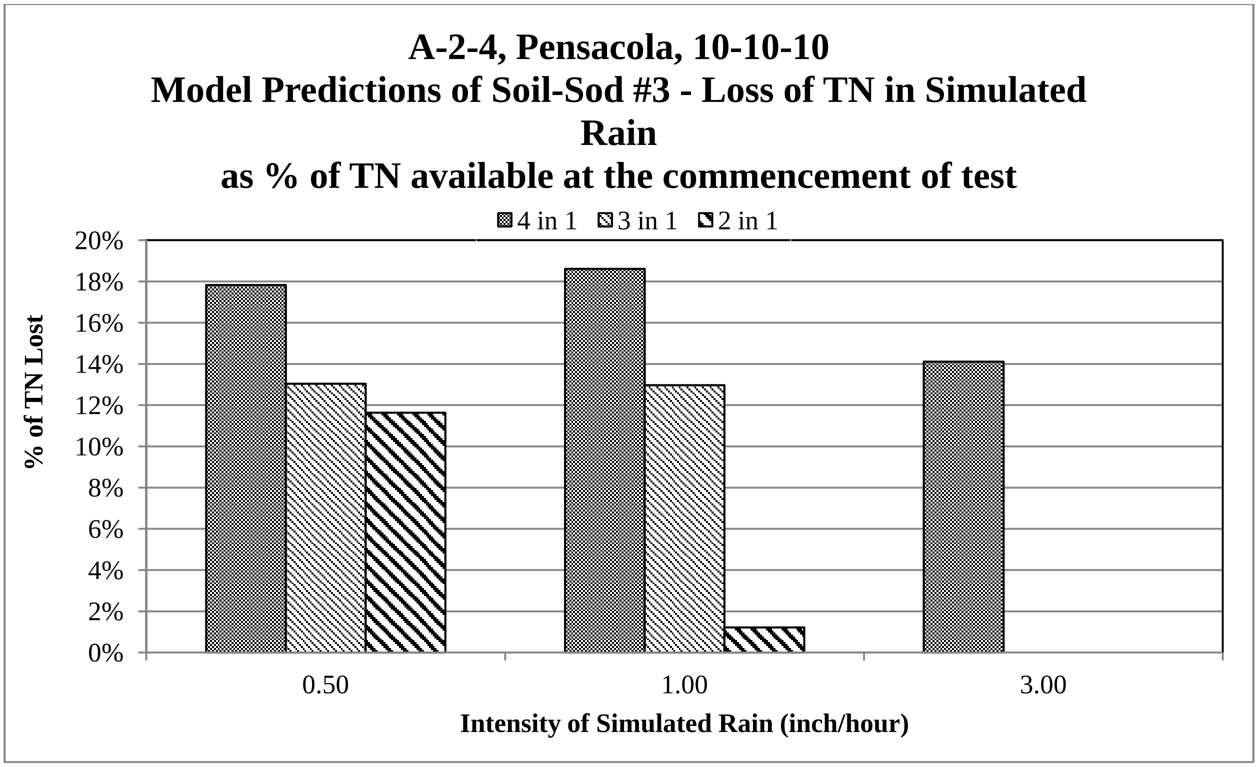

Figure 74: A-2-4 Soil, Pensacola Bahia Sod, 10-10-10 Fertilizer Model Predictions of Soil-Sod Combination #3 – Loss of TN in Simulated Rain as a Percentage of TN Available at the Commencement of Test

In Figure 75, this comparison for the 10-10-10 fertilizer seven-day test is illustrated. On the first day, when fertilizer is applied, significant TN mass loss occurs. Since no fertilizer is added before day three or seven the TN loss decreases dramatically for each successive test. Seven days after fertilization, with rain events occurring in between, TN loss from fertilizers can still occur.

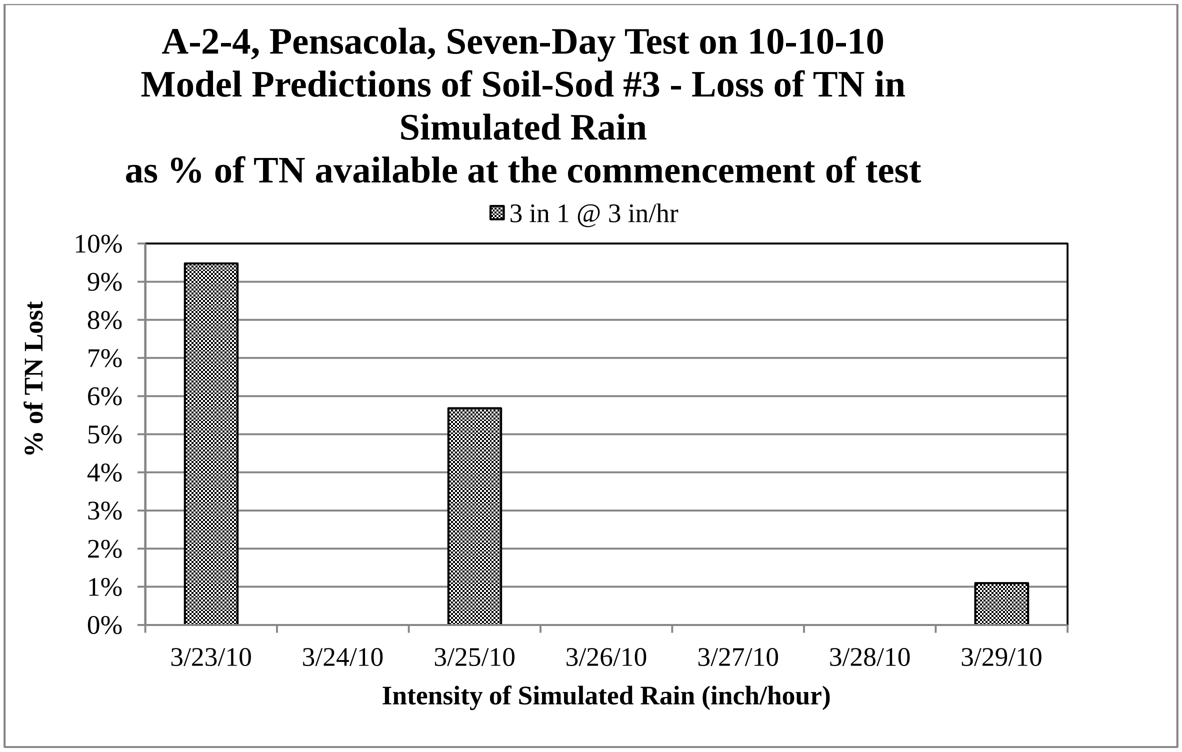

Figure 75: A-2-4 Soil, Pensacola Bahia Sod, Seven-Day Test on 10-10-10 Model Predictions of Soil-Sod Combination #3 – Loss of TN in Simulated Rain as a Percentage of TN Available at the Commencement of Test

Figure 76 displays the accumulation of TP in the system over time. From the figure, it can be seen that the mass of phosphate in the soils built up over time as tests were run and fertilizer was applied but dropped when none was added. From Table 100 in Appendix C, it was noted that both the extractable phosphorus (X) and the non-extractable phosphorus (Y) built up quickly. The extractable phosphorus built up the quickest for this soil type. This portion of soil phosphorus is dissolved and leaves the system predominately through runoff. It was also observed that the rate of phosphate gain was much more than the rate of phosphate lost, even during the no fertilizer tests.

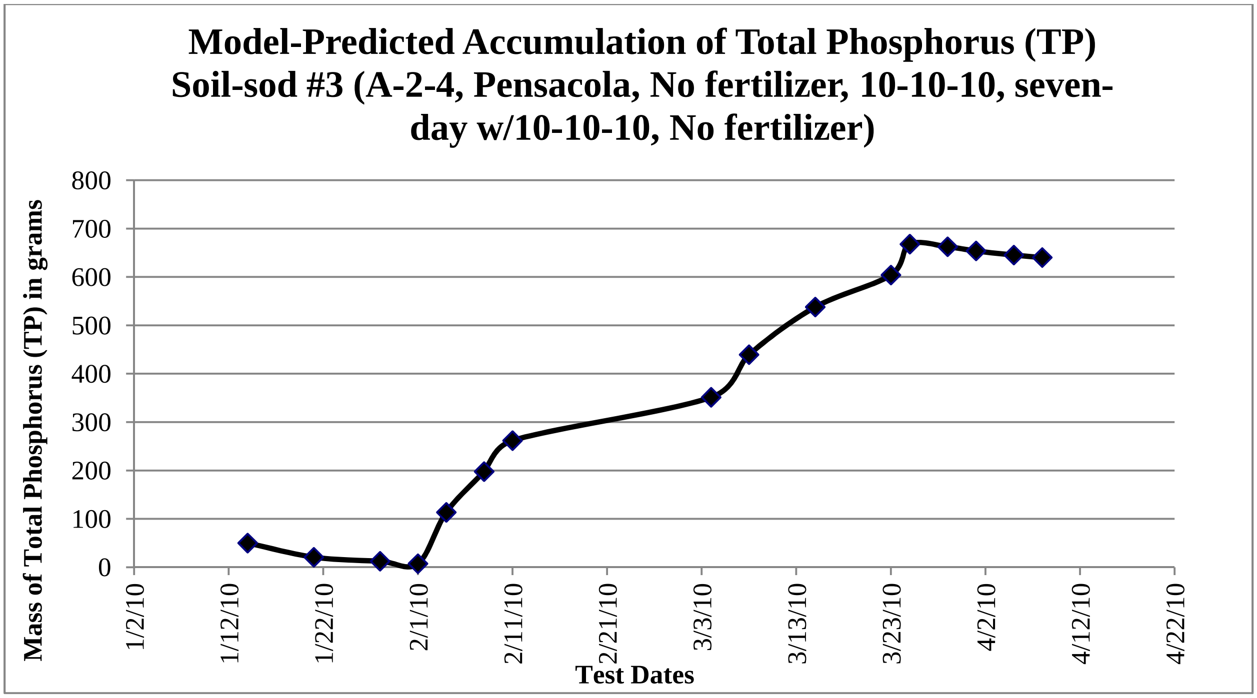

Figure 76: Model-Predicted Accumulation of Total Phosphorus (TP) for Soil-Sod Combination #3 (A-2-4 Soil, Pensacola Bahia Sod, No-Fertilizer, 10-10-10 Fertilization Practice, Seven-Day Test with 10-10-10 Fertilization Practice, No Fertilizer)

Figure 77 shows the distribution of TP pathways in the system. The phosphorus lost via sod uptake and seepage since previous test is insignificant and played only a minor role in the mass lost accounting for about 1% of the total applied. The flush event after the simulated rainfall event and the simulated rain event were the most significant pathways for TP loss accounting for 21% and 25% respectively. The remaining TP in the system accounted for about 53% of the total applied. This, along with the minor decreases in soil TP noted above when no fertilizer is applied shows that phosphorus readily adsorbs to this soil type.

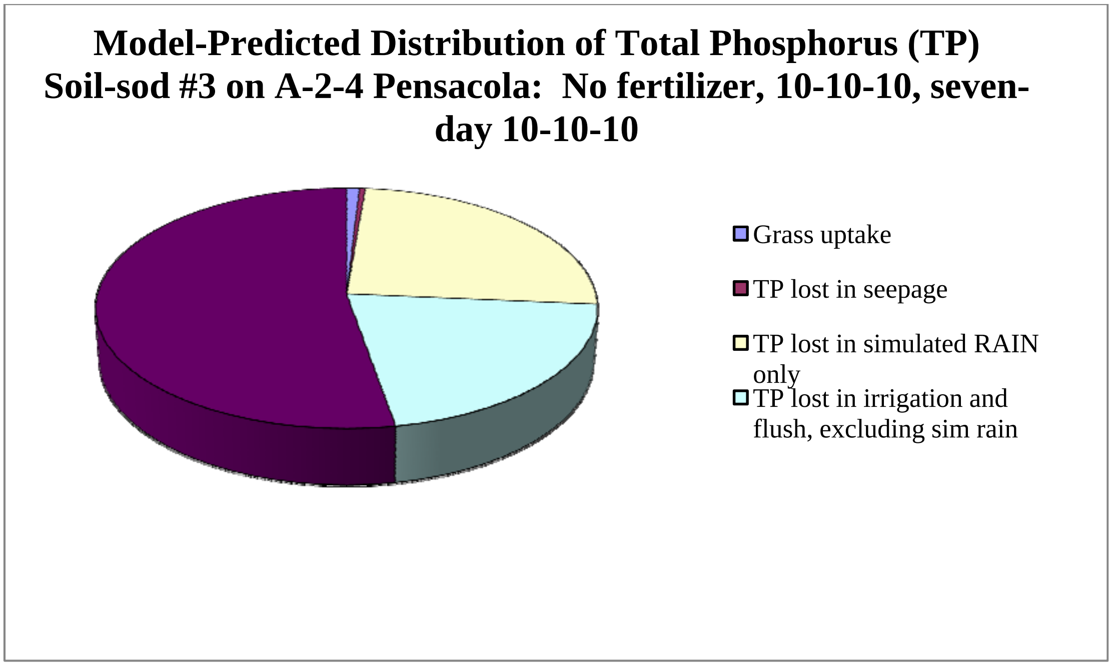

Figure 77: Model-Predicted Distribution of Total Phosphorus (TP) in Soil-Sod Combination #3 on A-2-4 Pensacola Bahia Sod: No-Fertilizer, 10-10-10 Fertilization Practice, Seven-Day Test with 10-10-10 Fertilization Practice, No-Fertilizer

Figure 78 displays the percent of TP lost in the simulated rainfall event to the total available at the time of the test for the no-fertilizer tests. The TP lost increases with rainfall intensity however, the loss is not significant and likely due to the higher runoff and filtrate volumes generated. In Figure 79 this same comparison for the 10-10-10 fertilizer is shown. The TP loss tends to increase with increasing intensity however, the majority of the TP remains in the soil. This is a function of soil type as the A-2-4 soils have a higher CEC and larger particle surface area.

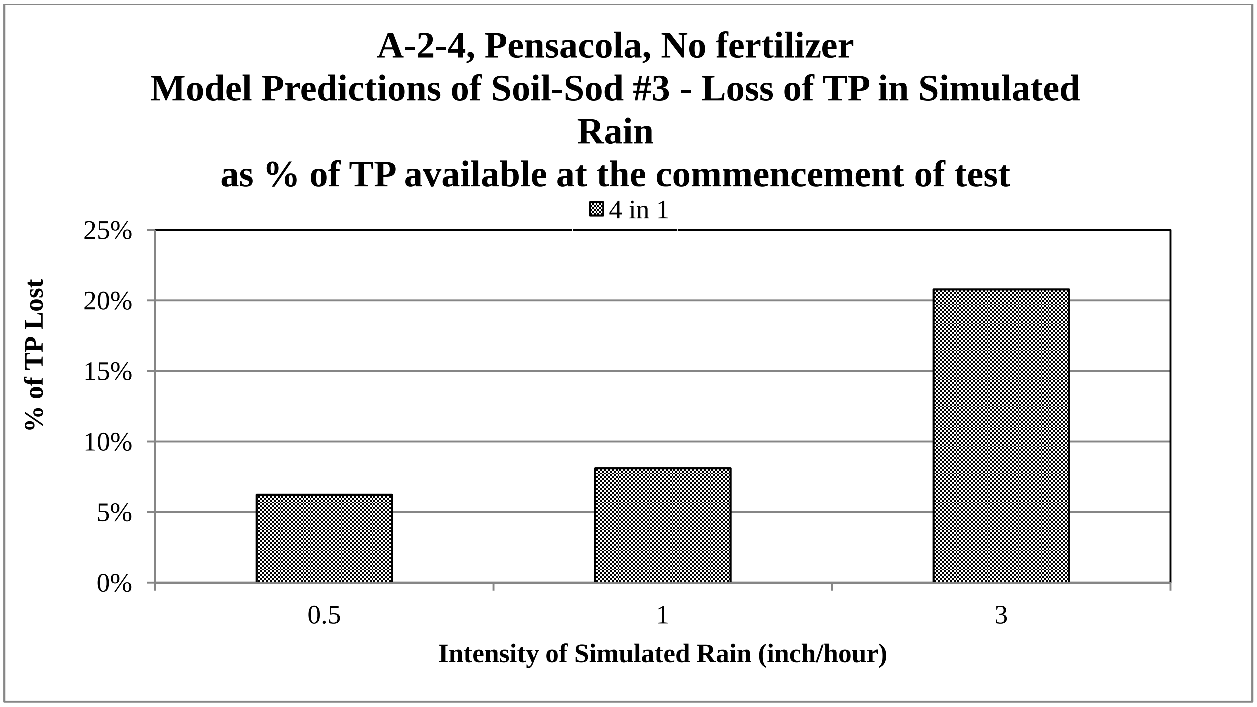

Figure 78: A-2-4 Soil, Pensacola Bahia Sod, No-Fertilizer Model Predictions of Soil-Sod Combination #3 – Loss of TP in Simulated Rain as a Percentage of TP Available at the Commencement of Test

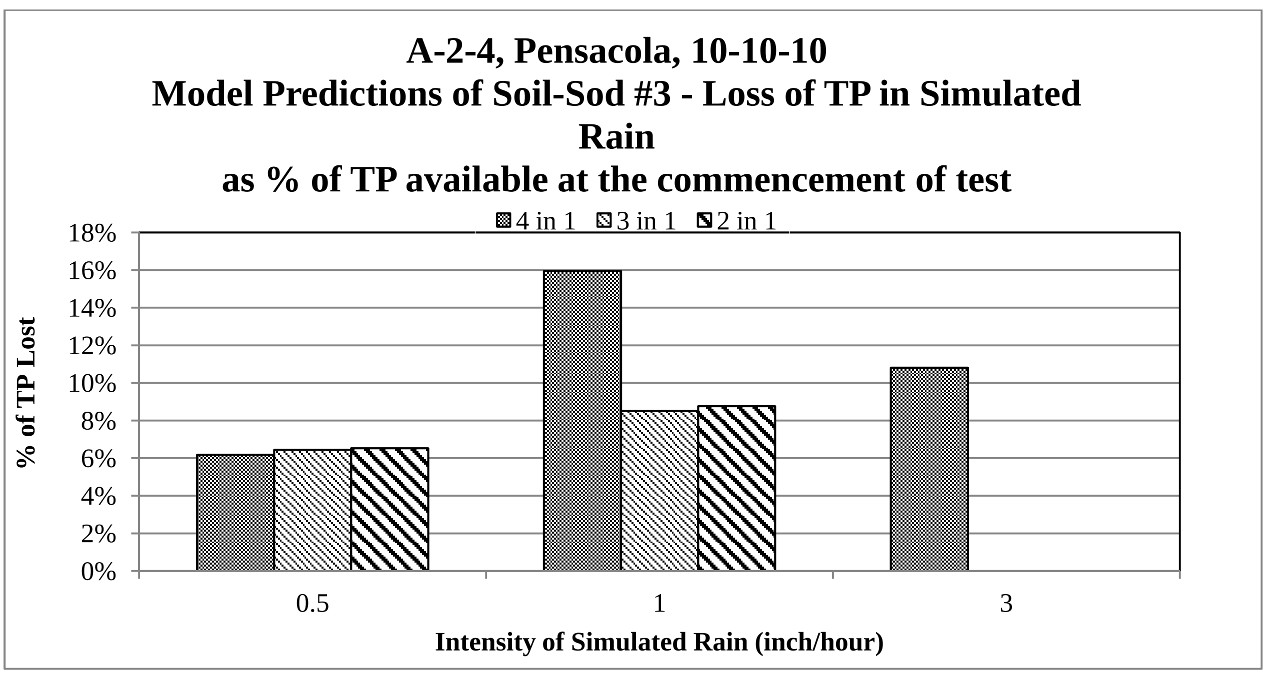

Figure 79: A-2-4 Soil, Pensacola Bahia Sod, 10-10-10 Fertilization Practice Model Predictions of Soil-Sod Combination #3 – Loss of TP in Simulated Rain as a Percentage of TP Available at the Commencement of Test

Lastly, Figure 80 illustrates this comparison for the 10-10-10 fertilizer seven-day test. The TP mass lost on the first day was shown to be significant while days three and seven were not. This is expected as fertilizer was only added on the first day. This result suggests that for phosphorus, most of the mass that leaves the system is washed out in the first rain event.

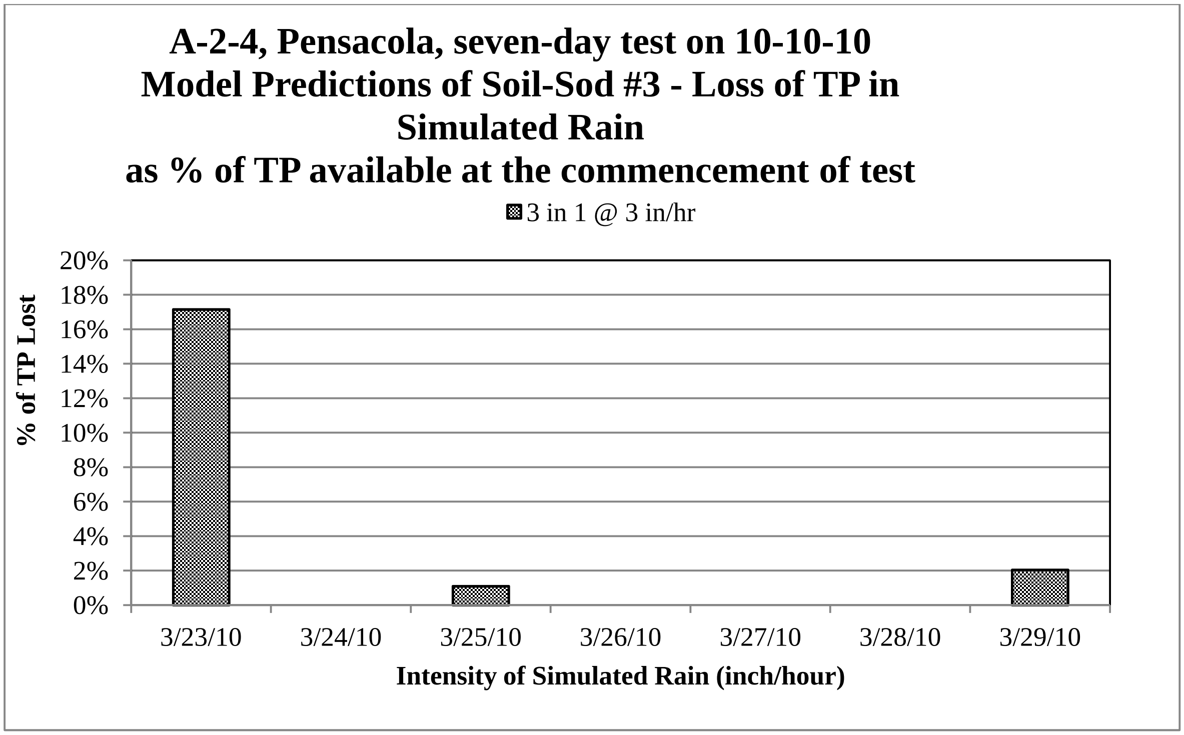

Figure 80: A-2-4 Soil, Pensacola Bahia Sod, Seven-Day Test on 10-10-10 Fertilization Practice Model Predictions of Soil-Sod Combination #3 – Loss of TP in Simulated Rain as a Percentage of TP Available at the Commencement of Test

5.5.2 Phase #2 Soil-Sod Combination 1 for No-Fertilizer and 10-10-10 Fertilization Practice

The 10 tests that were conducted on the soil-sod combination 2 for phase #2 of this study are reproduced from Table 31 and are listed in Table 75. As described before, the moisture balance of this combination was analyzed and is presented in Table 108. The mass balance of total nitrogen (TN) and total phosphate (TP) are also presented in Table 109 and Table 110, respectively.

Table 75: Chronological Sequence of Tests on Soil-Sod Combination 3 – Phase #2

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

The total nitrogen mass balance and Figure 81 revealed a few trends about the nitrogen in the system and its fate. This figure shows that TN mass is slowly released from the soil but stays relatively stable. Additionally, a comparison to measured TN mass values is compared to the values predicted by the model. This shows that while the modeled values initially give a decent representation of the measured values; however, the variability of the measured values became significant as time goes on.

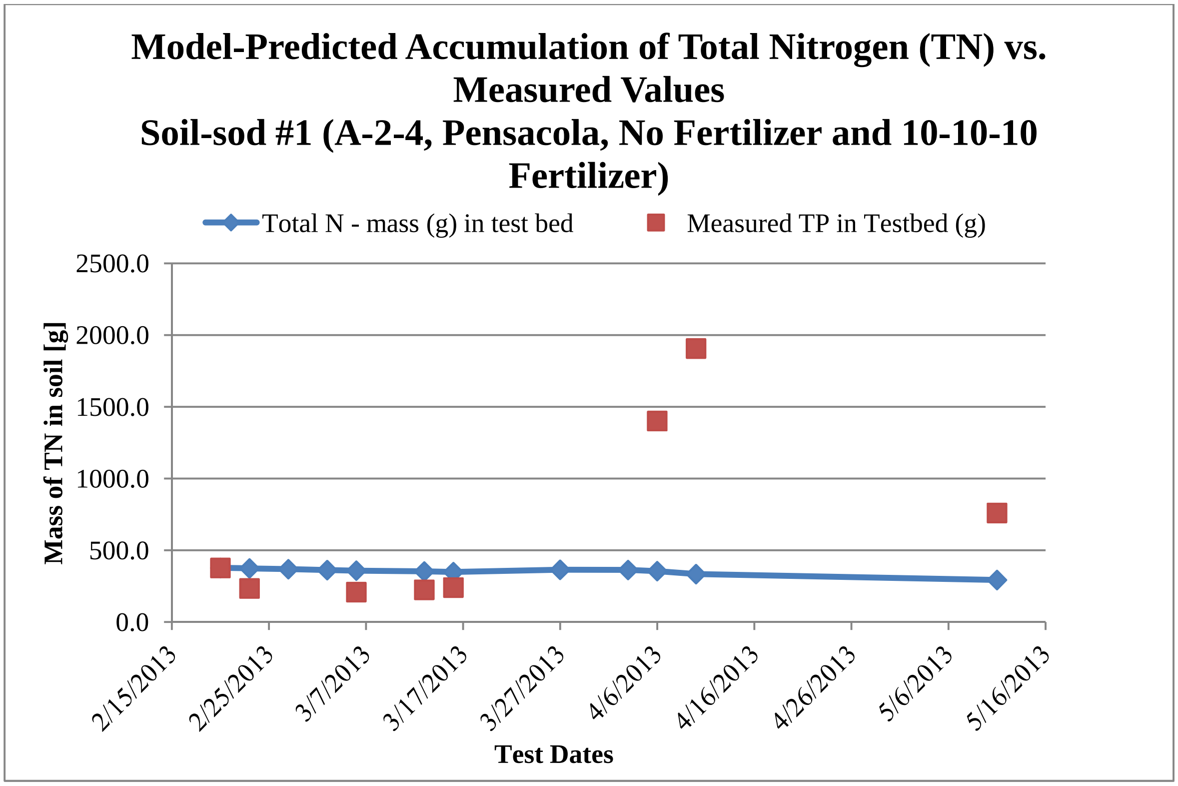

Figure 81: Phase #2 Model-Predicted Accumulation of TN vs Measured Values in Soil-Sod Combination #3 (A-2-4 Soil, Pensacola Bahia Sod, No Fertilizer and 10-10-10 Fertilization Practice)

Examination of Figure 82 shows the model prediction of the fate of TN in the system. It can be seen from this figure that ammonia volatilization loss and TN mass loss in simulated rainfall were minor factors in nitrogen loss from the system accounting for only 6% of the total lost from the test bed. Grass uptake and denitrification losses were shown to be significant accounting for 10% and 11% of the TN mass lost from the test bed. The TN mass loss from irrigation and the flush (excluding the simulated rain event) was also shown to be a significant form of mass loss from the system accounting for about 12% of the total lost from the test bed.

The most significant pathways for TN mass loss for this test series was through TN mass loss through seepage between tests accounting for 60% of the TN lost from the test bed.

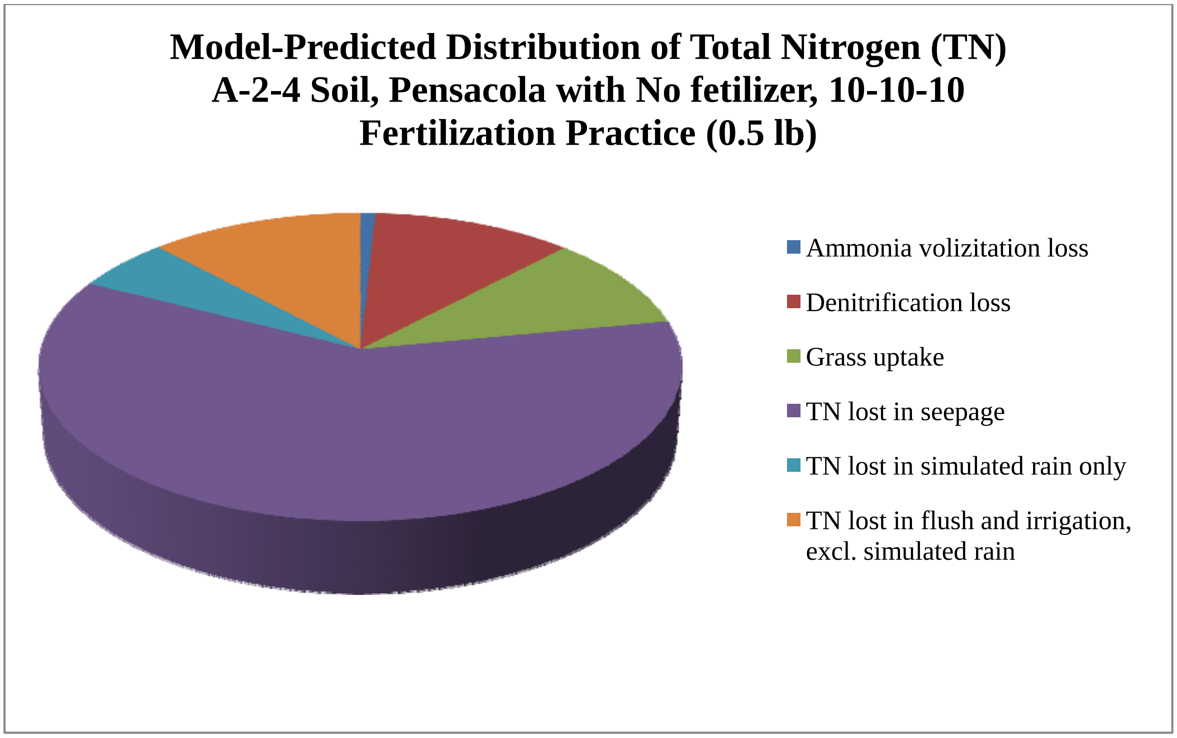

Figure 82: Phase #2 Model-Predicted Distribution of TN for Soil-Sod Combination #3 (A-2-4 Soil, Pensacola Bahia Sod, No Fertilizer and 10-10-10 Fertilization Practice)

The following observations can be made from Figure 83 and Figure 84 about the fate and transport of phosphate in the soil during the test series. The mass of phosphate in the soils built up over time as tests were run and fertilizer was applied (Figure 83). Additionally, measured TP mass values from soils analysis were compared to the modeled values and show good agreement as in the overall trend is for TP mass to build up in the soil. It should be noted that the measured values for soil TP mass were more variable than the modeled ones. The phosphorus lost via sod uptake, seepage since the previous test, from the flush events that occurred after the simulated rain event, and the mass of TP lost during the simulated rain event were significant and played a major role in the mass lost from the system (Figure 84). It should be noted that a significant amount of TP remained in the soil during the test series.

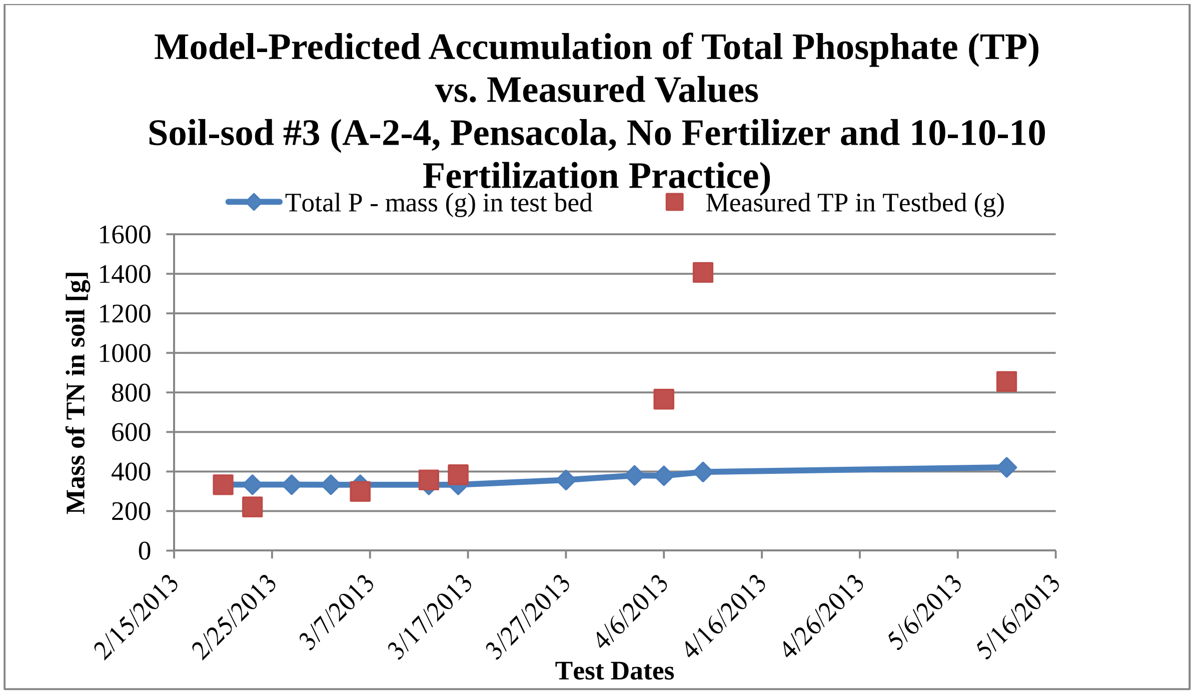

Figure 83: Phase #2 Model-Predicted Accumulation of Total Phosphate (TP) vs. Measured Values Soil-Sod Combination #3 (A-2-4 Soil, Pensacola Bahia Sod, No Fertilizer and 10-10-10 Fertilization Practice)

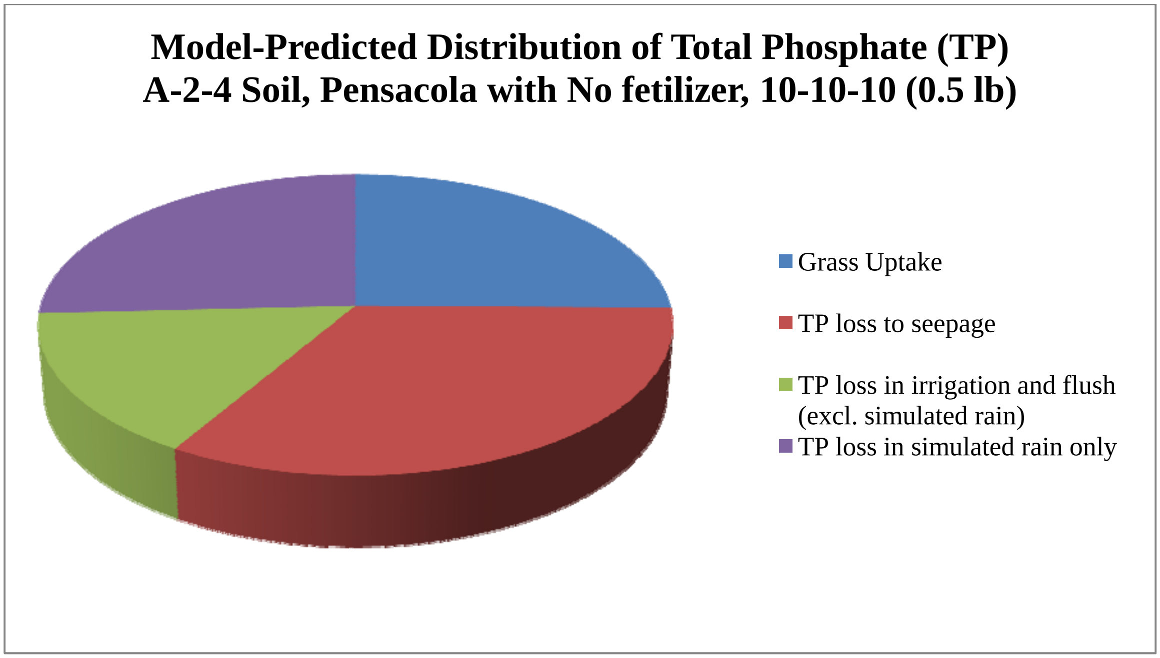

Figure 84: Phase #2 Model-Predicted Distribution of Total Phosphate (TP) for Soil-Sod Combination #3 (A-2-4 Soil, Pensacola Bahia Sod, No Fertilizer and 10-10-10 Fertilization Practice)

5.5.3 Phase #1 Soil-Sod Combination 4 for 16-0-8 (SR) Fertilization Practice

The seven tests that were conducted on the soil-sod combination 4 are reproduced from Table 2 and are listed in Table 76. The moisture balance of this combination was analyzed as per models described before and using a spreadsheet and presented in Table 101. The mass balance of total nitrogen (TN) is also presented in Table 102.

Table 76: Chronological Sequence of Tests on Soil-Sod Combination 4 – Phase #1

Test #	Soil	Bahia Sod	Fertilizer	Slope	in/hr	Date
1	A-2-4	Pensacola	16-0-8	25%	1	5/13/2010
2	A-2-4	Pensacola	16-0-8	25%	3	5/17/2010
3	A-2-4	Pensacola	16-0-8	25%	0.5	5/20/2010
4	A-2-4	Pensacola	16-0-8	33%	1	5/24/2010
5	A-2-4	Pensacola	16-0-8	33%	0.5	5/27/2010
6	A-2-4	Pensacola	16-0-8	50%	0.5	6/1/2010
7	A-2-4	Pensacola	16-0-8	50%	1	6/4/2010

Figure 85 shows the accumulation of TN in the system over time. The mass generally increases with time and fertilizer application but can decrease under the right conditions. Figure 86 shows the distribution of TN pathways in this system. The losses from ammonia volatilization, seepages since previous test, and denitrification were insignificant playing a minimal role in TN mass loss accounting for about 2% of the total applied. The sod uptake, the flush between simulated rain events, and the simulated rainfall events were shown to account for about 11%, 15%, and 31% respectively, which is significant compared to other potential loss avenues. The remaining TP in the system accounted for about 38%.

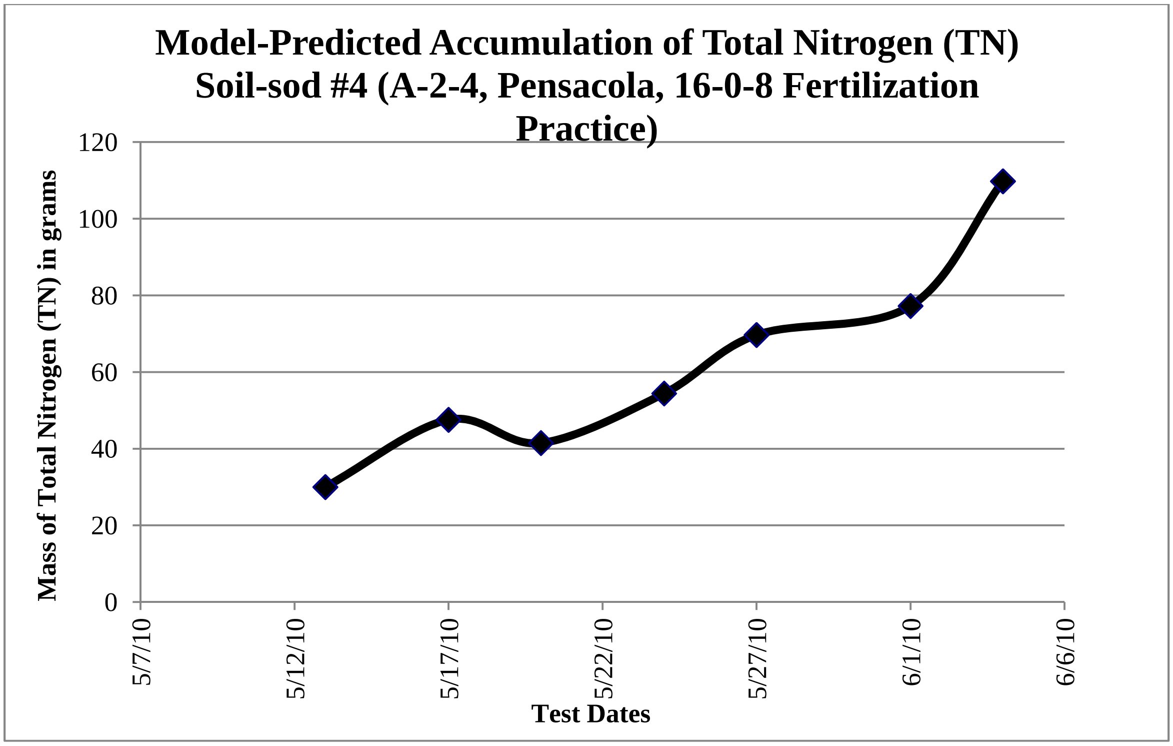

Figure 85: Model-Predicted Accumulation of Total Nitrogen (TN) for Soil-Sod Combination #4 (A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 (SR) Fertilization Practice)

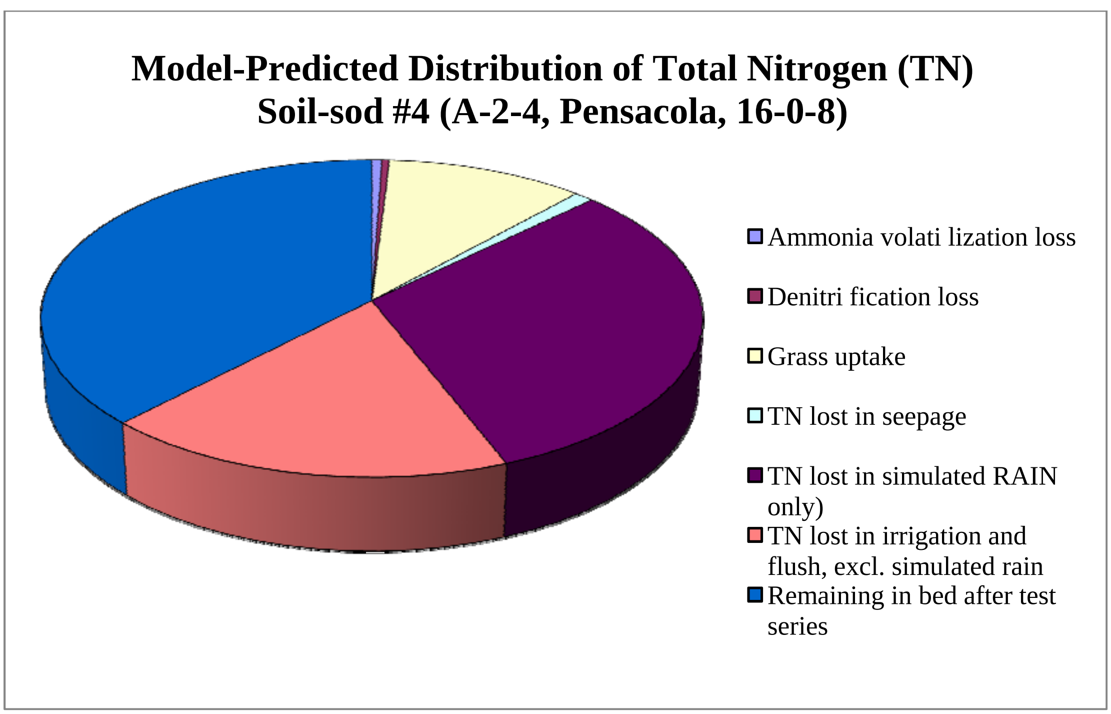

Figure 86: Model-Predicted Distribution of Total Nitrogen (TN) Soil-Sod Combination #4 (A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 (SR) Fertilization Practice)

Figure 87 displays the percent of TN lost in the simulated rainfall event to the total available at the time of the test. With the exception of the two tests run on the 1 to 2 slope, the TN mass loss was significant and tended to increase with rainfall intensity. The tests run on the 1 to 2 slope seem too low to be reasonable.

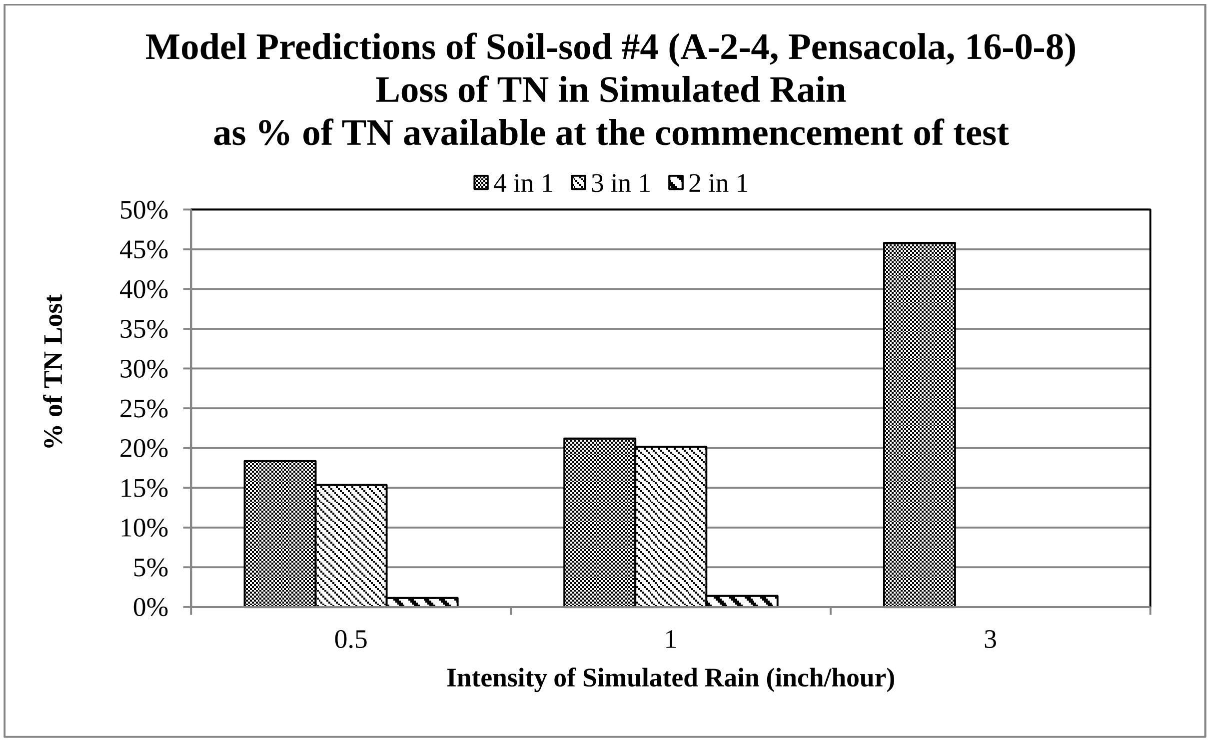

Figure 87: Model Predictions of Soil-Sod Combination #4 (A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 (SR) Fertilization Practice) Loss of TN in Simulated Rain as a Percentage of TN Available at the Commencement of Test

5.5.4 Phase #2 Soil-Sod Combination 4 for 16-0-8 (SR) Fertilization Practice

The six tests that were conducted on the soil-sod combination 1 for phase #2 of this study are reproduced from Table 31 and are listed in Table 77. As described before, the moisture balance of this combination was analyzed and is presented in Table 111. The mass balance of total nitrogen (TN) is also presented in Table 112.

Table 77: Chronological Sequence of Tests on Soil-Sod Combination 4 – Phase #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 total nitrogen mass balance and Figure 88 revealed a few trends about the nitrogen in the system and its fate. This figure shows that TN mass is slowly released from the soil but stays relatively stable. Additionally, a comparison to measured TN mass values is compared to the values predicted by the model. Due to insufficient measured data no trends were able to be observed. Examination of Figure 89 shows the model prediction of the fate of TN in the system. It can be seen from this figure that only the seepage between tests is a major pathway for the loss of TN mass from the system accounting for about 80% of the total lost from the test bed.

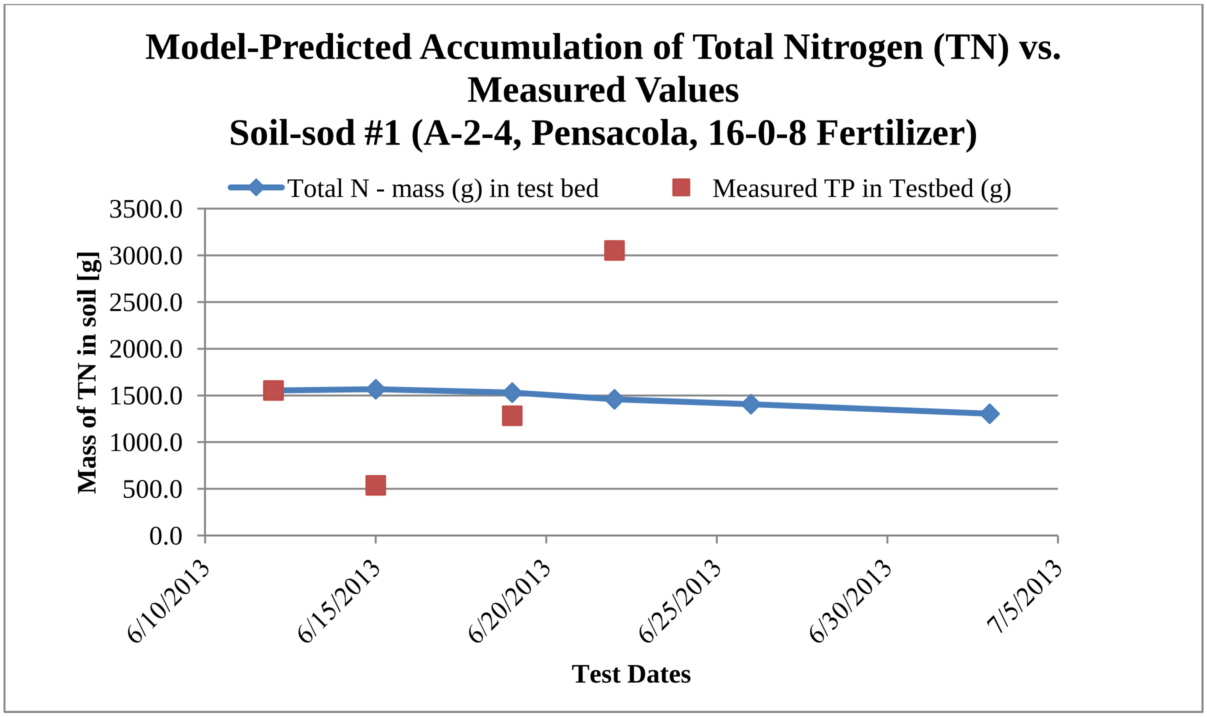

Figure 88: Phase #2 Model-Predicted Accumulation of TN vs Measured Values in Soil-Sod Combination #4 (A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 Fertilization Practice)

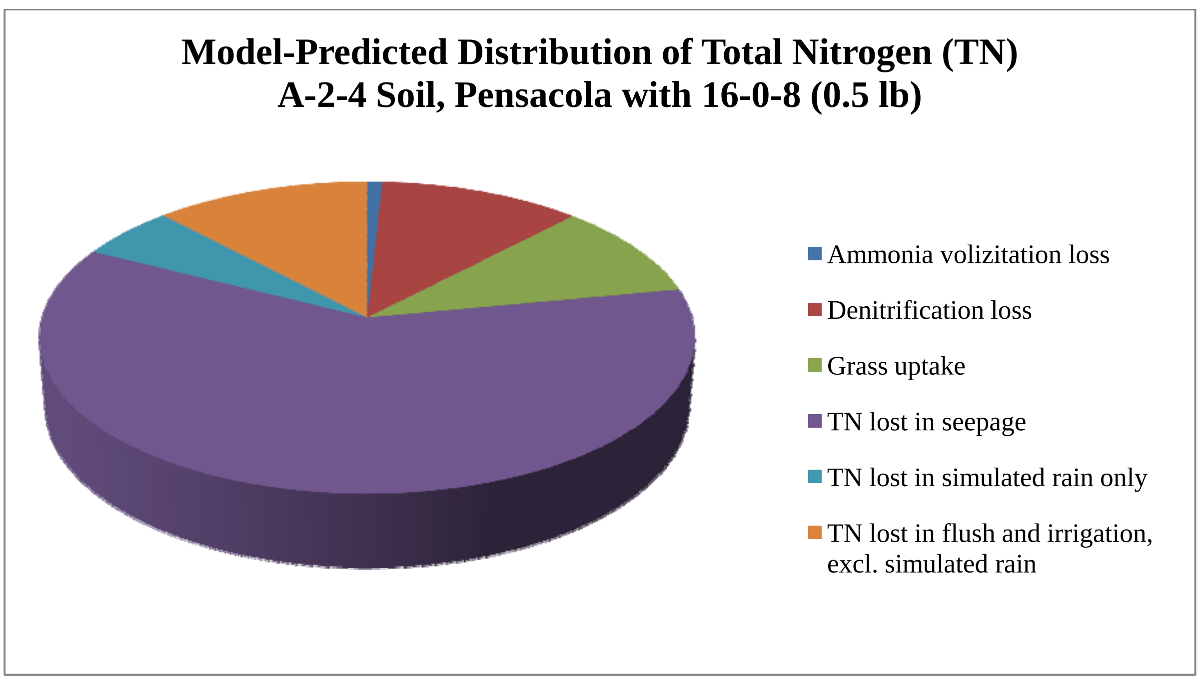

Figure 89: Phase #2 Model-Predicted Distribution of TN for Soil-Sod Combination #4 (A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 Fertilization Practice)

CHAPTER 6. ONE-DAY TESTS COMPARED TO SEVEN-DAY TESTS, 10-10-10 FERTILIZATION PRACTICE

As described in chapter 3 in the phase #1 study, two seven-day tests were also conducted using the 10-10-10 fertilizer at 3 in/hr rainfall intensity, one each on A-3 soil and A-2-4 soil. These tests were in addition to the two tests conducted as one-day tests with the same fertilizer and soils at 3 in/hr rainfall intensity. These two additional tests were conducted as per FDOT's suggestion for examining the loss of nutrients on a more long-term and worst-case-scenario basis. The prime research objective of these tests was to compare the results of the seven-day tests with the one-day tests for getting insights into the differences in nutrient losses between solitary and repeated applications of intensive rainfall. For serving as a common basis, the fertilizer was applied on the first day only, for both one-day and seven-day tests, the differences being only in the number and timing of rainfall application. As described in chapter 4, in the phase #2 study, four more seven-day tests were also conducted using both the 10-10-10 fertilizer as well as the 16-0-8 fertilizer on both soil and sod combinations for the 0.25 in/hr rainfall intensity. The comparisons between these tests are analyzed and presented in this section.

6.1 AASHTO A-3 Soil with Argentine Bahia Sod – Phase #1

Table 78 shows the comparison of TN and TP losses for the one day test at the 3 in/hr rainfall intensity (on 1 to 4 slope) to the seven-day test at the same rainfall intensity (on 1 to 3 slope) for phase #1 of the study. From the table, it is seen that while the losses of TN and TP for the seven-day tests are lower than in the one-day tests, the masses of both total nitrogen and total phosphate are significant. After examining the data, it is difficult to make any significant conclusions from this comparison. Several factors might have influenced these results, such as the seven-day test preceded by several 16-0-8 (SR) fertilizer tests, while the one-day test preceded by several 10-10-10 fertilizer tests. This should have accumulated both TP and TN in the soil, thus potentially elevating the results for the one-day test compared to the seven-day test. The seven-day test, however, does show that the TN and TP continues to leave the system for rain events that happen three to seven days after fertilizer application. This implies that some portion of the fertilizer nutrients tend to remain in soil, notwithstanding all the biochemical processes and weather events.

Table 78: Comparison of 10-10-10 One-Day and Seven-Day Tests, TN and TP Losses (in grams)

	One-Day Test	**Seven-Day Test**		
	1:4 Slope, 10-10-10 (6-10-2009)	**1:3 Slope, 10-10-10, Day One (10-13-2009)**	**1:3 Slope, 10-10-10, Day Three (10-15-2009)**	**:3 Slope, 10-10-10, Day Seven (10-20-2009)**
Rainfall intensity in/hr	3 in/hr Intensity	3 in/hr Intensity	3 in/hr Intensity	3 in/hr Intensity
TN	57.78	38.86	25.38	18.9
TP	78.58	13.47	2.31	1.16

As described previously in Table 2, the one-day test on 6/10/2009 was conducted after conducting two tests using 10-10-10, which is quick release fertilizer with considerable phosphate. In contrast, the seven-day test from 10/13/2009 to 10/20/2009 was conducted after conducting seven tests using 16-0-8 (SR), which is slow release fertilizer with no phosphate. It is likely that there was considerably high accumulation of TN and TP in the test bed for the one-day test compared to the seven-day test. These are the primary causes for the seven-day tests resulting in lower losses of TN and TP than the one-day tests.

6.2 AASHTO A-2-4 Soil with Pensacola Bahia Sod – Phase #1

Table 79 shows the comparison of the 10-10-10 fertilizer one-day test to the seven-day test for phase #1 of the study. Once again, while the losses of TN and TP for the seven-day test were higher than the one-day test, the masses of both total nitrogen and total phosphate were significant for both tests. It is hard to make any significant conclusions from this comparison. There were several factors that might have influenced the nutrient losses, such as the ones noted in the previous sub-section which indicates that both TN and TP mass loss was low compared to other tests in that series.

Table 79: Comparison of 10-10-10 One-Day Test with Seven-Day Test, TN and TP Losses (in grams)

	One-Day Test	**Seven-Day Test**		
	1:4 Slope, 10-10-10 (2-4-2010)	**1:3 Slope, 10-10-10, Day One (3-23-2010)**	**1:3 Slope, 10-10-10, Day Three (3-25-2010)**	**1:3 Slope, 10-10-10, Day Seven (3-29-2010)**
Rainfall intensity in/hr	3 in/hr Intensity	3 in/hr Intensity	3 in/hr Intensity	3 in/hr Intensity
TN	25.12	36.89	19.51	3.32
TP	24.14	77.59	4.07	5.03

As described in Table 2, the one-day on 2/4/2010 was conducted after conducting just one test using 10-10-10. In contrast, the seven-day test from 03/23/2009 to 03/29/2010 was conducted after conducting seven tests using 10-10-10. Therefore, there was considerably high accumulation of both TN and TP in the test bed for the seven-day test compared to the one-day test. In addition, TP accumulation was probably high because of its lower uptake by the grass, and its greater affinity to the A-2-4 soil. These are the primary causes for the seven-day tests resulting in lower losses of TN and TP than the one-day tests.

6.3 AASHTO A-3 Soil with Argentine Bahia Sod – Phase #2

Table 80 shows the comparison of the 10-10-10 fertilizer total nitrogen and total phosphorus losses from a one-day test to the seven-day test at the same rainfall intensity from A-3 soil with Argentine Bahia sod. As mentioned above in chapter 4, no runoff was generated from A-3 soil tests. One-day test losses of both total nitrogen and total phosphorus were greater than losses from both days of the seven-day test. Chronologically speaking, however, the seven-day tests were performed last and several one-day tests were conducted prior to them. As discussed in chapter 4, soil tests showed that this soil and sod combination was already nutrient heavy suggesting that the sod was previously fertilized prior to any addition of fertilizer. Thus, the one day tests may be showing higher TN and TP masses due to fertilizer applied by the sod provider prior to testing.

Table 80: Comparison of One-Day Test with Seven-Day Test on A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice

Intensity (in/hr)	0.25	0.25	0.25
Test Type	**One-Day**	**Seven-Day, Day 1**	**Seven-Day, Day 7**
TN Mass (g)			
Base flow	0.71	0.24	0.27
Runoff	0	0	0
Total	0.71	0.24	0.27
TP Mass (g)			
Base flow	0.02	0.005	0.003
Runoff	0	0	0
Total	0.02	0.01	0.0030

Table 81 shows the comparison of the 16-0-8 fertilizer total nitrogen and total phosphorus losses from a one-day test to the seven-day test at the same rainfall intensity from A-3 with Argentine Bahia sod. One-day losses were lower than losses on the first day of the seven-day test, but slightly higher than losses on the seventh day. Based on the soil tests before any fertilizer addition, this batch of A-3 and Argentine bahia was also nutrient heavy prior to addition of fertilizer, and the testing sequence was such that the seven-day tests were conducted after the one-day tests. The reasons for this could be that contrary to the 10-10-10 fertilizer, the slow-release 16-0-8 could have accumulated in the soil and gradually released nutrients into the soil resulting in higher losses after a period. Total phosphorus losses were not significant, which is expected as 16-0-8 fertilizer does not contain any phosphorus.

Table 81: Comparison of One-Day Test with Seven-Day Test, on A-3 Soil, Argentine Bahia Sod, and 16-0-8 Fertilization Practice

Intensity (in/hr)	**0.25**	**0.25**	**0.25**
Test Type	**One-Day**	**Seven-Day, Day 1**	**Seven-Day, Day 7**
TN Mass (g)			
Base flow	0.23	0.80	0.19
Runoff	0	0	0
Total	0.23	0.80	0.19
TP Mass (g)			
Base flow	0.004	0.003	0.003
Runoff	0	0	0
Total	0.004	0.003	0.003

6.4 AASHTO A-2-4 Soil with Pensacola Bahia Sod – Phase #2

Table 82 shows the comparison of the 10-10-10 fertilizer total nitrogen and total phosphorus losses from a one-day test to the seven-day test at the same rainfall intensity from A-2-4 and Pensacola Bahia sod. The TN and TP losses were lower for the seven-day test than the one-day test; however, losses were significant for both tests. The likely cause of the discrepancy between day one of the seven-day test and the one-day test is potential accumulation of nutrients; however, chronologically the seven-day tests were performed between the two one-day tests at 0.25 in/hr. Thus, the likely cause was variation in soil temperature and soil moisture content resulting in differences in amounts lost from the test bed. Additionally, it can be seen that mass losses of TN and TP on day seven were not significant. This is likely because no runoff was generated for this test, which is the dominate mechanism of TN and TP mass transport out of the system.

Table 82: Comparison of One-Day Test with Seven-Day Test on A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice

Intensity (in/hr)	0.25	0.25	0.25
Test Type	One-Day	Seven-Day, Day 1	Seven-Day, Day 7
TN Mass (g)			
Base flow	1.15	0.66	0.18
Runoff	3.87	2.04	0
Total	5.02	2.69	0.18
TP Mass (g)			
Base flow	0.21	0.11	0.0006
Runoff	1.70	1.19	0
Total	1.91	1.30	0.0006

Table 83 shows the comparison of the 16-0-8 fertilizer total nitrogen and total phosphorus losses from a one-day test to the seven-day test at the same rainfall intensity. Total nitrogen losses from the seven-day test on both days were greater than the losses from the one-day test. This is likely because of unintended accumulation of nitrogen in the soil, since the seven-day test was performed after several one-day tests, the first couple of which were at the 0.25 in/hr intensity. The results from the seven-day test show that nitrogen continues to leave the system a week after the initial application of fertilizer. Total phosphorus losses were not significant, which is expected as 16-0-8 fertilizer does not contain any phosphorus.

Table 83: Comparison of One-Day Test with Seven-Day Test on A-2-4 Soil, Pensacola Bahia Sod, and 16-0-8 Fertilization Practice

Intensity (in/hr)	0.25	0.25	0.25
Test Type	One-Day	Seven-Day, Day 1	Seven-Day, Day 7
TN Mass (g)			
Base flow	1.89	5.6	3.09
Runoff	1.04	3.91	1.06
Total	2.93	9.51	4.15
TP Mass (g)			
Base flow	0.02	0.02	0.05
Runoff	0.06	0.09	0.05
Total	0.08	0.11	0.11

CHAPTER 7. COMPARISON OF 10-10-10 AND 16-0-8 (SR) FERTILIZATION PRACTICES

One of the main objectives of this study was to examine the potential water quality benefits due to the change in fertilization practices of the FDOT, viz., replacing 10-10-10 quick-release fertilizer @ 1 lb of N per 1000 ft^2 (former practice), to the current practice of using 16-0-8 (slow-release) fertilizer @ either 1 lb or 0.5 lb of N per 1000 ft^2. During the course of this project a new FDOT fertilization practice was brought to the attention of the authors, viz., 16-0-8 (SR) @ 0.5 lb of N per 1000 ft^2. It is for this reason that 16-0-8 (SR) fertilizer was tested at an application rate of 0.5 lb of N per 1000 ft^2 and compared to the results of the 16-0-8 (SR) fertilizer applied at 1 lb of N per 1000 ft^2. Comparing the 35 tests in phase #1 and 34 tests in phase #2 on the A-3 and A-2-4 soils that were conducted following one of these practices, it is found that nutrient losses were considerably less from 16-0-8 (SR) than from the 10-10-10 application. Presented below are detailed comparisons for both fertilization practices.

7.1 AASHTO A-3 Soil and Argentine Bahia – Phase #1

The first case examined is the 10-10-10 fertilizer compared to the 16-0-8 (SR) fertilizer with both applied at a rate of 1 lb of N per 1000 ft^2. The tables and figures presented here and above in Chapter 3 show that there is an environmental benefit in the form of reduced TN and TP loss when using a 16-0-8 (SR) fertilizer at both application rates compared to the 10-10-10 fertilizer. The most noticeable difference was with the mass of TP lost from the system; the TP losses from the 16-0-8 (SR) fertilizers at either application rate were much lower than that from 10-10-10 fertilizer (see Figure 90 and Figure 91). This is because there is no phosphate in the

16-0-8 (SR) fertilizer and FDOT's borrow area soils or the sod contains no significant phosphate content.

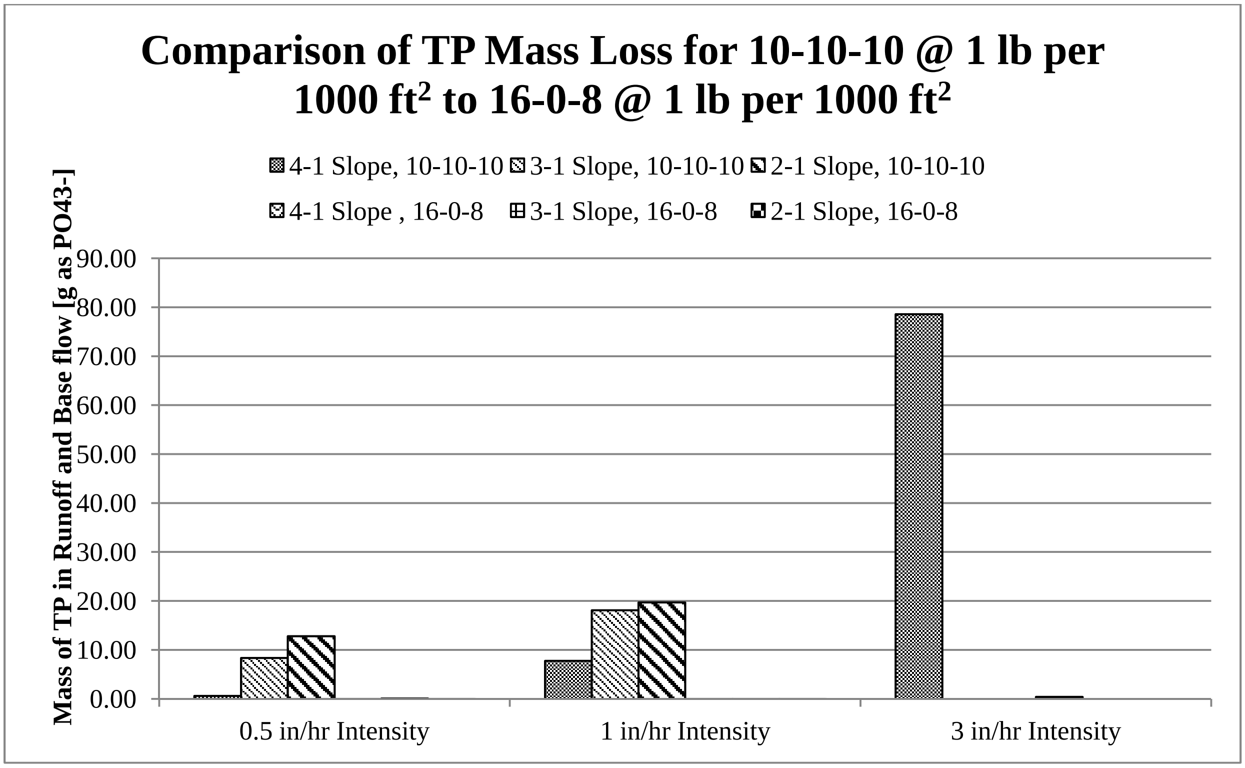

Figure 90: Comparison of TP Loss from A-3 Soil for 10-10-10 and 16-0-8 (SR) Fertilization Practice @ 1 lb of N per 1000 ft^2 – Phase #1

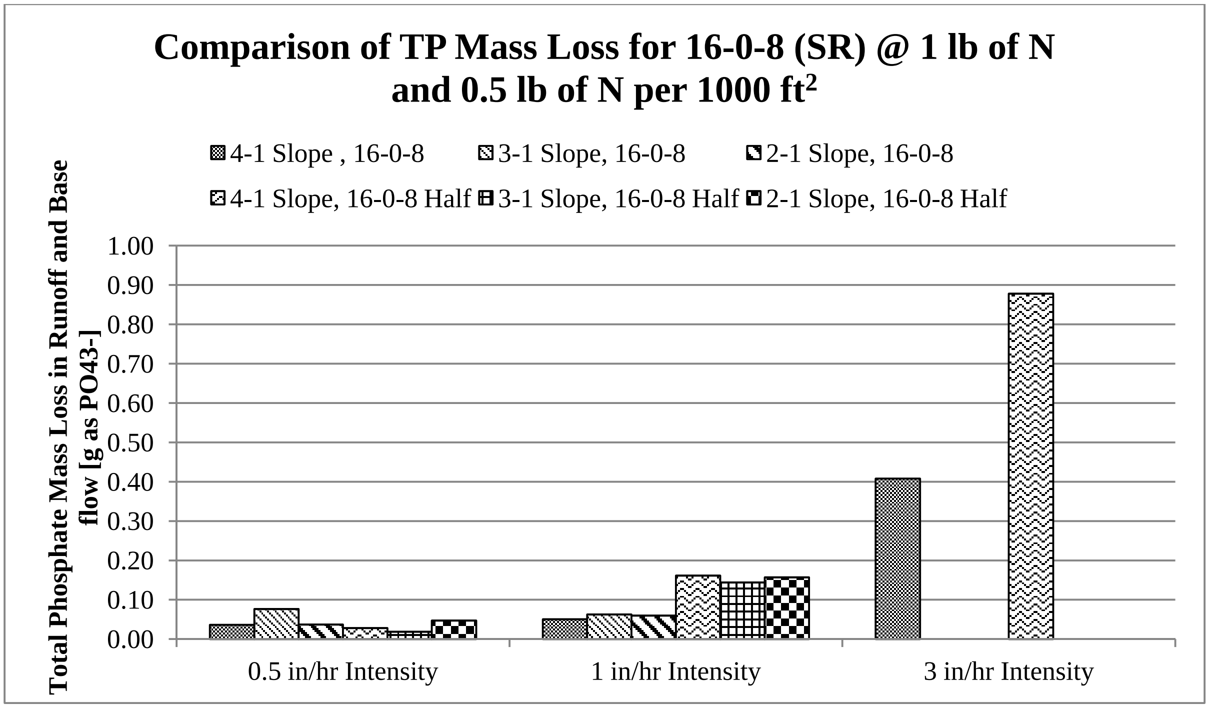

Figure 91: Comparison of TP Losses from A-3 Soil for 16-0-8 (SR) Fertilization Practice at (1 lb and 0.5 lb of N per 1000 ft^2) – Phase #1

Comparing the TN mass loss from the 10-10-10 fertilizer at an application rate of 1.0 lb of N per 1000 ft^2 to the 16-0-8 (SR) fertilizer at an application rate of 1.0 lb of N per 1000 ft^2 on the A-3 soil (Figure 92). It can be seen that there is a general trend for the nutrient loss to increase with increasing slope and rainfall intensity. At the 0.5 in/hr rainfall intensity, there is no real difference in TN mass loss for both fertilizers. At the 1.0 in/hr rainfall intensity, however, there is a significant difference between the two fertilizer types. The 10-10-10 fertilizer lost significantly more TN mass than the 16-0-8 (SR) fertilizer maxing out at 57.78 g/test bed area and 11.52 g/test bed area, respectively. This difference could be the result of several factors such as the 16-0-8 (SR) fertilizer having a portion of the nitrogen in a slow release form preventing it from being mobilized and washed out of the soil-sod system. Furthermore, difference can br attributed to the percentage of runoff collected to total water collected, and the concentration of total nitrogen in the different water transport methods (i.e. runoff and base flow).

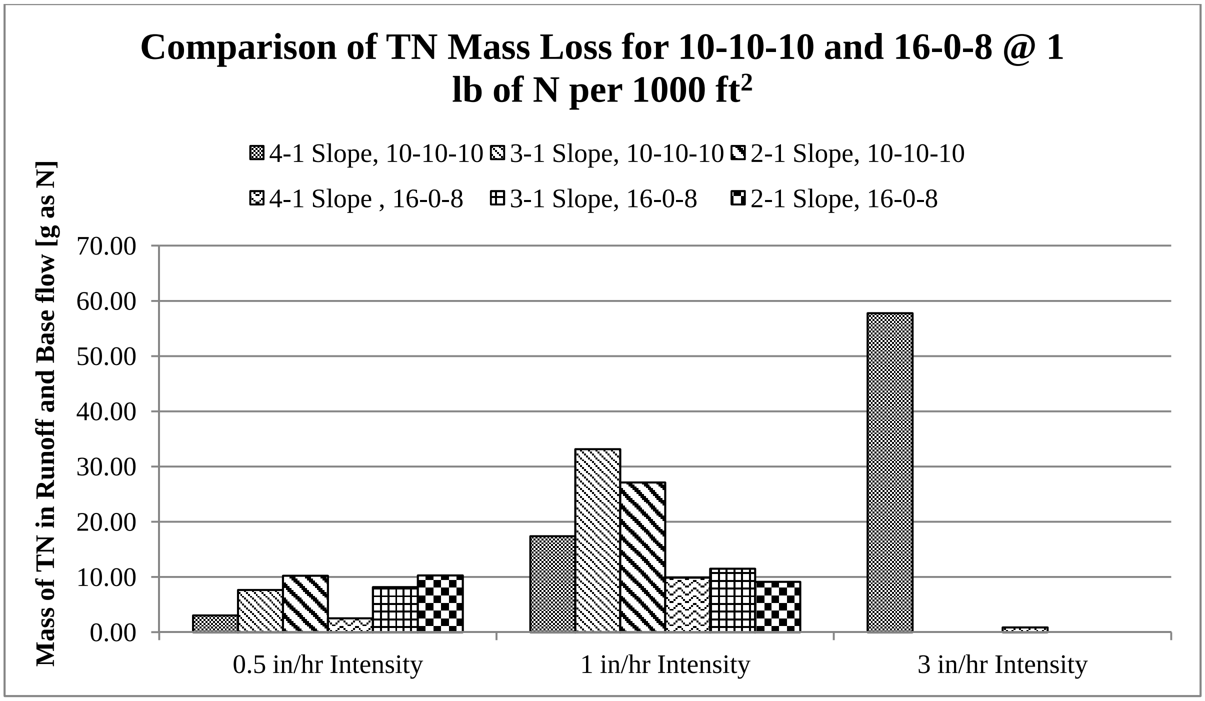

Figure 92: Comparison of TN Loss from A-3 Soil for 10-10-10 and 16-0-8 Fertilization Practices @ 1 lb of N per 1000 ft^2 – Phase #1

Examining the forms of water transport from the system, runoff vs. base flow, several observations can be made. First, runoff volumes collected for the 10-10-10 fertilizer were a larger percentage of the overall water volume collected. The 10-10-10 fertilizer had a percent runoff collected to total water collected that ranged from 8.91% to 79.1% (See Table 6 in chapter 3). The low value, 8.91% was from the 1:4 slope at 0.5 in/hr, the lowest rainfall intensity and slope. The next highest value had a significant increase up to 36.44% at 0.5 in/hr. on 1 to 3 slope. This difference of 27.5% is significant and likely due to starting soil moisture content as well as other environmental conditions. The 1.0 in/hr intensity tests showed a counterintuitive trend of increasing runoff percentage with decreasing slope, again likely due to soil moisture and environmental conditions such as rainfall between tests. As would be expected, the 3.0 in/hr intensity produced the largest percentage runoff. Overall, with the exception of the 0.5 in/hr tests, the dominant form of water lost from this system was from runoff.

The 16-0-8 (SR) fertilizer tests had a runoff percentage that ranged from 0% to 36% showing that the dominant path of water lost from this system was through base flow as opposed to runoff (see Table 12 in chapter 3). All three tests run at 0.5 in/hr intensity did not produce any runoff. The 1.0 in/hr tests generally increased with slope except the 1 to 3 slope which was only slightly higher, about 1%, than the 1 to 2 slope. The 3.0 in/hr test produced the largest percentage runoff. Despite the fact that both the 10-10-10 fertilizer and the 16-0-8 (SR) fertilizer used the same kind of soil and sod, both acquired from the same source, both installed in an identical manner, and both compacted to the same levels and verified using a nuclear density gage, there was a large difference between the runoff percentages collected. This could be the result of a number of factors including, variations in the soil (i.e. more organic matter, difference in gradation, etc.), not being able to match compaction levels identically, and seasonal effects (natural rainfall effecting beginning moisture content, sod uptake, etc.).

An examination of the TN concentrations in runoff and base flow volumes lost from the soil-sod system show a significant difference between fertilizer types (as seen in Table 84). The 10-10-10 fertilizer showed much higher concentrations in the runoff collected as compared to the base flow ranging from 39.57 mg/L as N (an abnormally low value compared to the other values measured) to 104.34 mg/L as N and from 0.48 mg/L as N (abnormally low) to 2.79 mg/L as N for runoff and base flow, respectively. The average concentration of TN in the runoff and base flow is 91.08 mg/L as N and 1.98 mg/L as N, respectively. It should be noted that these averages do not include the abnormal values noted above which are considered to be outliers.

Table 84: Comparison of 10-10-10 and 16-0-8 (SR) Fertilization Practice TN Concentrations in Runoff and Base Flow – Phase #1

	10-10-10							**16-0-8**						
	1:4 Slope			**1:3 Slope**		**1:2 Slope**		**1:4 Slope**			**1:3 Slope**		**1:2 Slope**	
Rainfall intensity inch/hour	0.5 in/hr Intensity	1 in/hr Intensity	3 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity	3 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity
	TN Concentration [mg/L as N]							**TN Concentration [mg/L as N]**						
Base flow	1.66	2.25	0.48	2.79	1.32	2.95	1.89	7.77	13.82	0.39	21.26	19.79	27.30	12.21
	W/ Abnormal Points		W/out Abnormal Points					W/ Abnormal Points		W/out Abnormal Points				
Average	1.91		2.14					14.65		17.03				
Median	1.89							13.82						
Standard Deviation	0.86		0.64					9.01		7.08				
Runoff	88.90	67.42	39.57	85.91	99.65	104.34	100.27	0.00	35.74	1.60	0.00	19.15	0.00	23.65
	W/ Abnormal Points		W/out Abnormal					W/ Abnormal Points		W/out Abnormal Points				
Average	83.72		91.08					20.03		26.18				
Median	88.90							21.40						
Standard Deviation	23.09		13.60					14.15		8.58				

Similar to the 10-10-10 fertilizer, the 16-0-8 (SR) fertilizer showed high runoff concentrations but the base flow concentrations were also high. However, overall the runoff concentrations were higher than the base flow concentrations ranging from 1.6 mg/L as N (abnormal value, low) to 35.74 mg/L as N and from 0.39 mg/L as N (abnormal value, low) to 27.30 mg/L as N respectively. The average concentration of TN in the runoff and base flow is 26.18 mg/L as N and 17.03 mg/L as N respectively. It should be noted that these averages do not include the abnormal values noted above.

These differences in TN concentrations in runoff and base flow along with the differences in total volume collected between the two types of fertilizer might explain the difference in TN mass lost in the system. Since the 10-10-10 fertilizer had a higher percent runoff collected to total volume collected, when compared to the 16-0-8 (SR) fertilizer, higher erosive forces may have been generated by the higher energy runoff waters. This might result in more of the fertilizer washed out of the system resulting in the higher TN concentrations that were observed in runoff between the two fertilizer types. The fact that base flows were the dominant path for water loss from the system for the 16-0-8 (SR) fertilizer could have also played a role in allowing more of the TN to seep into the soil thus increasing base flow concentrations and reducing runoff concentrations compared to the 10-10-10 fertilizer. Another potential factor is the fact that a portion of the 16-0-8 (SR) fertilizer is slow release and may remain bound in the soil/fertilizer particles preventing it from leaving the system through water transport except through erosive forces.

A closer examination of the TN mass fraction leaving the system as runoff and base flow reveals a few trends. The dominant form of TN mass loss from the 10-10-10 fertilizer was through runoff (see Table 8 in chapter 3 above) while the dominant form of TN mass loss from the 16-0-8 (SR) fertilizer was through base flow (see Table 14 in chapter 3 above). The percentage of TN mass lost in runoff for the 10-10-10 fertilizer ranged from 82.72% to 99.65% with the mass loss increasing with increasing slope and rainfall intensity. The percentage of TN mass lost in runoff for the 16-0-8 (SR) fertilizer ranged from 0% to 8.59%, leaving out 67.32% measured in the 3.0 in/hr intensity as the TN mass was abnormally low at 0.87 g as N. This percentage also increased with increasing rainfall intensity and slope.

While the TN lost for both application rates of 16-0-8 (SR) was lower than the 10-10-10 fertilizer, the loss was still significant, up to 11.52 g as N (excluding abnormal data points). The TN mass lost for the 0.5 in/hr. rainfall intensity was noticeably higher for the 1 lb of N per 1000 ft^2 application rate than the 0.5 lb of N per 1000 ft^2 application rate (see Figure 93). The 1.0 in/hr rainfall intensity showed a similar results but had a few abnormal data points, namely the 1 to 4 slope and the 1 to 2 slope for the 16-0-8 (SR) fertilizer at the 0.5 lb of N per 1000 ft^2 application rate which both seemed too high. No conclusions were able to be drawn from the 3.0 in/hr. rainfall intensity as TN mass loss appeared too low to be reasonable for the 16-0-8 (SR) fertilizer applied at 1.0 lb of N per 1000 ft^2. These abnormal data points could be the result of a number of factors such as transformations in the soil, unintentional concentration/dilution in the soil, or other unidentified error.

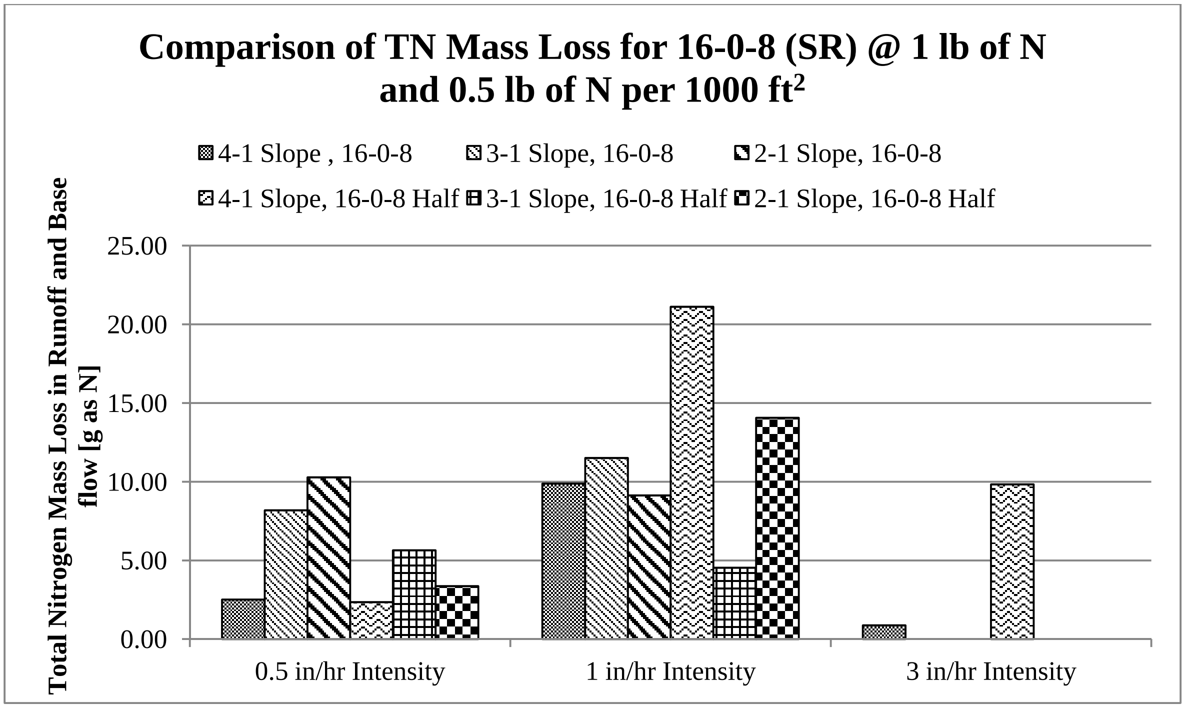

Figure 93: Comparison of TN Mass Loss from A-3 Soil for 16-0-8 (SR) Fertilization Practice at Two Application Rates (1 lb and 0.5 lb of N per 1000 ft^2) – Phase #1

Analyses of the percentage of runoff to total water volume collected showed that no real difference exists (see Figure 12 and Figure 15 in chapter 3). The main form of water transport out of the system is through base flow. However, there was a significant increase in runoff percentage for the 3.0 in/hr. rainfall intensities for both application rates. The percent of TN mass lost in runoff followed a similar trend being very low and increasing on the 3.0 in/hr rainfall intensity (see Table 14 and Table 17 in chapter 3). This is expected as neither the soil nor the sod was changed between the two test series. The average TN concentrations for both runoff and base flow were higher for the 1.0 lb of N application and the TN concentrations were slightly higher in runoff than base flow, as seen in Table 85.

Overall, the TP losses in the seven tests conducted with 16-0-8 (SR) @ 0.5 lb were more than in the TP losses in the seven tests conducted with 16-0-8 (SR) @ 1 lb. As described in Table 3.2, the series of tests @ 0.5 lb rate was conducted during October-November of 2009, after conducting a seven-day test using 10-10-10 fertilizer. Therefore, there was some TP left over in the test bed. The series of tests @ 1.0 lb rate were conducted during August-September of 2009 on virgin soils, before any phosphate fertilizer was applied. Definitive conclusions could not be drawn based on the masses of TP lost or from the mass balance analyses presented in chapter 3. Detailed modeling studies are needed for accurate analysis and interpretation.

Table 85: Comparison of 16-0-8 (SR) and Half 16-0-8 (SR) Fertilization Practices TN Concentrations in Runoff and Base Flow – Phase #1

	16-0-8							Half 16-0-8						
	1:4 Slope			1:3 Slope		1:2 Slope		1:4 Slope			1:3 Slope		1:2 Slope	
Rainfall intensity inch/hour	0.5 in/hr Intensity	1 in/hr Intensity	3 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity	3 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity
	TN Concentration [mg/L as N]							**TN Concentration [mg/L as N]**						
Base flow	7.77	13.82	0.39	21.26	19.79	27.30	12.21	14.18	56.15	8.93	15.89	6.86	7.95	17.48
	W/ Abnormal Points		W/out Abnormal Points					W/ Abnormal Points		W/out Abnormal Points				
Average	14.65		17.03					18.21		11.88				
Median	13.82							14.18						
Standard Deviation	9.01		7.08					17.23		4.52				
Runoff	0.00	35.74	1.60	0.00	19.15	0.00	23.65	0.00	12.67	14.43	0.00	7.34	0.00	19.49
	W/ Abnormal Points		W/out Abnormal Points					W/ Abnormal Points		W/out Abnormal Points				
Average	20.03		26.18					13.48		NA				
Median	21.40							13.55						
Standard Deviation	14.15		8.58					5.01		NA				

7.2 AASHTO A-2-4 Soil and Pensacola Bahia – Phase #1

Both the 10-10-10 fertilizer and 16-0-8 (SR) fertilizer, applied at 1.0 lb of N and 0.5 lb of N per 1000 ft^2 respectively, were also tested on A-2-4 soil with Pensacola Bahia sod. This represents typical of conditions in northern Florida. Similar to the A-3 soil there was a benefit to switching from the 10-10-10 fertilizer to the 16-0-8 (SR) fertilizer. This benefit was most obvious in the TP mass lost from the system. The 16-0-8 (SR) fertilizer had much lower loss (as seen in Figure 94). This is expected as the 10-10-10 fertilizer added 142 grams of phosphate to the test bed while the 16-0-8 (SR) fertilizer added none.

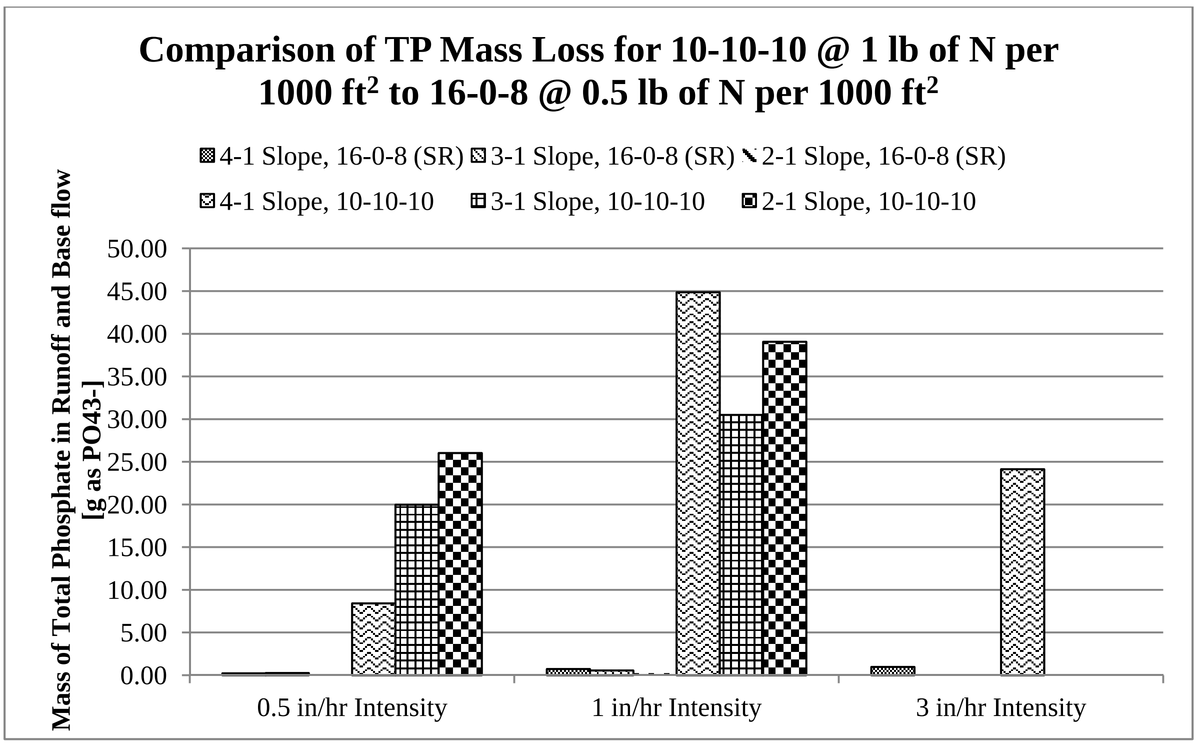

Figure 94: Comparison of TP Losses from A-2-4 Soil for 10-10-10 Fertilization Practice @ 1.0 lb and 16-0-8 (SR) Fertilization Practice @ 0.5 lb of N per 1000 ft^2 – Phase #1

Examination of the TN mass lost from the system showed that the 10-10-10 fertilizer lost significantly more than the 16-0-8 (SR) fertilizer, except for the 3.0 in/hr intensity (see Figure 95). Excluding the 3.0 in/hr rainfall intensity, the TN mass loss from the 10-10-10 fertilizer was as high as 38.85 g as N/test bed area and the 16-0-8 (SR) fertilizer was as high as 21.69 g as N/test bed area. Generally, the TN mass lost increased with slope and rainfall intensity.

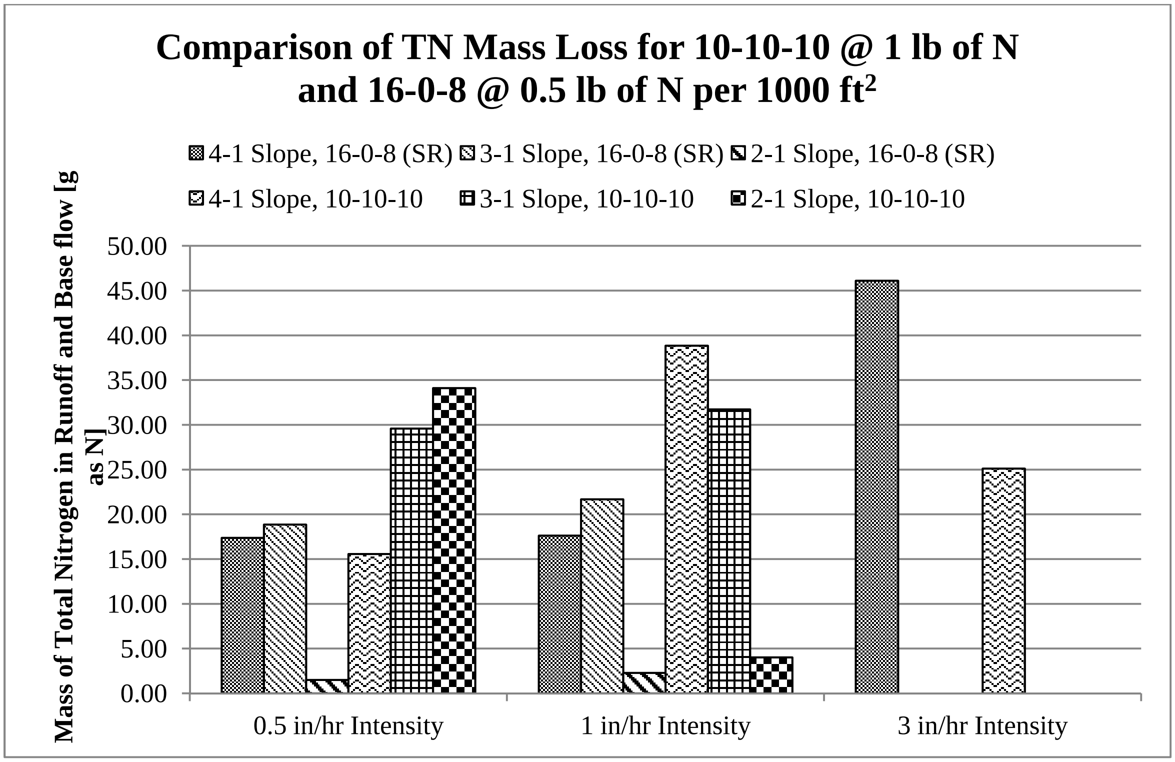

Figure 95: Comparison of TN Mass Loss from A-2-4 Soil for 10-10-10 and 16-0-8 Fertilization Practices at 1 lb and 0.5 lb of N, Respectively, per 1000 ft^2 – Phase #1

Examination of the percentage of runoff to total water collected for the 10-10-10 fertilizer showed that runoff is dominant form of water lost from the system. The percentage of runoff increased, as expected, with increasing rainfall intensity (Table 21 in chapter 3) ranging from 64.8% to 91.93%. However, an increase in slope did not necessarily increase the runoff percentage. This is likely due to local environmental conditions such as temperature and natural rainfall to name a few. The percentage of runoff to total water collected for the 16-0-8 (SR) fertilizer ranged from 78.19% to 94.07% and increases with increasing rainfall intensity (from Table 27 in chapter 3). Increasing the slope however, did not necessarily increase the runoff percentage. The difference between the two fertilizer types are minor and are likely due to changing the soil and sod between test series, or environmental conditions. The dominant means of water loss from the system for both fertilizer types again is from runoff.

The percentage of TN mass lost in runoff for the 10-10-10 fertilizer ranged from 91.17% to 99.09% (see Table 23 in chapter 3). The 91.17% loss was from the 1 to 2 slope at 1.0 in/hr test had an abnormally low TN mass loss value of 4 g as N/test bed area. This may be due to 3.5 inches of natural rainfall that occurred before the test possibly flushing out some fertilizer or an analytical/equipment error. All other tests had percent of TN mass lost in runoff values in the high 90%'s and no trend was observed. The percentage of TN mass lost in runoff for the 16-0-8 (SR) fertilizer ranged from 98.03% to 99.69% showing no trend for rainfall intensity or slope (see Table 3.29 in chapter 3 above). The total mass lost for two tests, 0.5 in/hr and 1.0 in/hr at 1 to 2 slope was abnormal with unusually low values of 1.5 and 2.3 g of N/test bed area. This may be due to 2.4 and 0.5 inches of natural rainfall that occurred before the 0.5 in/hr and 1.0 in/hr test, respectively, or another unknown intended error. From the data provided it is evident that the dominant form of TN mass transport out of the system was from runoff for both fertilizer types.

The concentrations of TN measured in runoff and base flow support the findings above, that is runoff is the dominant transport mechanism of TN mass from this soil-sod system for both fertilizer types, as evident from Table 86. The 10-10-10 fertilizer had a TN concentration in runoff that ranged from 60.68 mg/L as N to 104.66 mg/L as N and ranged from 1.47 mg/L as N to 3.68 mg/L as N for base flow. The average concentration of TN in runoff was 86.46 mg/L as N and 3.14 mg/L as N for base flow. These ranges and averages do not include abnormal values, which seemed unreasonable and were deemed to be outliers.

The 16-0-8 (SR) fertilizer had TN concentrations that ranged from 28.93 to 55.78 mg/L as N for runoff and 0.17 to 2.27 mg/L as N for base flow. The average concentration of TN in runoff was 41.55 mg/L as N and 1.27 mg/L as N for base flow. The average TN concentrations in runoff and base flow for the 16-0-8 (SR) fertilizer are less than half of the TN concentrations in runoff and base flow for the 10-10-10 fertilizer.

Table 86: Comparison of 10-10-10 and Half 16-0-8 (SR) Fertilization Practices TN Concentrations in Runoff and Base Flow

	10-10-10							**Half 16-0-8 (SR)**						
	1:4 Slope			**1:3 Slope**		**1:2 Slope**		**1:4 Slope**			**1:3 Slope**		**1:2 Slope**	
Rainfall intensity inch/hour	0.5 in/hr Intensity	1 in/hr Intensity	3 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity	3 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity	0.5 in/hr Intensity	1 in/hr Intensity
	TN Concentration [mg/L as N]							**TN Concentration [mg/L as N]**						
Base flow	1.47	2.77	2.44	3.60	14.60	12.80	5.42	1.37	2.27	0.81	1.93	1.85	0.17	0.47
	W/ Abnormal Points		W/out Abnormal Points					W/ Abnormal Points		W/out Abnormal Points				
Average	6.16		3.14					1.27		NA				
Median	3.60							1.37						
Standard Deviation	5.32		1.49					0.80		NA				
Runoff	93.59	72.71	38.38	100.65	60.68	104.66	7.18	55.78	36.86	28.93	54.57	31.62	4.61	3.29
	W/ Abnormal Points		W/out Abnormal Points					W/ Abnormal Points		W/out Abnormal Points				
Average	68.26		86.46					30.81		41.55				
Median	72.71							31.62						
Standard Deviation	35.86		18.95					21.10		12.76				

7.3 AASHTO A-2-4 Soil with Pensacola Bahia Sod – Phase #2

The application rate of fertilizer for the 10-10-10 and 16-0-8 fertilization practice were 0.5 lb N/1000 ft^2 for phase #2 of the study. Figure 96 revealed that more TN mass was lost from the test bed using the 16-0-8 fertilization practice than the 10-10-10 fertilization practice at the 0.1 in/hr rainfall intensity tests. However, at the 0.25 in/hr rainfall intensity tests, there was slightly less mass of TN collected from the 16-0-8 than the 10-10-10 fertilization practices. Figure 97 showed that the mass of TP loss from the 16-0-8 fertilization practice was much lower than the 10-10-10 fertilization practice at the 0.25 in/hr rainfall intensity. However, at the 0.1 in/hr rainfall intensity tests, even though the values were marginal, the mass of TP was slightly higher in the 16-0-8 than 10-10-10 fertilization practices, even though there was no phosphate added to the soil with use of the 16-0-8 fertilization practice. The discrepancy suggests that there might have been some nutrients inherent in the soil and sod combination used for the 16-0-8 fertilization practice.

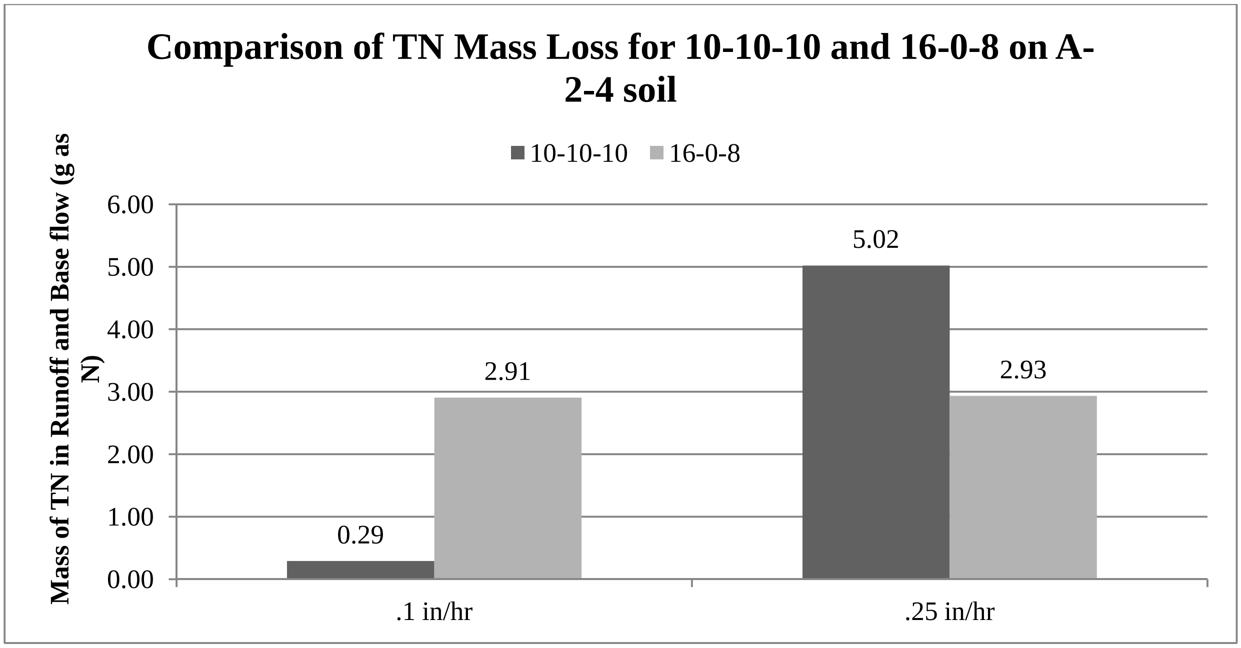

Figure 96: Comparison of TN Losses from A-2-4 Soil for 10-10-10 and 16-0-8 Fertilization Practices @ 0.5 lb of N per 1000 ft^2 – Phase #2

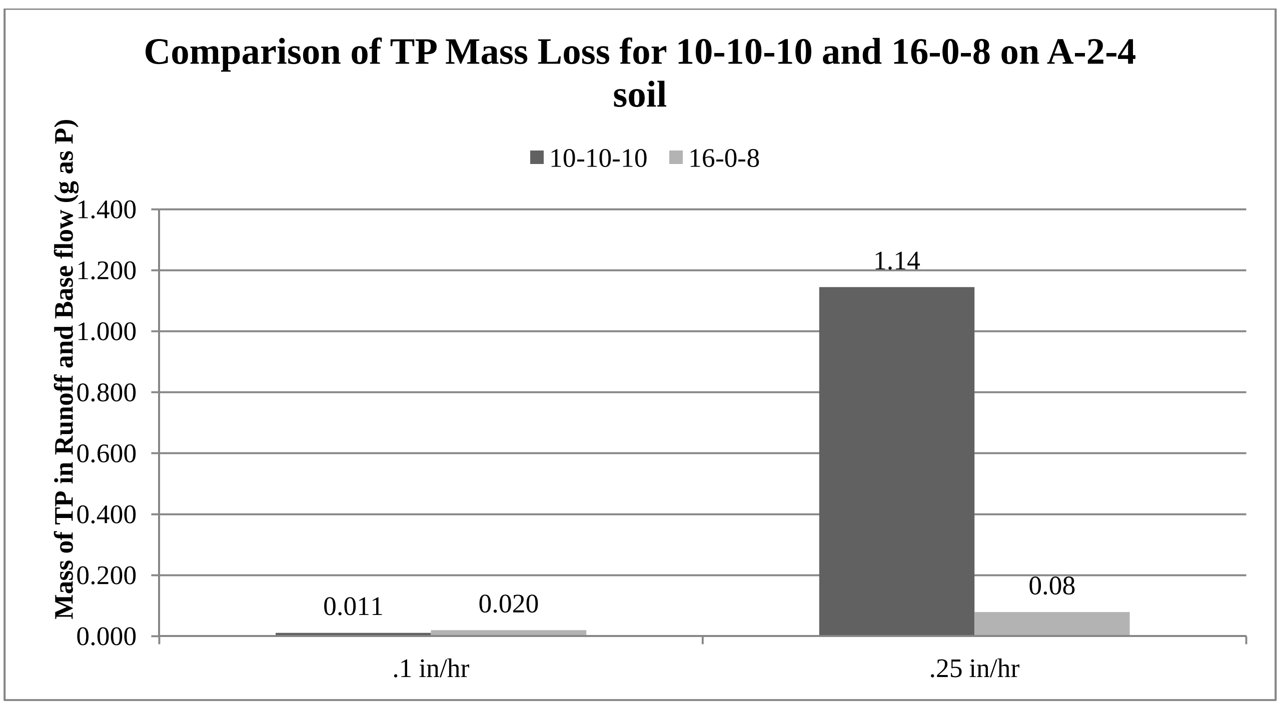

Figure 97: Comparison of TP Losses from A-2-4 Soil for 10-10-10 and 16-0-8 Fertilization Practices @ 0.5 lb of N per 1000 ft^2 – Phase #2

The authors examined the amount of runoff versus base flow that occurred during all the tests in phase #2. Either fertilization practices did not generate runoff at the 0.1 in/hr rainfall intensity tests. At the 0.25 in/hr rainfall intensity, the percentage of runoff collected to total volume collected was 53.6% and 39.2% for the 10-10-10 and 16-0-8 fertilization practices, respectively. The most significant difference between these tests was the amount of base flow collected for both fertilization practices. The average moisture content of the soil prior to the 10-10-10 tests was lower than the 16-0-8 tests (Table 35 and Table 41), which required longer duration rainfall for the test bed to reach saturation needed to generate base flow and/or runoff. Thus, despite comparable equal volumes of applied rainfall, the 10-10-10 fertilization practice tests had 79.4% and 21.2% less base flow collected at the 0.1 in/hr and 0.25 in/hr rainfall intensities, respectively. Thus, more nitrogen and residing phosphorus could have leached from 16-0-8 than 10-10-10. In addition, 10-10-10 fertilization practice tests had 42% more base flow collected than 16-0-8 fertilization practice tests, even though the 16-0-8 fertilization practice tests had slightly more rainfall volume. The relatively lower antecedent moisture condition during the 16-0-8 fertilization practice tests needed more rainfall volume for the soil in the test bed to initiate the movement of runoff and base flow, and the soil retained more water in the system.

7.4 AASHTO A-3 Soil with Argentine Bahia – Phase #2

The application rate of fertilizer for the 10-10-10 and 16-0-8 fertilization practice were 0.5 lb N/1000 ft^2 for phase #2 of the study. Figure 98 revealed that more nitrogen was lost from the test bed using the 10-10-10 fertilization practice compared to the 16-0-8 fertilization practice. Figure 99 shows the total phosphorus collected for both fertilization practices and reveals that the mass of TP was more in the 10-10 fertilization practice than in the 16-0-8 fertilization practice.

The measured losses in the mass of TN and TP collected supports the earlier claim of the environmental benefits gained in the use of the 16-0-8 over the 10-10-10 fertilization practices, because there is no phosphate in the 16-0-8 fertilization practice.

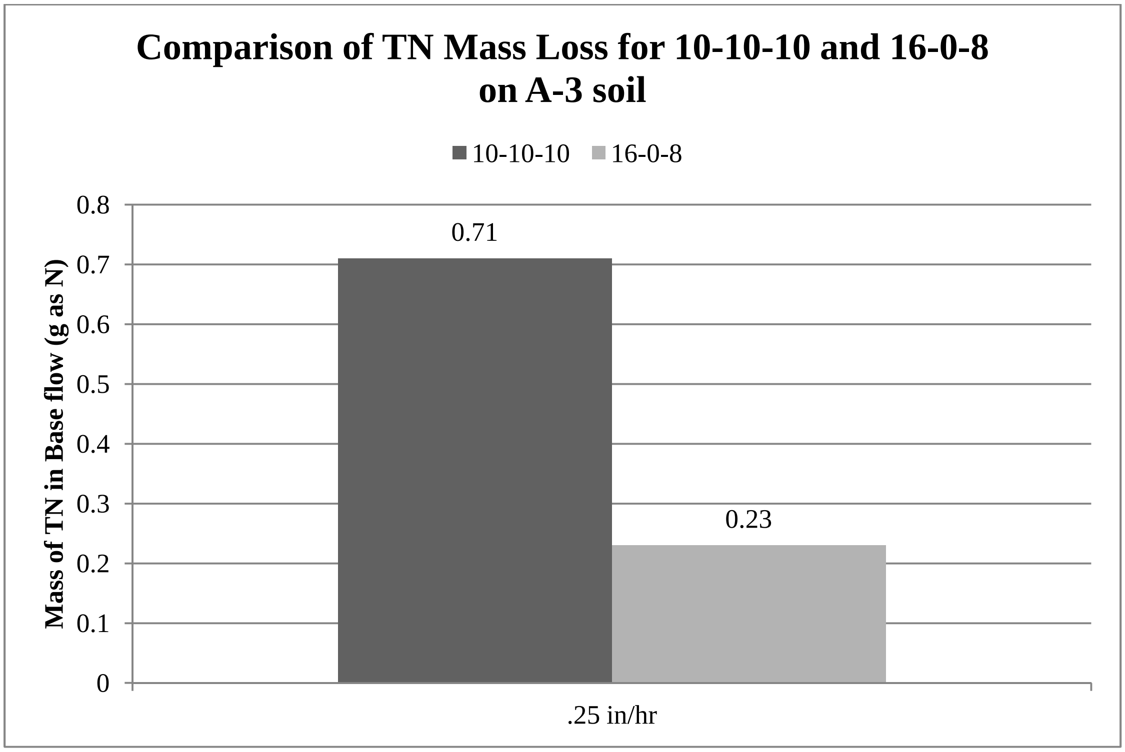

Figure 98: Comparison of TN Losses from A-3 Soil for 10-10-10 and 16-0-8 Fertilization Practices @ 0.5 lb of N per 1000 ft^2 – Phase #2

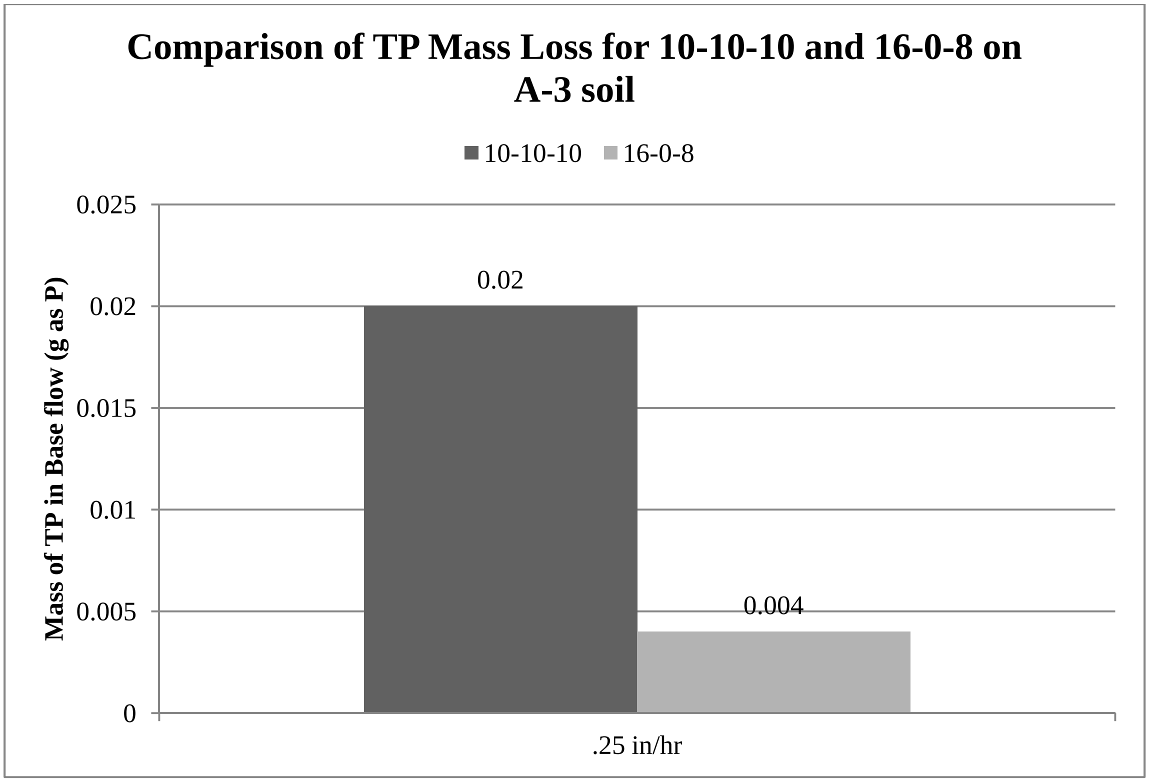

Figure 99: Comparison of TP Losses from A-3 Soil for 10-10-10 and 16-0-8 Fertilization Practices @ 0.5 lb of N per 1000 ft^2 – Phase #2

CHAPTER 8. ARGENTINE BAHIA ON A-3 SOIL COMPARED WITH PENSACOLA BAHIA ON A-2-4 SOIL

Due to the varying soil types in northern versus central and south Florida, two soil types that are representative soils from each region were selected. These were AASHTO A-2-4 (silty sands) and AASHTO A-3 (clean sand). Since the A-3 soil, typical in central Florida, is a sandy soil and is expected to allow more water to infiltrate resulting in less runoff and potentially less mass of nutrients leaving the system. The A-2-4 soil, typical in northern Florida, is also a sandy soil but has a silty/clay fraction potentially reducing infiltration resulting in more runoff and more mass of nutrients leaving the system. The analysis below examines the difference in how fertilizer nutrient mass is lost from a soil-sod system.

8.1 No Fertilizer Comparison – Phase #1

Tests with no fertilizer application were run on both soil types to establish a base line for the nutrient mass loss from an unfertilized soil-sod system. Figure 100 shows that, as expected, the percent of total water lost as runoff from the A-2-4 Pensacola Bahia system was much more than from the A-3 Argentine Bahia system. The percent captured as runoff increased with increasing rainfall intensity and there was an increase from the first A-2-4 soil test to the second A-2-4 soil test. A major factor that could be attributed to this increase is the fact that the first run was conducted in January, typically a dry month, while the second run was conducted in April, a month that receives more rainfall. This might have resulted in an increase in runoff as the soil's available water storage capacity was closer to saturation.

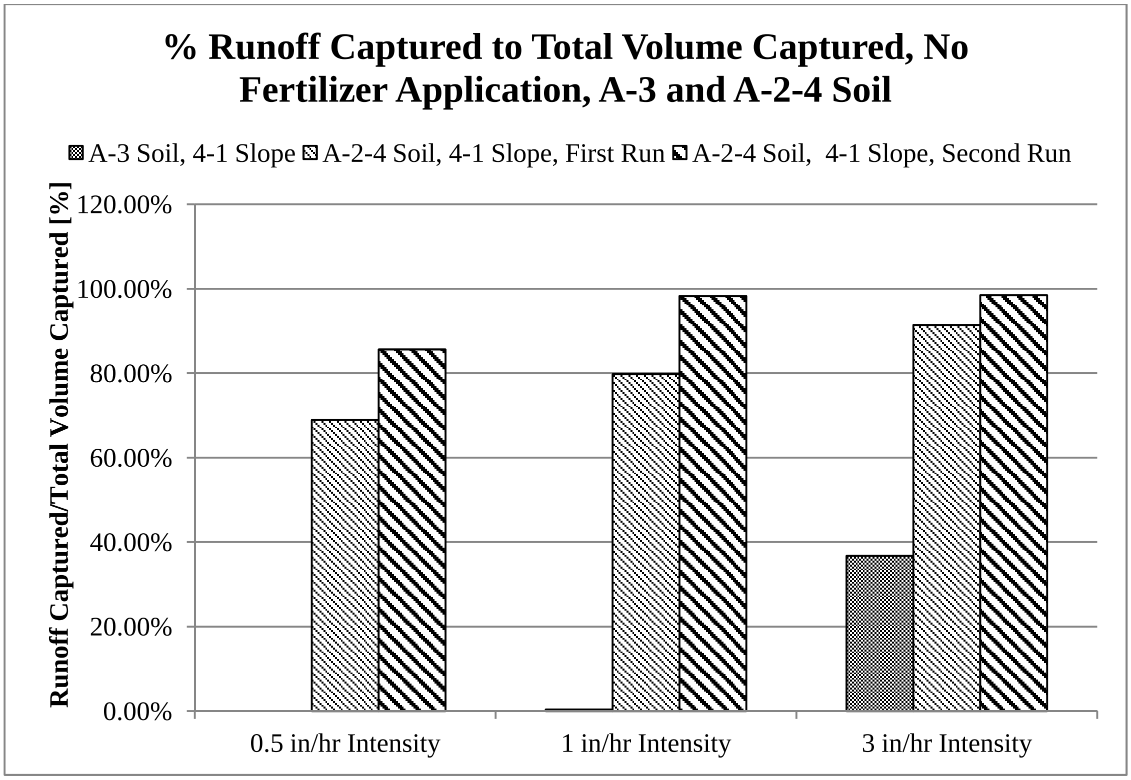

Figure 100: Comparison of the Percentage of Runoff Captured to the Total Volume Captured, No Fertilizer Application, A-3 and A-2-4 Soils – Phase #1

The comparison of pH in all the test series showed that both A-2-4 soil series had a lower average pH than the A-3 soil test series, as seen in Figure 101. Figure 102 presents the average alkalinity. The alkalinity comparison shows that the alkalinity is much lower for the A-2-4 soil test series than the A-3 soil test series. This, combined with the lower pH values, shows that the A-2-4 soil tended to be more acidic and thus used up more alkalinity to maintain a neutral pH.

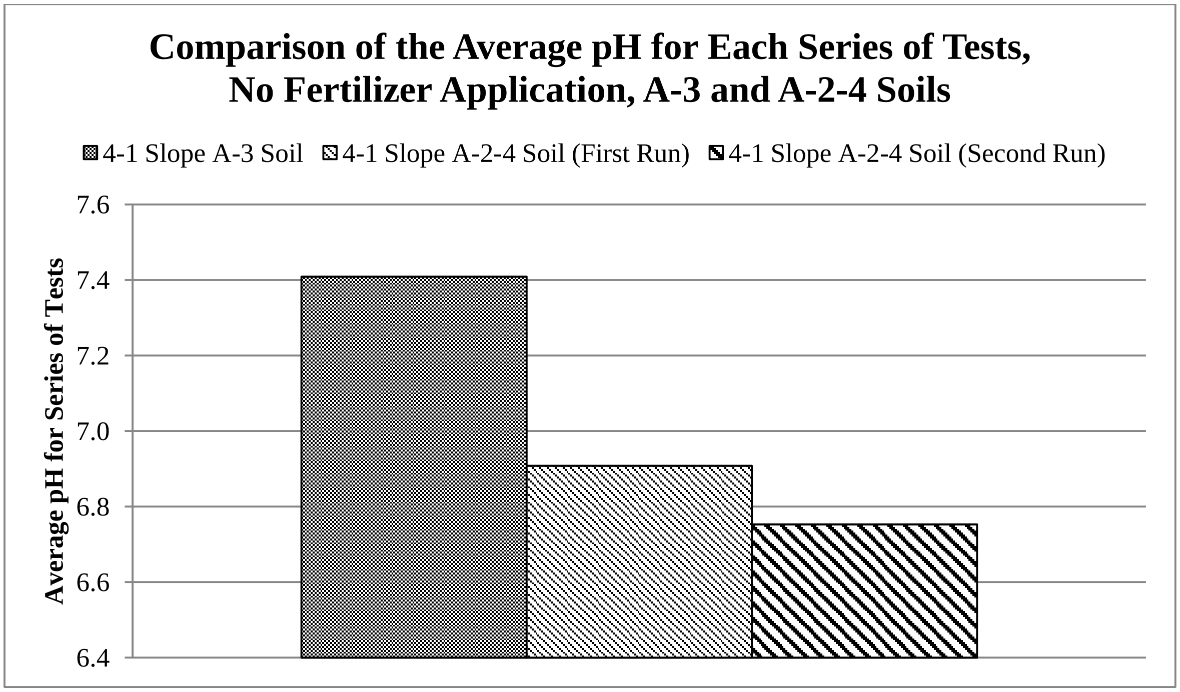

Figure 101: Comparison of the Average pH for Each Series of Tests, No Fertilizer Application, A-3 and A-2-4 Soils – Phase #1

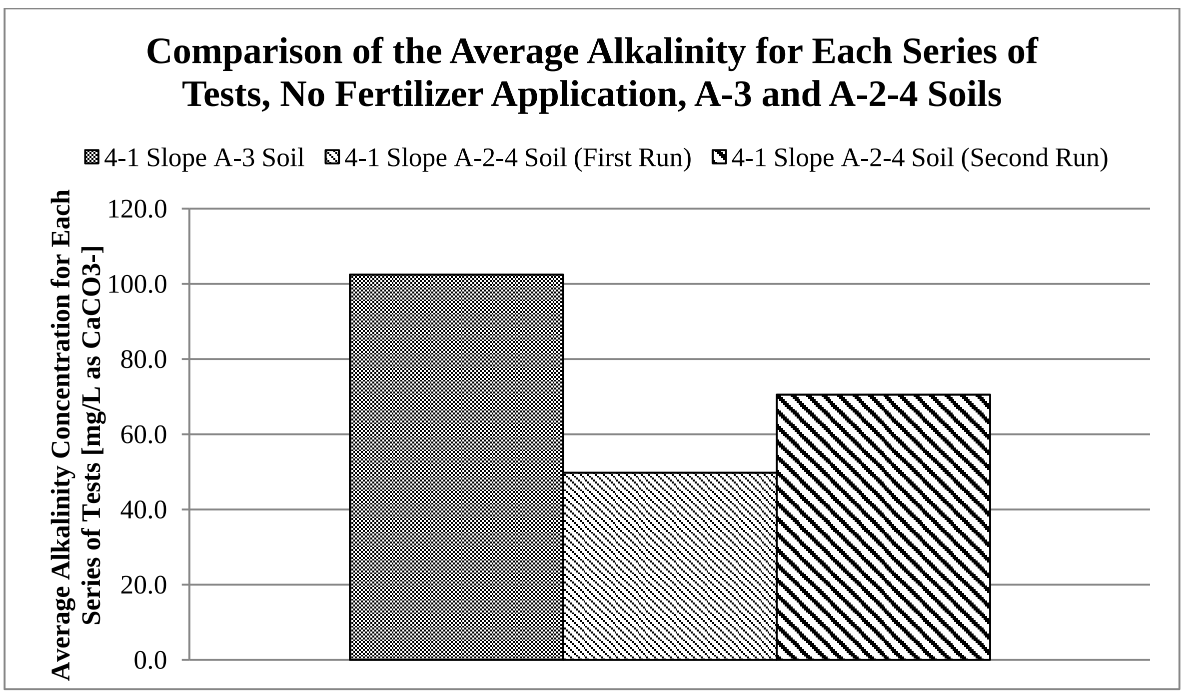

Figure 102: Comparison of the Average Alkalinity for Each Series of Tests, No Fertilizer Application, A-3 and A-2-4 Soils – Phase #1

Figure 103 shows a comparison of the total mass of nitrogen collected in runoff and base flow. From the figure, it can be seen that the TN lost from all three series of tests was insignificant. The 0.5 in/hr rainfall intensity on the 1 to 4 slope and A-2-4 soil for the second run had a relatively high TN mass loss, this may be a result of left over fertilizer from the 10-10-10 test that was run prior. Figure 104 shows the total phosphate mass loss from all three series of tests. As with the total nitrogen mass loss, the total phosphate lost was minimal but highest with the A-2-4 soil. There were no other observed trends. Overall, this analysis suggests that the A-2-4 soil has a higher initial TP mass content compared to the A-3 soil.

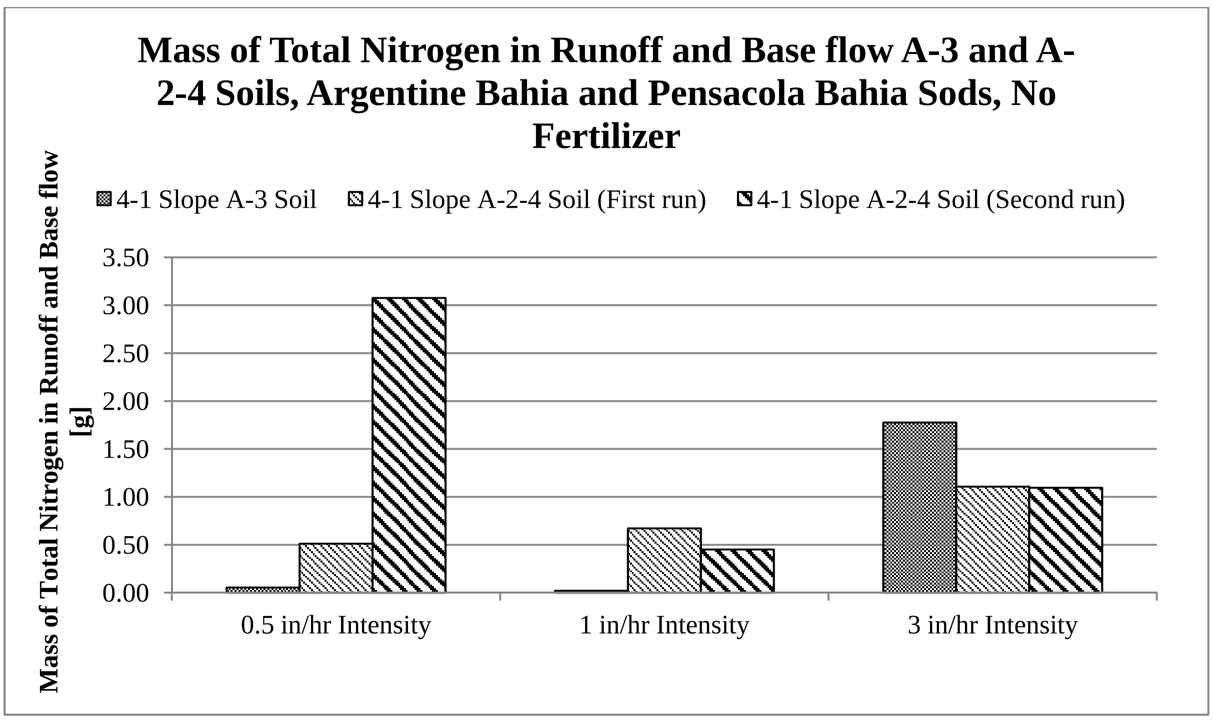

Figure 103: Comparison of Total Nitrogen Mass Lost in Runoff and Base Flow for A-3 and A-2-4 Soils and No Fertilizer Application – Phase #1

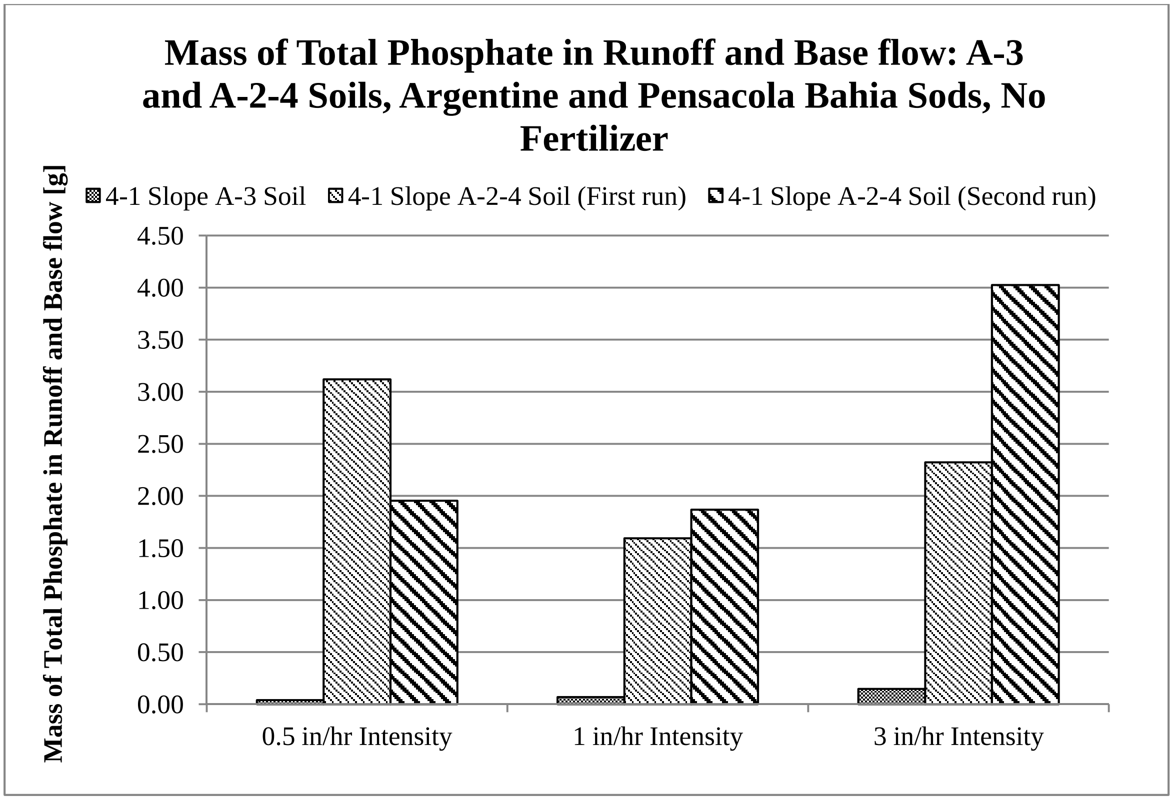

Figure 104: Comparison of Total Phosphate Mass Lost in Runoff and Base Flow for A-3 and A-2-4 Soils and No Fertilizer Application – Phase #1

8.2 10-10-10 Fertilization Practice @ 1 lb of N per 1000 ft^2 Comparison – Phase #1

Tests with 10-10-10 fertilizer applied at 1 lb of N per 1000 ft^2 were run on both soil types. Figure 105 shows that the percent of total water lost as runoff from the A-2-4 soil with Pensacola Bahia sod system was much more than from the A-3 Argentine Bahia system for the 0.5 in/hr tests. The 1.0 in/hr tests and 3.0 in/hr tests both showed this same trend but the difference was just not as large. The percent captured as runoff tended to increase with increasing rainfall intensity and slope. However, as the percent captured as runoff increased, these differences were less obvious. This is likely because rainfall intensity and volume play a more significant role in the overall volume of water that goes to runoff compared to the steepness of the slope.

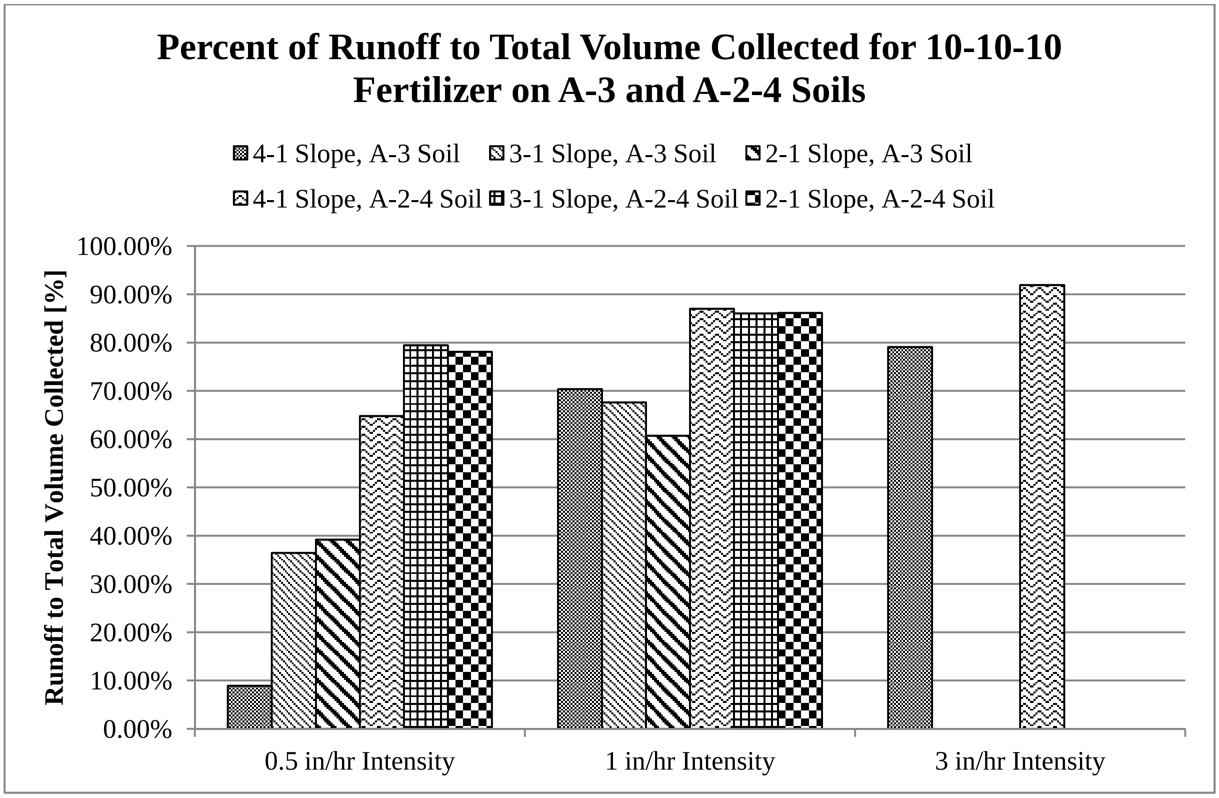

Figure 105: Comparison of Percentage Runoff to Total Volume Collected for 10-10-10 Fertilization Practice on A-3 and A-2-4 Soils – Phase #1

The comparison of TN and TP mass lost from the 10-10-10 fertilizer applied at 1.0 lb of N per 1000 ft^2 for both soil types is shown in Figure 106 and Figure 107, respectively. It can be seen from the figure that the TN and TP loss generally increases with the A-2-4 soil. This is likely because more runoff was generated with the A-2-4 soil resulting in higher erosive forces and thus more fertilizer/nutrient transport out of the system. This was most noticeable with the 0.5 in/hr rainfall intensity for TN and both the 0.5 in/hr and 1.0 in/hr rainfall intensity for TP. The 1.0 in/hr rainfall intensity TN loss values were closer together for both soil types likely due to the higher rainfall intensity exceeding both soils infiltration capacity thus generating more runoff. The 3.0 in/hr rainfall intensity did not show this trend for either TN or TP. This could be due to any number of factors such as environmental conditions, untended concentration/dilution in the test bed or other unidentified error.

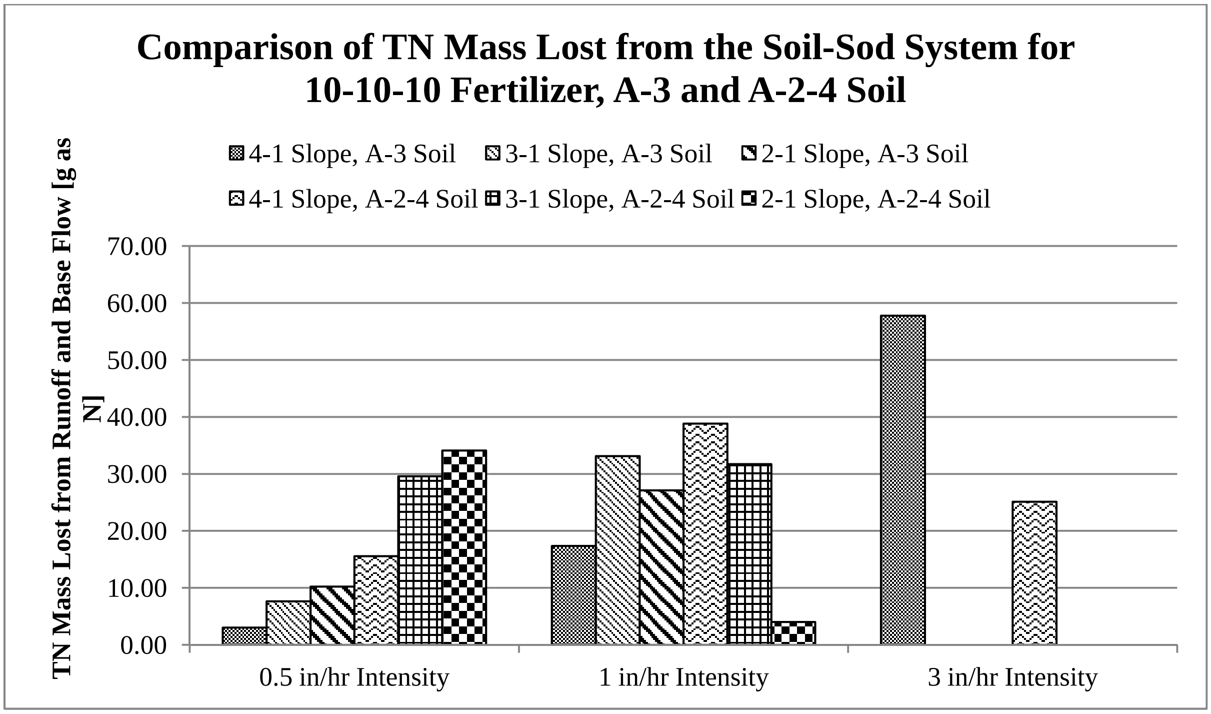

Figure 106: Comparison of the TN Mass Lost from the Soil-Sod System, 10-10-10 Fertilization Practice, A-3 and A-2-4 Soils – Phase #1

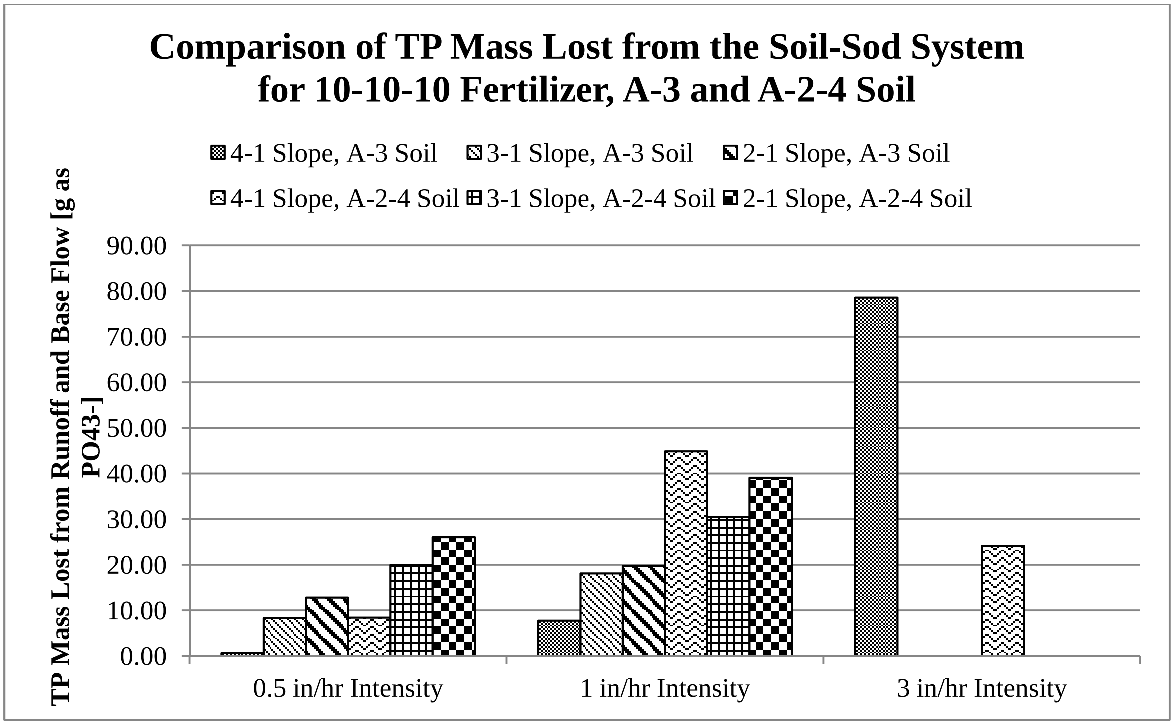

Figure 107: Comparison of TP Mass Lost from the Soil-Sod System, 10-10-10 Fertilization Practice, A-3 and A-2-4 Soils – Phase #1

8.3 10-10-10 Fertilization Practice @ 1 lb of N per 1000 ft^2 Seven-Day Test Comparison – Phase #1

The seven day tests for the 10-10-10 fertilizer applied at a rate of 1 lb of N per 1000 ft^2 on day one was also conducted on both soil types. Figure 108 displays the comparison of the percent captured as runoff to the total volume captured for both soil types.

This reinforces the earlier observation that A-2-4 soils generate more runoff than A-3 soils. This is significant because, as stated earlier, runoff is the dominant form of nutrient mass loss for both TN and TP masses. It should be noted however, this correlation was much stronger for TP than TN.

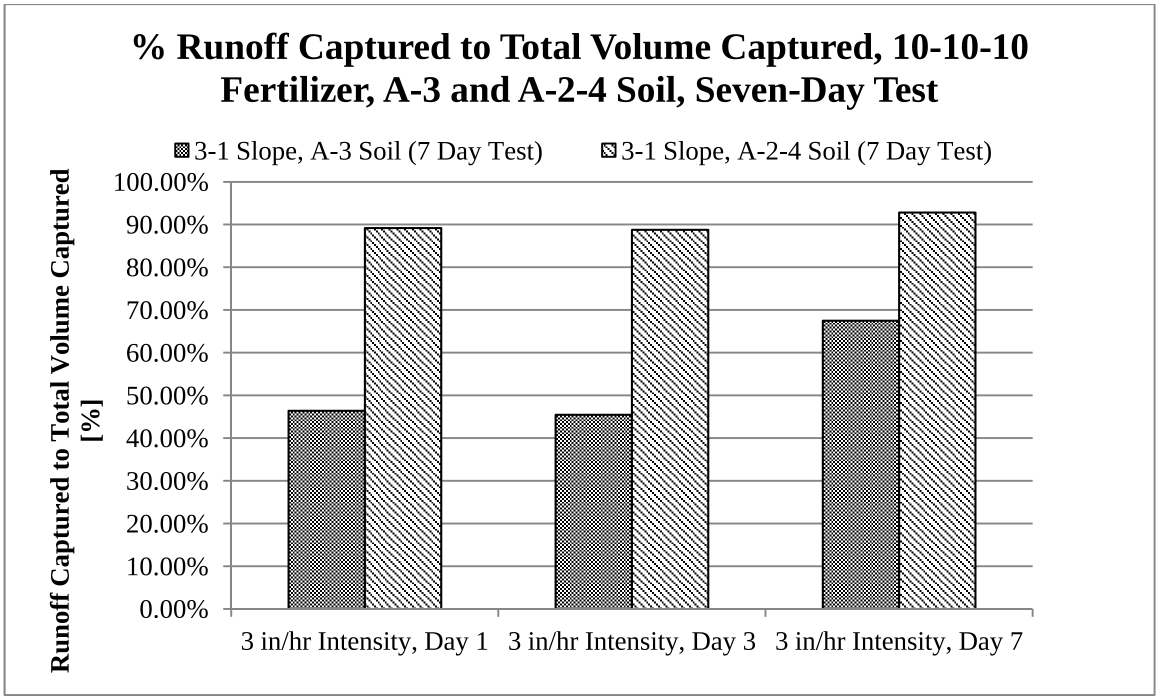

Figure 108: Comparison of Percentage Runoff Captured to Total Volume Captured, 10-10-10 Fertilization Practice, A-3 and A-2-4 Soils (Seven-Day Test) – Phase #1

Figure 109 shows the TN mass loss comparison for both soil types. For the mass of TN, the A-3 soil lost more over the seven days and particularly for day seven. This is likely due to the more significant base flow contribution from the A-3 soil. The TP mass loss comparison, shown in Figure 110, depicts that the A-2-4 soil lost significantly more TP than the A-3 soil. This is because almost all of the TP loss was generated from runoff and the base flow concentrations generally had very low concentrations and thus, mass. The difference in runoff generated is likely the reason for the additional TP lost in the A-2-4 soil.

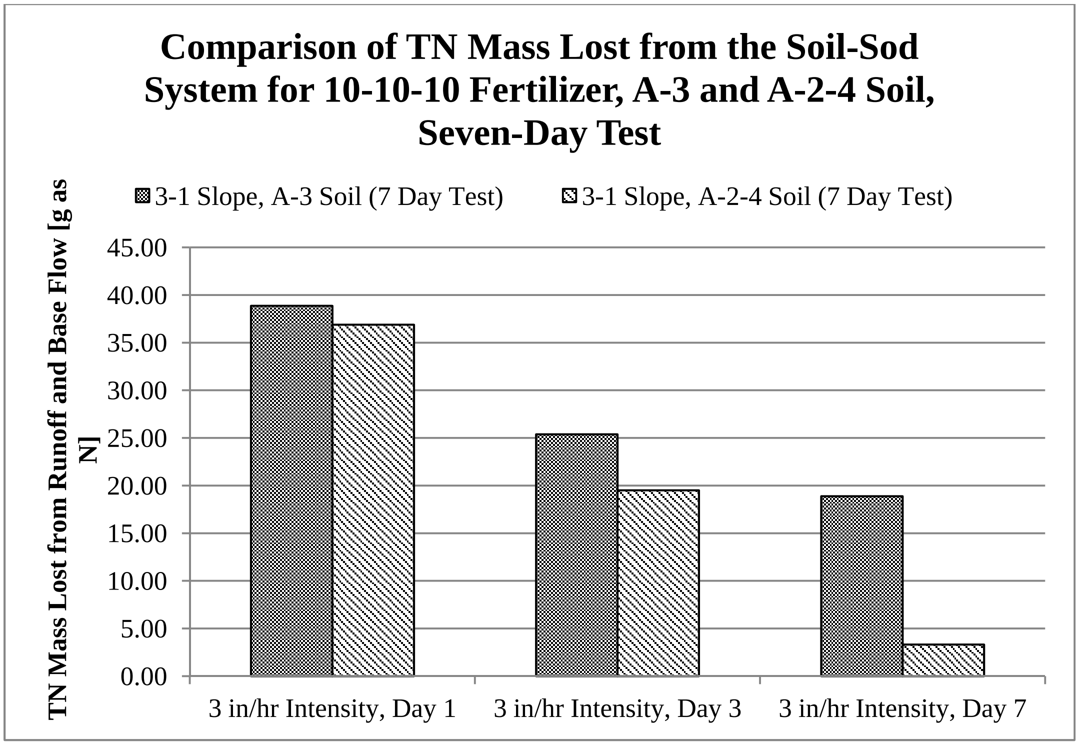

Figure 109: Comparison of TN Mass Lost from the Soil-Sod System for 10-10-10 Fertilization Practice, A-3 and A-2-4 Soils (Seven-Day Test) – Phase #1

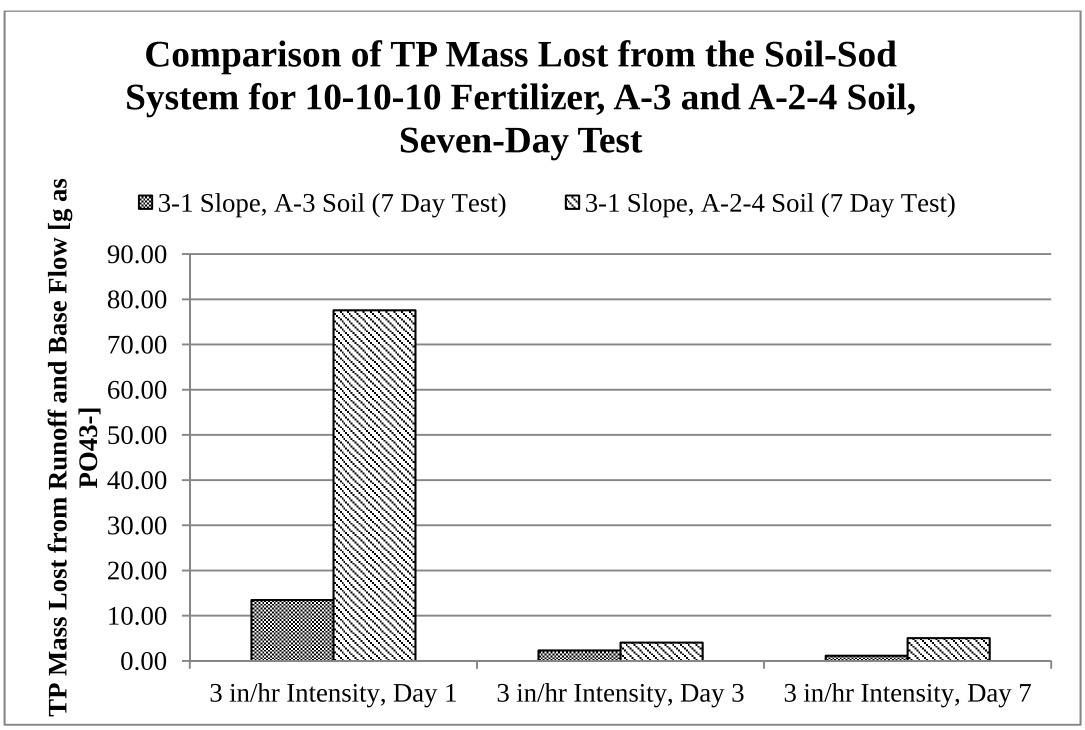

Figure 110: Comparison of TP Mass Lost from the Soil-Sod System for 10-10-10 Fertilization Practice, A-3 and A-2-4 Soils (Seven-Day Test) – Phase #1

8.4 16-0-8 (SR) Fertilization Practice @ 0.5 lb of N per 1000 ft^2 Comparison – Phase #1

This subsection describes the results for 16-0-8 (SR) fertilizer applied at 0.5 lb of N per 1000 ft^2 as a function of soil type. Figure 111 shows the comparison of the percent runoff to the total volume collected for both soil types. It can be seen that the A-3 soils generate little to no runoff while the A-2-4 soils generate mostly runoff and little base flow. This highlights the importance of the soil type in determining the manner in which water leaves the system.

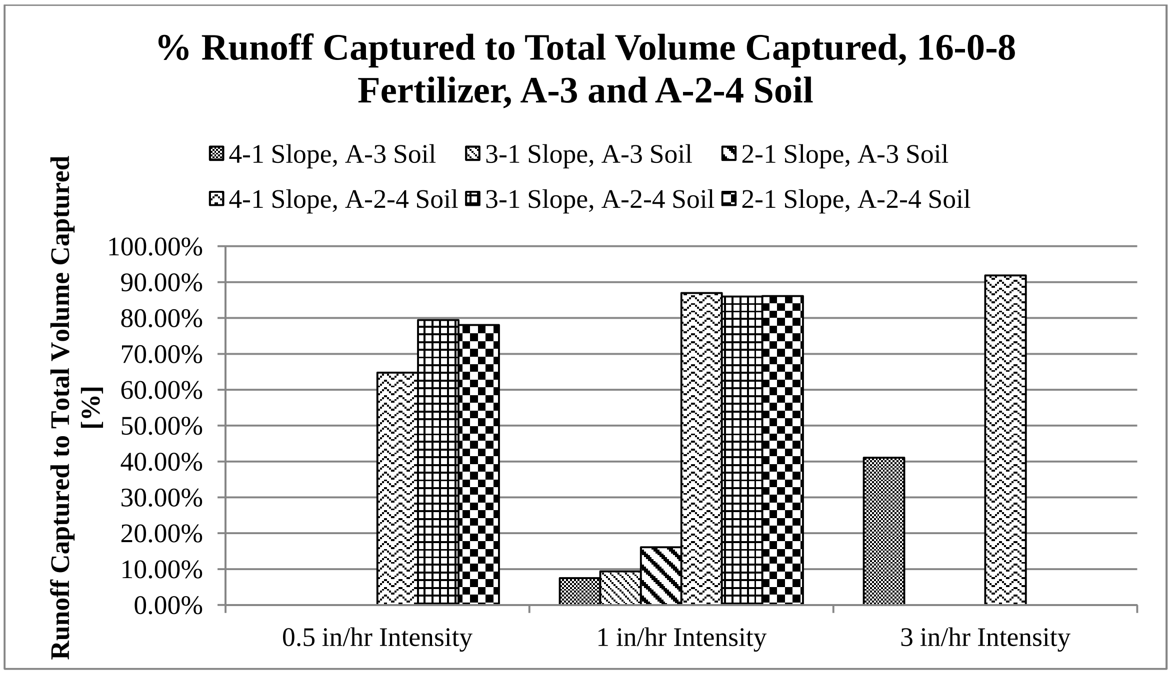

Figure 111: Comparison of Percent Runoff Captured to Total Volume Captured, 16-0-8 Fertilization Practice, A-3 and A-2-4 Soils – Phase #1

Figure 112 shows the TN mass loss comparison between the two soil types. Once again, the A-2-4 soil lost the most TN mass. The TN mass lost tended to increase with increasing rainfall intensity and steepness of slope. Two data points seemed abnormal in that the values were very low compared to the other values. These were the 1.0 in/hr rainfall intensity on both the 1 to 3 slope with A-2-4 soil and the 1 to 2 slope with A-3 soil, which might have been affected by local or temporal issues, such as unintended concentration/dilution in the test bed, or other unidentified error.

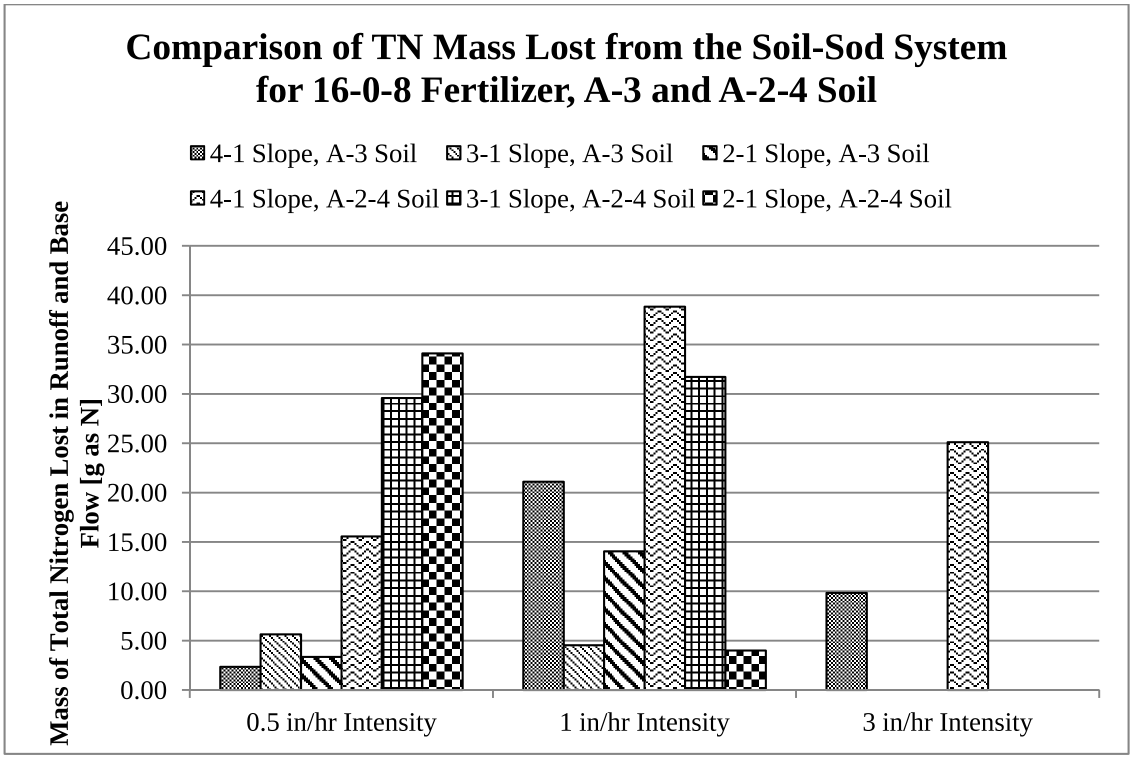

Figure 112: Comparison of TN Mass Lost from the Soil-Sod System for 16-0-8 (SR) Fertilization Practice, A-3 and A-2-4 Soils – Phase #1

8.5 No Fertilizer Comparison – Phase #2

The no-fertilizer tests were to establish a baseline for the nutrient mass loss from the unfertilized soil and sod combination. In the second phase of testing, the A-2-4 soil tests had only four no-fertilizer tests prior to the application of the 10-10-10 fertilization practice. At the completion of the 10-10-10 fertilization practice tests, used soil and sod were removed and replaced new soil and sod for the 16-0-8 fertilization tests. There was no test conducted with the no-fertilizer condition prior to application of 16-0-8 fertilization, because of the assumption that the starting conditions would be identical to the previous batch of soil and sod. The assumption was not necessarily correct because each batch of sod delivered had varying fertilizer application rate. Thus, the nutrient starting conditions for the 16-0-8 fertilization practice may not necessarily be identical to that of the 10-10-10 fertilization practice. As a result, prior to the application of the 10-10-10 fertilization on each soil and sod combination, there was a no-fertilizer test performed.

The graphical representations shown in Figure 113 and Figure 114 validate the assumption that the starting conditions for each batch of soil and sod are different, which is evident in the nutrient losses between both batches of A-3 soil and Argentine Bahia sod. However, the losses in TN and TP were insignificant as was observed in phase #1 of the study (Figure 103 and Figure 104).

Figure 113 shows that there was approximately, 90% more TN loss at the 0.1 in/hr. rainfall intensity tests between the different soil and sod combination prior to the application of 10-10-10 and 16-0-8 fertilization. At the 0.25 in/hr rainfall intensity it was 93.3% more TN loss collected between both fertilization practices. Comparison between soil types showed different responses, the TN losses for the no-fertilizer tests prior to the 10-10-10 fertilization were significantly higher in the A-3 soil than the A-2-4 soil. However, for the no-fertilizer tests prior to the 16-0-8 fertilization, the TN losses in A-3 soil were approximately 50% less the losses in the A-2-4 soil. In the no-fertilizer tests, there was no runoff except for the 0.10 in/hr rainfall intensity on A-2-4 soil, which had 0.02 g as N or 8% of the total outflow. Thus, most of the TN losses for the no fertilizer tests were from base flow.

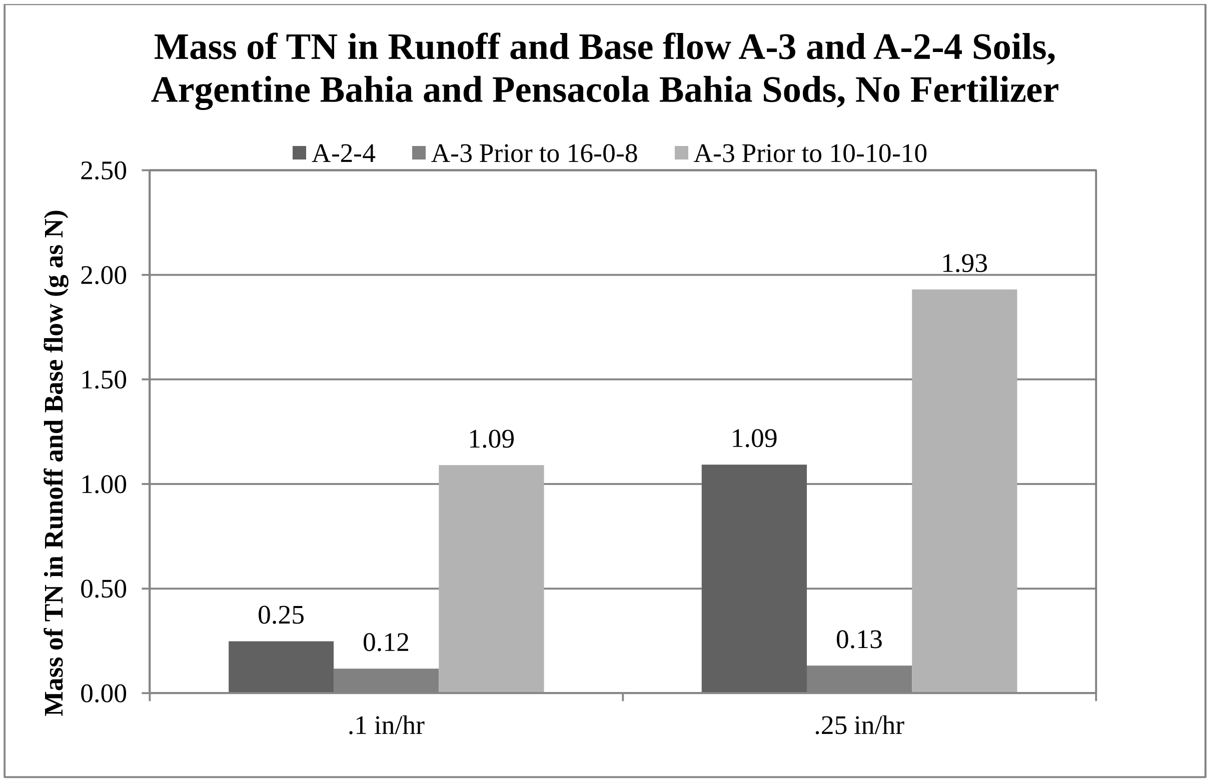

Figure 113: Comparison of TN Loss for the No Fertilizer Tests between A-2-4 vs. A-3 soils – Phase #2

Error! Reference source not found. shows the comparison on the losses of TP mass etween both soil and sod combinations. The TP loss was marginal, but the highest TP loss was in the A-2-4 soil tests at 0.1 in/hr rainfall intensity. Compared to the TN loss, the TP loss was mainly from the runoff on the A-2-4 soil tests at 0.1 in/hr rainfall intensity (approximately 92% TP loss); otherwise, the loss was from base flow as is shown in Figure 115. The result suggests that the A-2-4 soil and Pensacola Bahia sod combination had higher initial TP mass content compared to the A-3 soil and Argentine Bahia sod combination.

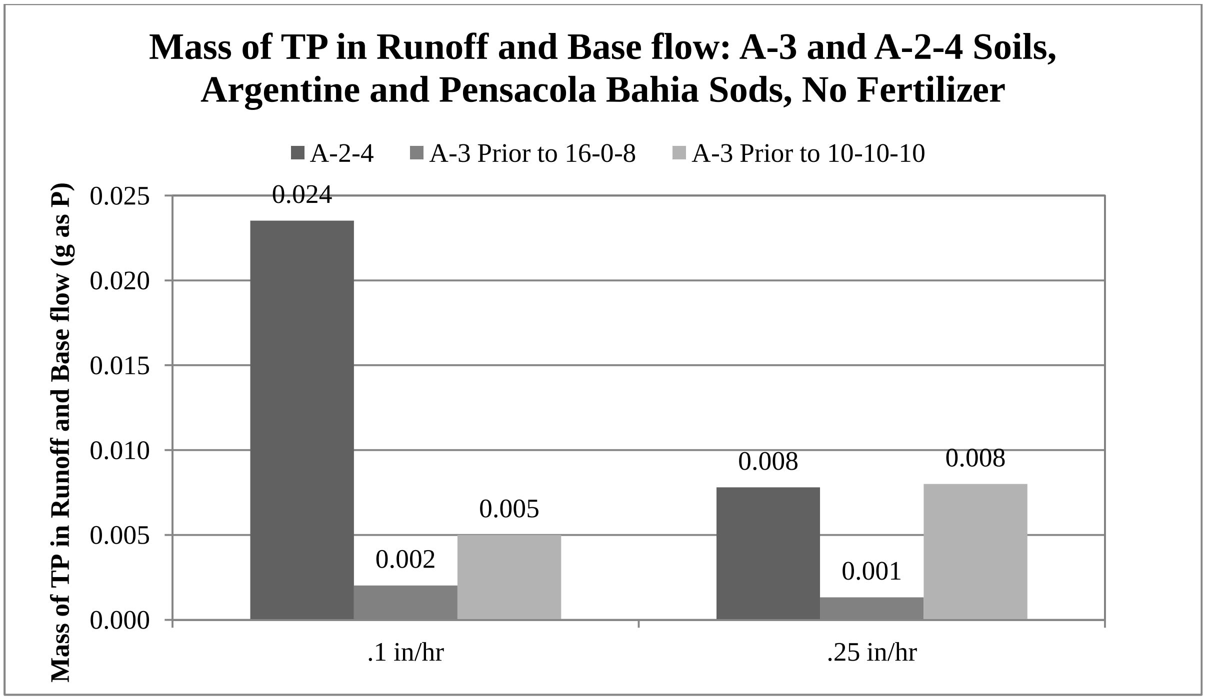

Figure 114: Comparison of TP Loss for the No Fertilizer Tests between A-2-4 vs. A-3 soils – Phase #2

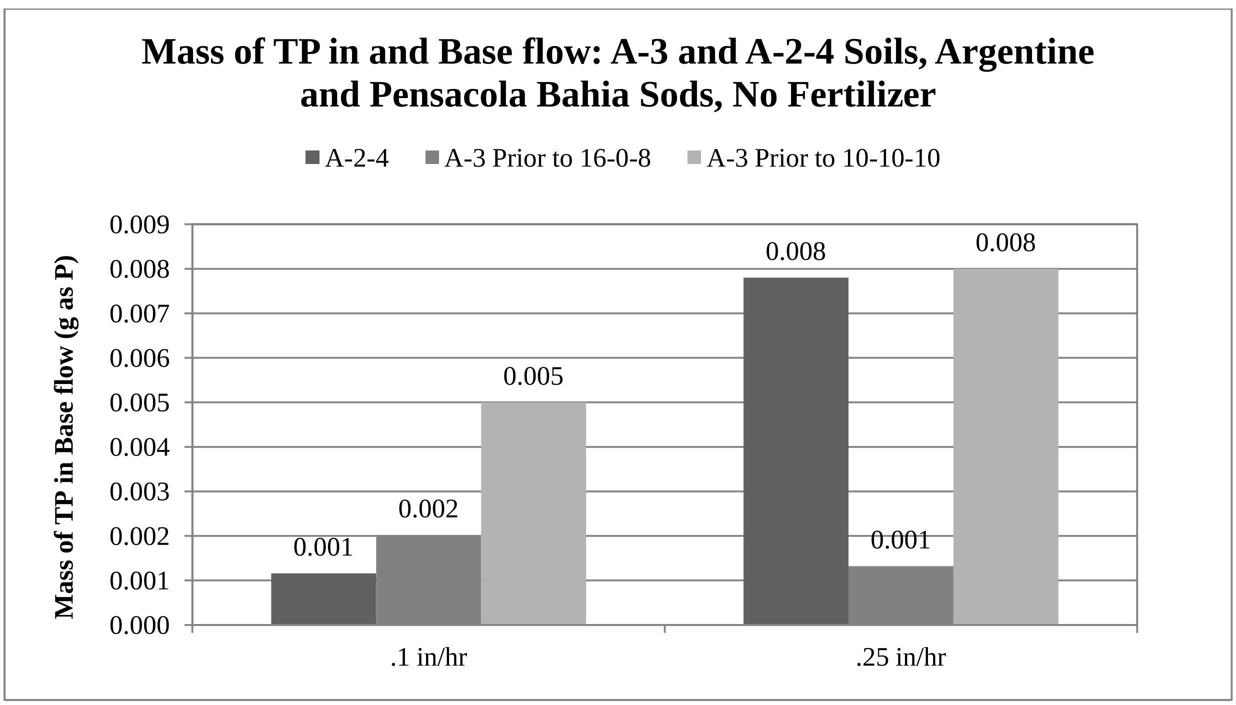

Figure 115: Comparison of TP Loss in Base flow only for the No Fertilizer Tests between A-2-4 vs. A-3 soils – Phase #2

8.6 10-10-10 Fertilization Practice @ 0.5 lb of N per 1000 ft^2 Comparison – Phase #2

The 10-10-10 fertilization application rate for the one-day tests was at 0.5 lb N/1000 ft^2 for both soil types in the phase #2 study. Figure 116 shows that, at 0.25 in/hr rainfall intensity on A-2-4, the mass of TN outflow are significantly higher than the TN collected at the other rainfall intensity and soil type, because of the higher volume of runoff generated and the resulting higher runoff velocity and erosive force. Thus, more fertilizer/nutrients washed out as runoff and the estimated loss of TN masses from runoff was 77.1%, as is evident Figure 117, which shows the TN losses from base flow only. The loss of TN at the 0.1 in/hr rainfall intensity tests was not significantly different between soil types (base flow only). However, the TN loss was marginally low from both soil and sod combinations evaluated likely because of the low rainfall intensity.

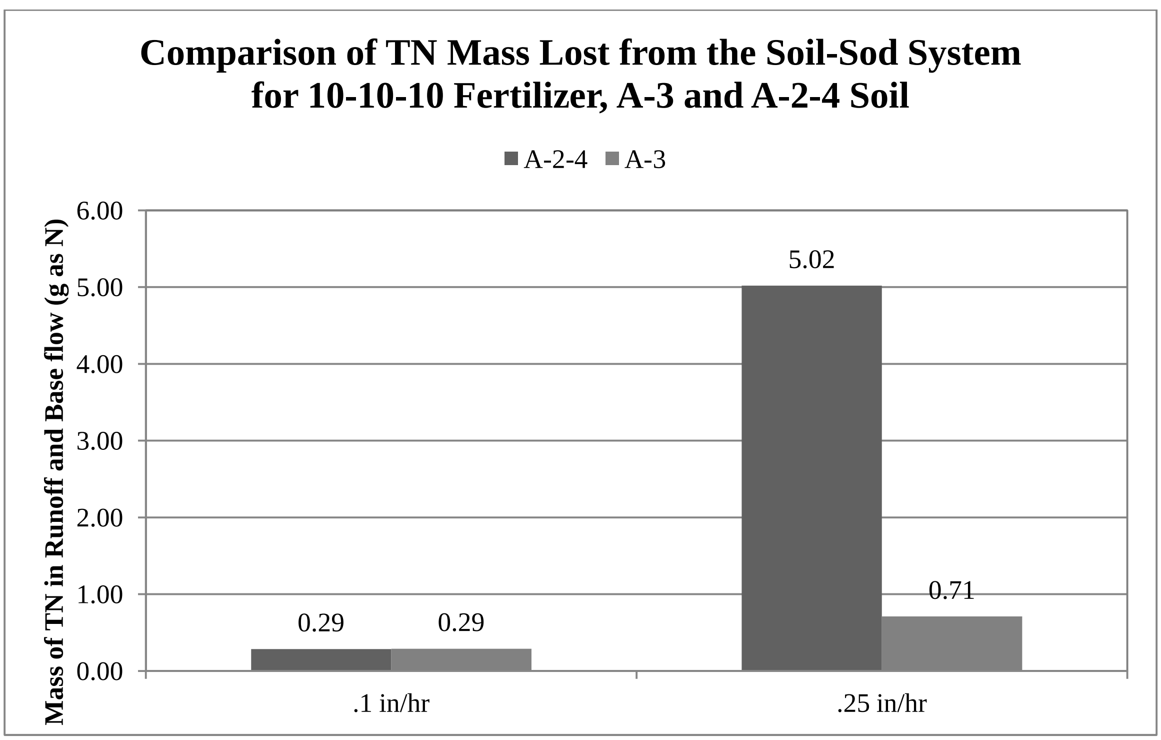

Figure 116: Comparison of TN Losses from Total Outflow in the Soil-Sod System, 10-10-10 Fertilization Practice, A-3 and A-2-4 Soils

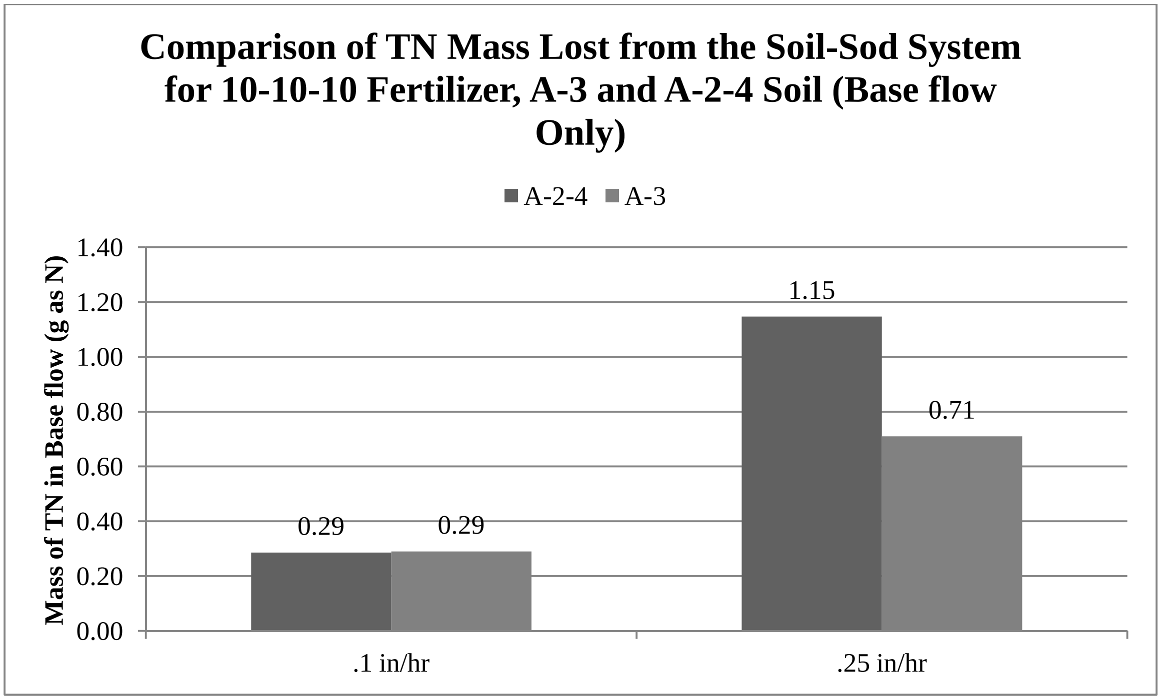

Figure 117: Comparison of TN Losses from Base flow in the Soil-Sod System, 10-10-10 Fertilization Practice, A-3 and A-2-4 Soils

Figure 118 show the variation of TP losses, which had identical trend with the TN losses. The highest loss was from A-2-4 at 0.25 in/hr rainfall, which again was the only test that generated runoff. The total loss in TP mass was 0.21 g as P from the A-2-4 soil at 0.25 in/hr rainfall intensity tests, which is higher than tests performed on A-3 soil and both soil types at 0.1 in/hr rainfall intensity tests. This could be because of a number of reasons such as build-up of fertilizer in the soil, environmental conditions, etc.

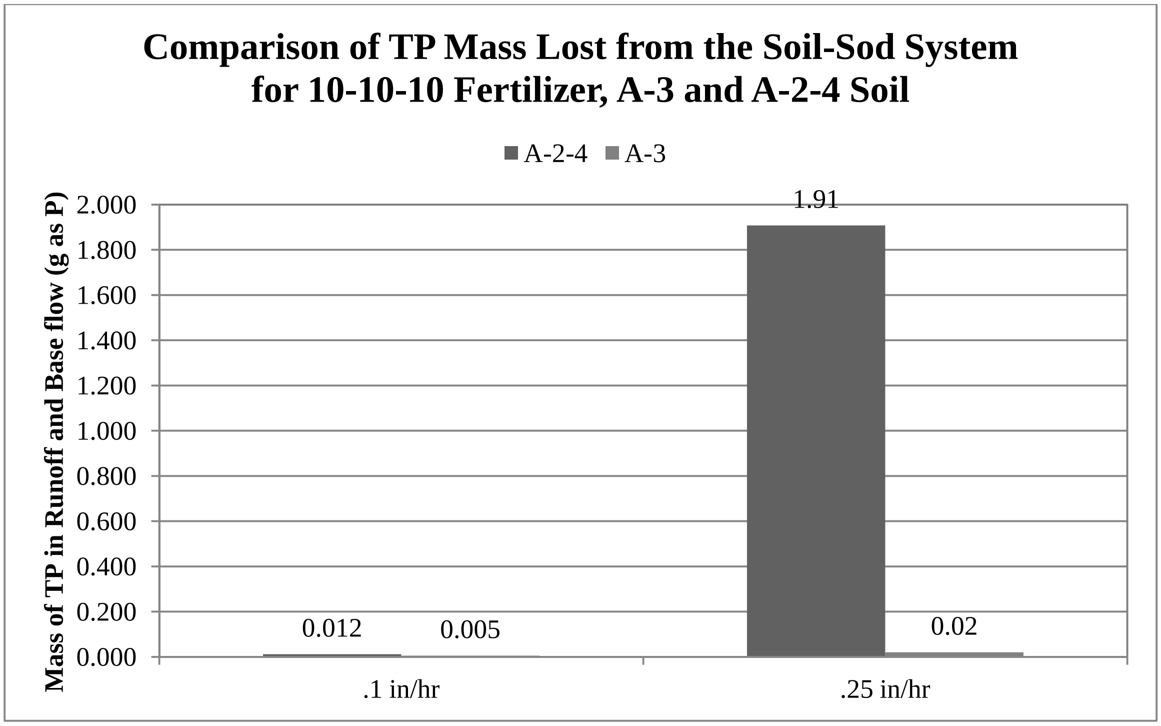

Figure 118: Comparison of TP Losses from Total Outflow in the Soil-Sod System, 10-10-10 Fertilization Practice, A-3 and A-2-4 Soils

8.7 10-10-10 Fertilization Practice @ 0.5 lb of N per 1000 ft^2, Seven-Day Tests Comparison – Phase #2

The 10-10-10 fertilization application rate was 0.5 lb N/1000 ft^2 for the seven-day tests conducted on both soil types at 0.25 in/hr rainfall intensity. Only on the first day of testing was the fertilizer applied on the soil and sod combination. Figure 119 and Figure 120 show the comparison of TN and TP losses captured from the outflows, respectively. The high TN and TP losses on day one of testing for the A-2-4 soil had contributions from runoff and base flow; no other test generated runoff, only base flow losses. The tests on A-2-4 soil had significantly higher TN and TP losses because of the washout of fertilizer/nutrients by the generated runoff. The other tests had only base flow and thus, the TN and TP losses were much lower, which suggests more nutrients losses is associated to the runoff. There was no runoff on day seven of testing, thus the losses in TN and TP were significantly low, which is indicative of the adsorption of nutrients, sod utilization, and physiochemical processes between day one and day 7. The runoff on the A-2-4 soil on day one contributed 75.8% and 91.5% of the total outflow TN and TP losses, respectively. However, both TN and TP losses reduced on day 7 by 67% and nearly 100% for the A-2-4 soil tests, respectively. The losses on day 7 were not significantly different from day one for the tests on A-3 soils.

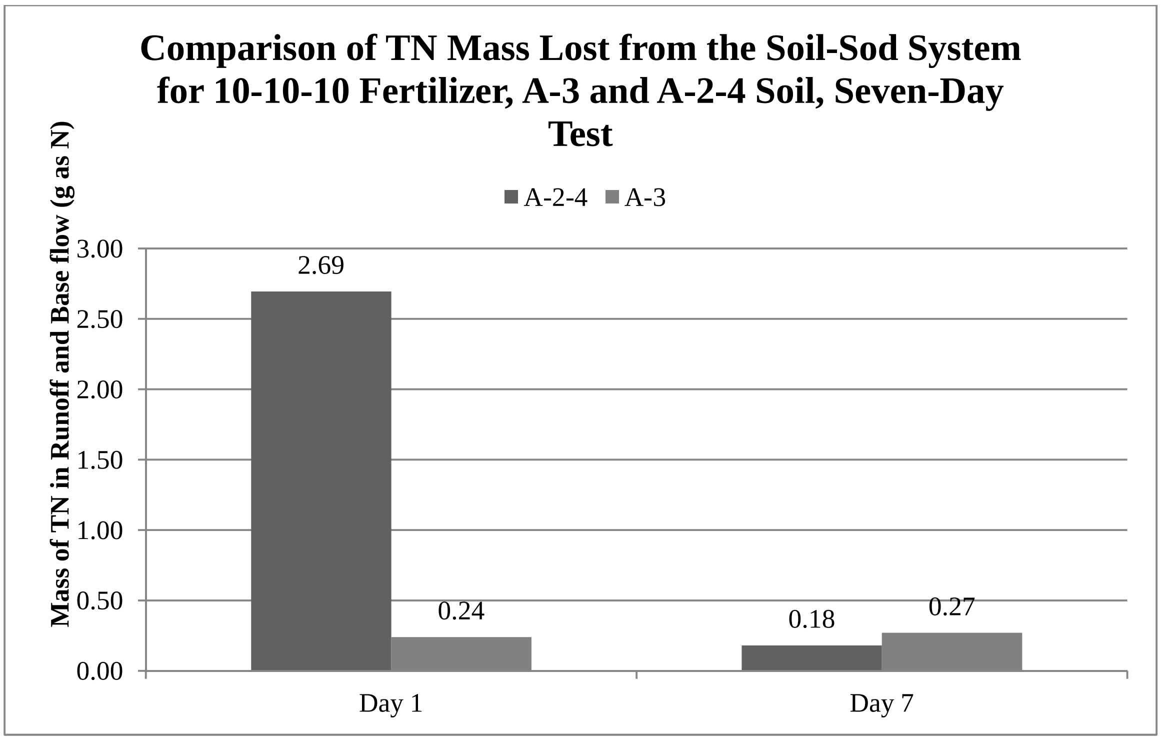

Figure 119: Comparison of TN Losses from Total Outflow in the Soil-Sod System, 10-10-10 Fertilization Practice, A-3 and A-2-4 Soils (Seven-Day Test)

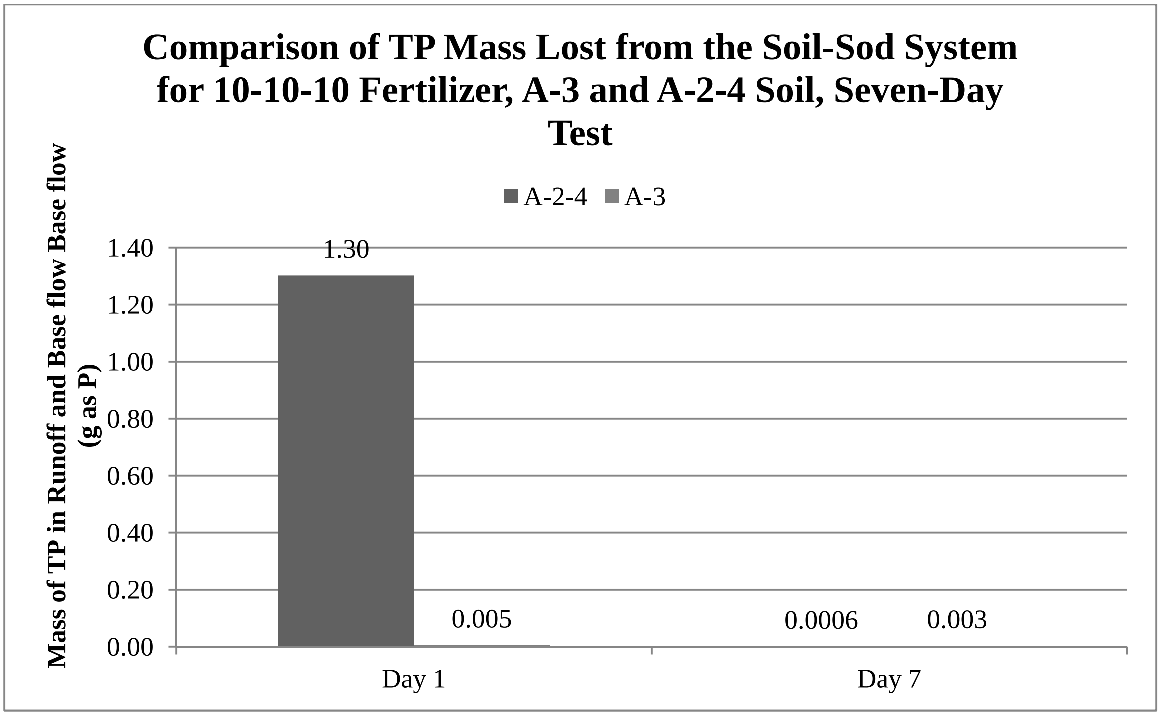

Figure 120: Comparison of TN Losses from Total Outflow in the Soil-Sod System, 10-10-10 Fertilization Practice, A-3 and A-2-4 Soils (Seven-Day Test)

8.8 16-0-8 Fertilization Practice @ 0.5 lb of N per 1000 ft^2 Comparison – Phase #2

The 16-0-8 fertilization application rate was at of 0.5 lb N/1000 ft^2 for both soil and sod combinations and rainfall intensities. Figure 121 shows the comparison of TN loss for both soil types at the 0.25 in/hr rainfall intensity (0.10 in/hr rainfall intensity is inconclusive). The A-2-4 soil had approximately 92% more TN loss than the A-3 soil because of the generated runoff on the A-2-4 soil. Approximately, 35.5% of TN collected on the A-2-4 soil test was from runoff. The mass of TN from base flow was1.89 g as N, and is significantly higher than the 0.23 g as N collected on A-3 soil tests, which might have been affected by local or temporal issues, such as unintended concentration/dilution in the test bed, or other unidentified error.

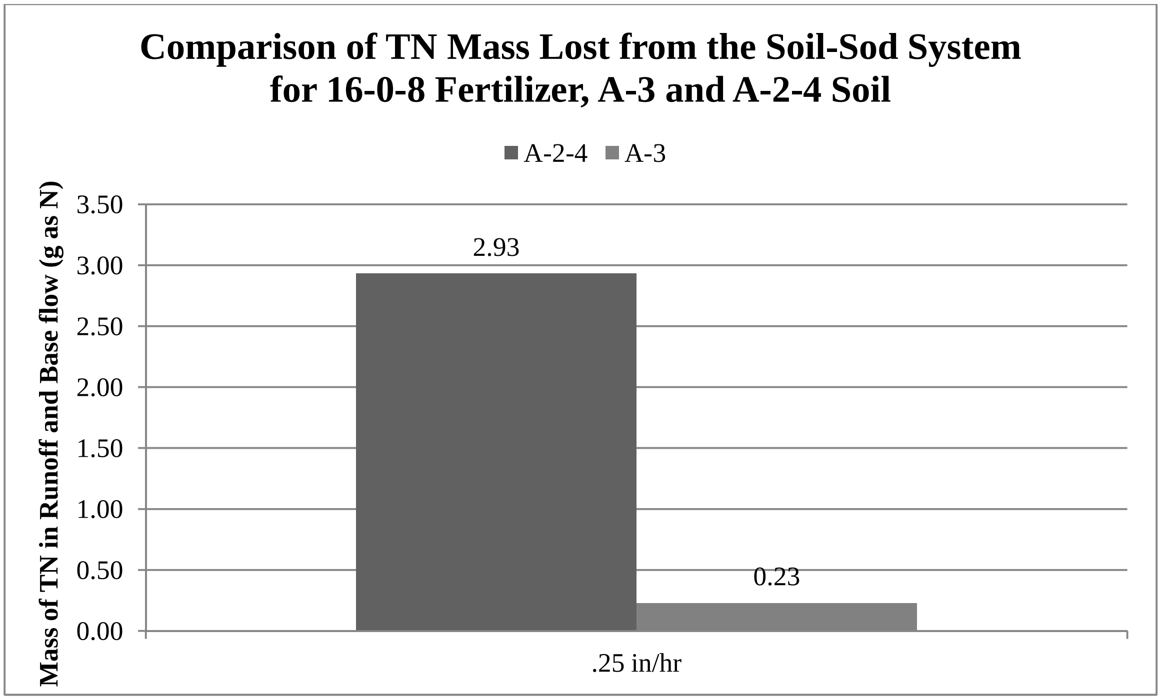

Figure 121: Comparison of TN Losses from Total Outflow in the Soil-Sod System, 16-0-8 Fertilization Practice, A-3 and A-2-4 Soils

Figure 122 shows the same trend of TP loss as the TN loss; however, the losses of TP are significantly low. The highest loss was from A-2-4, which had runoff. The base flow contribution to TP loss was 0.06 g as P from the A-2-4 soil tests, which is higher than the 0.004 g as P from A-3 soil tests. This could 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 and Pensacola Bahia combination than the A-3 and Argentine Bahia combination.

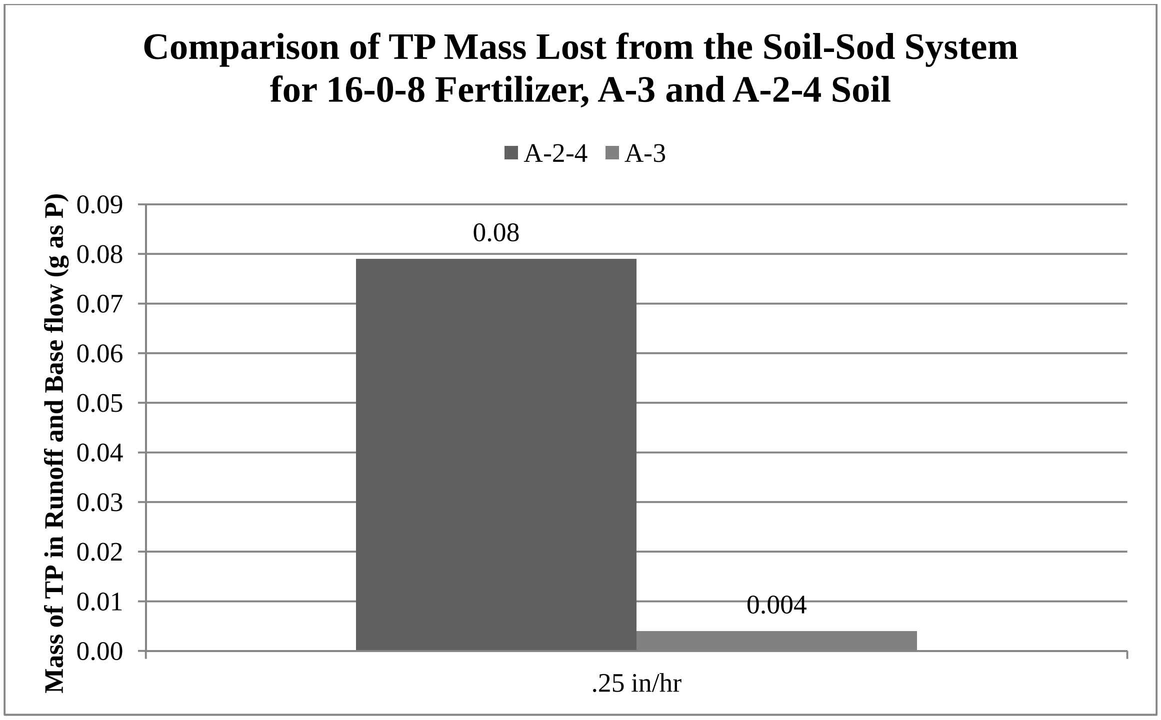

Figure 122: Comparison of TP Losses from Total Outflow in the Soil-Sod System, 16-0-8 Fertilization Practice, A-3 and A-2-4 Soils

8.9 16-0-8 Fertilization Practice @ 0.5 lb of N per 1000 ft^2, Seven-Day Tests Comparison – Phase #2

The 16-0-8 fertilization application rate was 0.5 lb N/1000 ft^2 for the seven-day tests conducted on both soil types at 0.25 in/hr rainfall intensity. Only on the first day of testing was the fertilizer applied on the soil and sod combination. Figure 123 and Figure 124 show the comparison of TN and TP collected from the two soil types and both days of testing (day one and day 7), respectively. Tests conducted on day one and day 7 generated runoff, thus the values on the plots represent total outflow (runoff and base flow) losses. On both days, the tests on A-2-4 soil had higher nutrient losses than the A-3 soil by ratio of 0.44 for the TN mass, but the mass of TP remained constant on both days because of zero phosphate in the fertilizer. The measured high mass of nutrient loss may be an indication that A-2-4 soil and Pensacola Bahia sod had inherently more nutrients than A-3 soil and Argentine Bahia sod. In addition, there could be fertilizer/nutrient built-up in the soil prior to the test, environmental conditions, and other physiochemical processes in the soil. Total Phosphate loss was relatively low for both soil types, which is expected, as 16-0-8 fertilizer does not contain phosphorus.

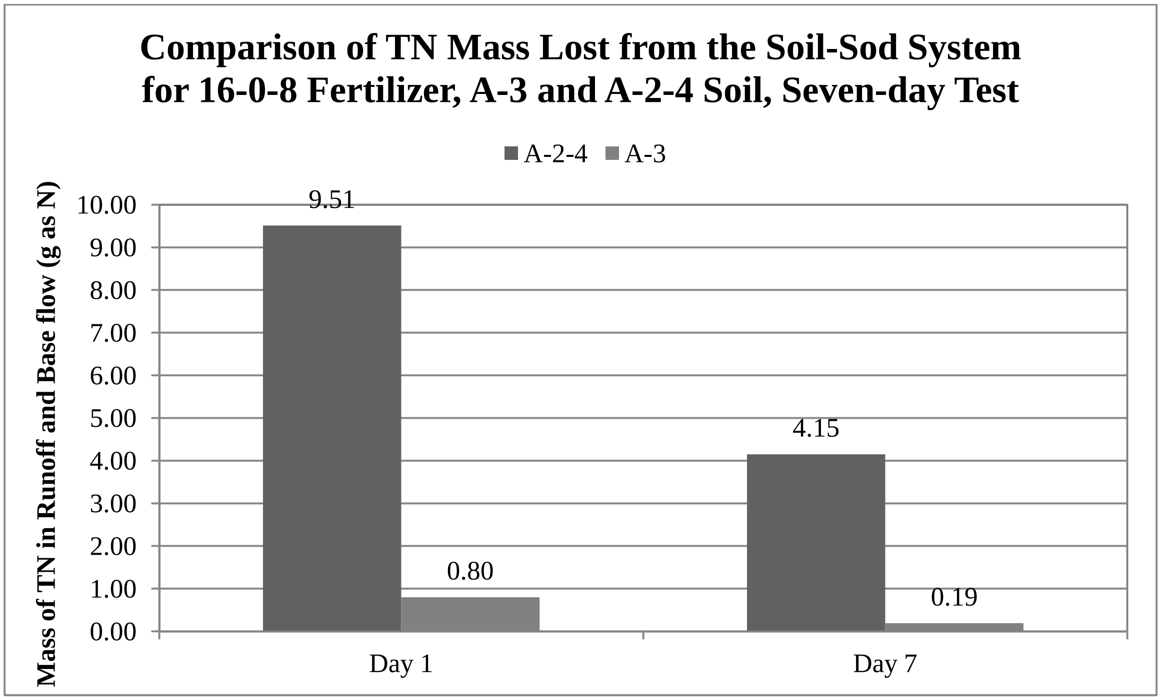

Figure 123: Comparison of TN Losses from Total Outflow in the Soil-Sod System, 16-0-8 Fertilization Practice, A-3 and A-2-4 Soils (Seven-Day Test)

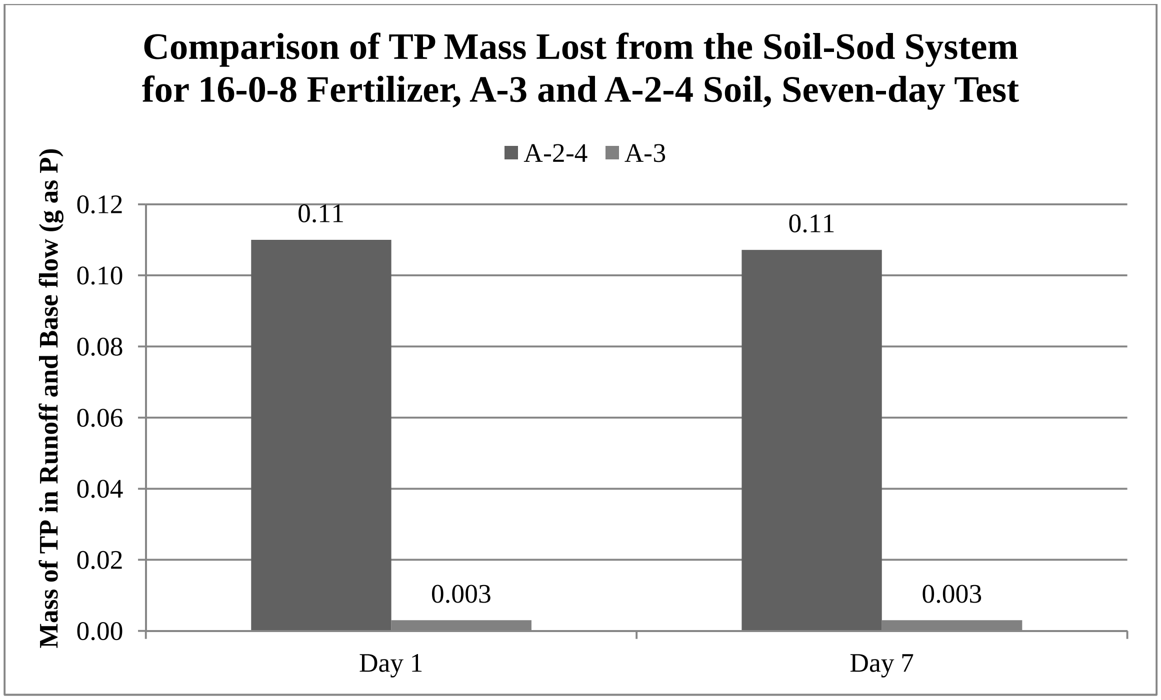

Figure 124: Comparison of TN Losses from Total Outflow in the Soil-Sod System, 16-0-8 Fertilization Practice, A-3 and A-2-4 Soils (Seven-Day Test)

8.10 Comparison of Total Nitrogen, Total Phosphorus, and CEC of A-2-4 and A-3 – Phase #2

Table 87 through Table 89 present the comparison of average total nitrogen (TN), total phosphorus (TP), and cation exchange capacity (CEC) for all tests with no fertilizer, 10-10-10 and 16-0-8 fertilization practice tests, respectively. Table 87 presents the soil analysis results from the no-fertilizer tests which were the baseline conditions for both soil and sod combinations. The A-3 soil and Argentine Bahia sod combination had approximately 30 times more TN and ten times more TP than A-2-4 soil and Pensacola Bahia sod combination. However, the A-2-4 soil and Pensacola Bahia sod combination had the highest CEC (approximately, 0.63 meq/g) due to its high silt content. The A-3 soil CEC prior to both fertilization practices were significantly different, which is indicative of the possibly varying levels of humus (organic matter) inherent to the soil and differences in soil pH.

Table 87: Comparison of TN, TP and CEC in Tests on A-2-4 and A-3 Soil-Sod Combinations, No Fertilizer

	A-2-4, No Fertilizer		A-3, No Fertilizer Prior to 10-10-10		A-3, No Fertilizer Prior to 16-0-8	
Rainfall Intensity [in/hr]	0.10	0.25	0.10	0.25	0.1	0.25
Total Nitrogen [g]	216.75	305.54	6637	6650	7668	9162
Total Phosphorus [g]	328.40	277.27	2474	2279	511	611
CEC [meq/g]	0.632	0.642	0.121	0.121	0.065	0.076

Table 88 presents the soil analysis results from the 10-10-10 fertilization practice tests for both soil and sod combinations at the 0.25 in/hr rainfall intensity. The mass of TN and TP are higher at the 0.1 in/hr rainfall intensity than 0.25 in/hr rainfall intensity, which is likely from the slight accumulation of nutrients in the test bed and the reduced potential for nutrient leaching at a low rainfall intensity such as 0.1 in/hr. The A-3 soil and Argentine Bahia sod combination had retained much as eight and four times more TN and TP, respectively, than A-2-4 soil and Pensacola Bahia sod. However, the nutrient storage capacity of the A-2-4 soil and Pensacola Bahia sod is much greater than A-3 soil and Argentine Bahia sod combination. The maximum TN increase in A-2-4 soil and Pensacola Bahia sod was approximately 88% and the maximum TP increase was approximately 75%. On the other hand, the A-3 soil and Argentine Bahia sod showed an overall reduction, which is indicative of the possibility that the Argentine Bahia sod had more fertilizer than the Pensacola Bahia sod at delivery to the testing site.

Table 88: Comparison of TN, TP and CEC in Tests on A-2-4 and A-3 Soil-Sod Combinations, 10-10-10 Fertilization Practice

Soil-Sod Combination	**A-2-4 and Pensacola Bahia**		**A-3 and Argentine Bahia**	
Rainfall Intensity [in/hr]	0.10	0.25	0.10	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

Table 89 presents the soil analysis results from the 16-0-8 fertilization practice tests for both soil and sod combinations at the 0.25 in/hr rainfall intensity (tests on 0.10 in/hr rainfall intensity were inconclusive because of equipment downtime). There were no tests performed with no fertilizer prior to the application of 16-0-8 on A-2-4 soil and Pensacola Bahia sod combination. The A-2-4 soil and Pensacola Bahia sod had different TN and TP contents prior to testing with the 16-0-8 fertilization practice than the 10-10-10 fertilization practice, which suggest that the batch of soil had varying nutrient contents (Table 88 and Table 89).

The A-3 soil and Argentine Bahia sod leached out 19.6% and 13.6% of the initial TN and TP contents, respectively. On the other hand, the A-2-4 soil and Pensacola Bahia sod lost 53.1% and 10.4% of the initial TN and TP contents, respectively at the 0.25 in/hr rainfall intensity. The TP loss was reasonably low because there was no phosphate in the fertilizer applied to the soil and sod combinations. However, the A-2-4 soil, which had higher CEC than the A-3 soil, lost more TN content to sod intake and/or outflow (runoff and base flow). The results for A-3 with Argentine Bahia sod do not have the information for 0.1 in/hr intensity due to equipment malfunction.

Table 89: Comparison of TN, TP and CEC in Tests on A-2-4 and A-3 Soil-Sod Combinations, 16-0-8 Fertilization Practice

Soil-Sod Combination	**A-2-4 and Pensacola Bahia**		**A-3 and Argentine Bahia**	
Rainfall Intensity [in/hr]	0.10	0.25	0.10	0.25
Total Nitrogen Before Test [g]	2168	1046	NA	9966
Total Nitrogen After Test [g]	486	491	NA	8013
Total Phosphorus Before Test [g]	792	568	NA	799
Total Phosphorus After Test [g]	552	509	NA	690
CEC Before Test [meq/g]	0.489	0.523	NA	0.050
CEC After Test [meq/g]	0.433	0.497	NA	0.052

CHAPTER 9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Summary of Conclusions

9.1.1 Phase #1

The primary objective of this research study was to evaluate the environmental benefits of changes in the fertilization practices of the Florida Department of Transportation, by simulating the conditions of highway slopes with respect to soil, turf, rainfall, and slope conditions. Comparing the seven tests conducted using 10-10-10 fertilizer on A-3 soil that represented the past practice, and the corresponding seven tests conducted using 16-0-8 (SR) fertilizer on A-3 soil that represented the new practice, it can be concluded that there is a 66.5 % reduction of total nitrogen (TN) loss to the environment due to the change in practice.

Each test was conducted after applying fertilizers to result in 1 lb of N per 1000 ft^2. This is based on the grand total mass of TN lost, during the irrigation and simulated rainfall events only, without any regard to the soil, turf, rainfall, and slope conditions. This environmental benefit can be attributed to the slow release component (sulfur-coated urea) of the 16-0-8 (SR) fertilizer, and the consequent bio-geochemical interactions in the soil-turf system.

A more recent practice of the FDOT is to reduce the application rate of 16-0-8 (SR) from 1 lb to 0.5 lb of N per 1000 ft^2, based on the presumption that 1 lb of N per 1000 ft^2 (that represented the UF-IFAS recommended fertilization rate for home lawns) is resulting in undesirable nutrient losses. At the request of FDOT, this study was initiated to evaluate the effects of this reduction in the application rate, seven additional tests were conducted on the combination of A-3 soil and Argentine Bahia @ 0.5 lb of N per 1000 ft^2, in addition to the seven tests @ 1 lb of N per 1000 ft^2 already planned and conducted. Surprisingly, it was found that the total mass of TN lost in the seven tests of 16-0-8 (SR) @ 0.5 lb was 60.9 grams, which is 8.5 grams more than the 52.4 grams of the total mass of TN lost in the corresponding seven tests of 16-0-8 (SR) @ 1 lb. As described in Table 3.2, the series of tests @ 1 lb of N were conducted during August-September of 2009, on virgin A-3 soil, i.e., before any prior tests involving fertilization. In contrast, the series of tests @ 0.5 lb of N were conducted during October-November of 2009, on A-3 soil that was already used for eight tests involving fertilization. This increased TN loss may be attributed to the biological and chemical transformations in the soil that increased easily leachable forms of nitrogen. In addition, because of lower temperatures and shorter daylight durations, there was a lower rate of nutrient uptake by the grass due to approaching winter, and less gaseous escape (ammonia volatilization and denitrification).

An attempt was made in chapter 5 towards analyzing the total nitrogen mass balance of the test bed, using the mechanistic models and parametric values available in the literature, and used that for calculating the TN loss as a percentage of the total available at the commencement of each test. Even after that analysis, it was found that the average percentage of TN lost in the seven tests of 16-0-8 (SR) @ 0.5 lb was 4.2%, which is 1.17% more than the 3.03% of the average percentage of TN lost in the corresponding seven tests of 16-0-8 (SR) @ 1 lb. These data suggest that fertilization during late fall may lead to more loss of nutrients, even if the application rate is reduced by 50%. In addition, the present analysis is based on very limited models and data, which may not be representative of FDOT's highway slopes. There is a need for more studies to develop a scientific basis.

The secondary objective of this research study was to examine the effect of soil and turf types on the nutrient losses from fertilized highway slopes. A comparison of the total masses of nutrient losses in the fourteen tests conducted on the Argentine Bahia sod over AASHTO A-3 soil that represented typical conditions in central and southern Florida with the past practice, and the corresponding fourteen tests conducted on the Pensacola Bahia sod over AASHTO A-2-4 soil that represented typical conditions in northern Florida. Without considering the effects of rainfall, and slope conditions, it is possible to conclude that the combination of A-3 soil and Argentine Bahia sod had resulted in 28.6 % less loss of TN, and about 24.4 % less loss of TP, compared to the combination of A-2-4 soil and Pensacola Bahia sod. This reduction is attributable to the higher infiltration capacity of A-3 soil compared with A-2-4, and possibly to the higher nutrient uptake capacity of Argentine Bahia compared with Pensacola Bahia. An additional reason may include the differences in nutrient transformations in the two soil-turf systems.

Additional objectives of this research included the development of a scientific understanding of the effects of slope and rainfall intensity on the nutrient losses. Intuitively, one can imagine that steeper slopes should result in higher losses, just as higher rainfall intensities. Though the data presented in chapter 3, in general, supports this intuition, there were several exceptions. The field-scale test bed and rainfall simulator at the University of Central Florida were used for simulating different slopes and rainfall intensities, and the practical challenges in maintaining similar conditions for different tests were explained in chapter 3. As these tests were conducted on four different set-ups of soil-sod combinations, over a period of two years, the bio-geochemical conditions had varied considerably. Variations in the weather conditions, physicochemical transformations of soils and nutrients, and the physiological conditions of turf have resulted in several exceptions to the expected trend. Other reasons, such as unintended accumulation of nutrients in the test bed, erroneous concentration or dilution of collected water samples, calibration errors of laboratory equipment, might have partially contributed to the seemingly low or high values. For the same reasons, the seven-day tests when compared with one-day tests did not exhibit definite trends.

The field-scale test beds and rainfall simulator were able to simulate the geophysical conditions of FDOT fertilized highway slopes. However, the loss of nutrients is also governed by the weather- and season-dependent chemical transformation of nutrients. In addition, such factors as the time after fertilization, soil organic matter, plant and microbial processes, and the chemical characteristics of the soil are also important. These transformations were analyzed in this study, and the loss of nutrients was determined in terms of percentage of total available nutrients. However, even these results also contained several exceptions to the intuitive trend of higher losses for steeper slopes and higher rainfall intensities. More scientific studies are required for better understanding these bio-geochemical processes and their influence on nutrient losses to the environment.

In all these tests, the turbidity and concentration of total suspended solids (TSS) in the collected run-off and base flow water samples were less than the acceptable values. These results suggest that the tested soil-turf combinations, under the tested rainfall and slope conditions, perform satisfactorily in preventing the soil erosion.

Overall, 2,971 grams of nitrogen was applied in the 35 one-day tests that involved fertilization. Out of this, 270 grams of nitrogen was measured in the water collected during irrigation and simulated rainfall events. This represents an average loss of 9.1%, over the range of 0.5 to 3 in/hr rainfall intensities and slopes ranging from 25% to 50%. The corresponding TP loss of 48.42 grams was only 2.4% of the 1,989.4 grams of TP applied. These percentages suggest that most of the applied nutrients are either taken up by the grass, escapes in gaseous forms, or adsorbed by the soil.

In the six tests conducted with no fertilizer application (for both A-3 and A-2-4 soils), the mass of TN measured in the water collected was just 4.14 grams. These low nutrient levels were measured because the soils were obtained from previously unfertilized areas that are being used as borrow areas for highway construction, and the sod did not contain significant leachable nutrients. The corresponding TP mass was 7.29 grams, slightly more than the TN mass, but not significant. These results reinforce the need for highway fertilization. Table 90 and Table 91 present the expected TN and TP mass loading rates for the different conditions in the phase #1 study on A-3 and A-2-4 soil types, respectively.

Table 90: Total Nitrogen and Total Phosphate Losses from Runoff on A-3 Soil and Argentine Bahia Sod

Nutrient Losses (lb/ac)	Slope	10-10-10 Fertilizer @ 1 lb/1000 ft^2			16-0-8 Fertilizer @ 1 lb/1000 ft^2			16-0-8 Fertilizer @ 0.5 lb/1000 ft^2		
		0.5 (in/hr)	1 (in/hr)	3 (in/hr)	0.5 (in/hr)	1 (in/hr)	3 (in/hr)	0.5 (in/hr)	1 (in/hr)	3 (in/hr)
TN Loss from Runoff	4:1	1.00	6.84	23.04	0	0.02	0.24	0	0.16	2.20
	3:1	2.92	13.20	-	0	0.31	-	0	0.16	-
	2:1	3.84	10.56	-	0	0.31	-	0	0.93	-
TP Loss from Runoff	4:1	0.20	3.08	31.40	0	0	0.10	0	0.05	0.27
	3:1	3.28	7.20	-	0	0.01	-	0	0.03	-
	2:1	5.12	7.84	-	0	0.01	-	0	0.04	-

Table 91: Total Nitrogen and Total Phosphate Losses from Runoff on A-2-4 Soil and Pensacola Bahia Sod

Nutrient Losses (lb/ac)	Slope	10-10-10 Fertilizer @ 1 lb/1000 ft^2			16-0-8 Fertilizer @ 0.5 lb/1000 ft^2		
		0.5 (in/hr)	1 (in/hr)	3 (in/hr)	0.5 (in/hr)	1 (in/hr)	3 (in/hr)
TN Loss from Runoff	4:1	6.17	15.4	9.93	6.88	6.96	18.4
	3:1	11.72	12.22	-	7.48	8.64	-
	2:1	13.22	1.46	-	0.6	0.88	-
TP Loss from Runoff	4:1	3.36	17.94	9.65	0.08	0.28	0.36
	3:1	7.98	12.19	-	0.08	0.2	-
	2:1	10.41	15.62	-	0.04	0.08	-

9.1.2 Phase #2

The objective of this research was to evaluate the environmental benefit of switching to a 16-0-8 (SR) fertilizer from an all-purpose 10-10-10 fertilizer by the Florida Department of Transportation. Additionally, it was desired to know the effect of low rainfall intensities and overland flow on nutrient loss. 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 of N per 1000 ft^2. Comparing the tests performed at 0.25 in/hr on A-2-4 soil with Pensacola Bahia sod for 10-10-10 and 16-0-8, it was found that there was a 41.6% reduction in total nitrogen (TN) and a 93% reduction in total phosphorus (TP) on that soil type for the 16-0-8 fertilizer type. Comparison of the tests performed at 0.25 in/hr on A-3 soil with Argentine Bahia sod showed similar results: a 67.6% reduction in total nitrogen (TN) and 80% reduction in total phosphorus (TP) when using the 16-0-8 fertilizer compared to the 10-10-10 fertilizer. Results at 0.1 in/hr., available only for A-2-4 soil with Pensacola Bahia sod, show that at this intensity, there was no significant benefit to the switch in fertilizers, and in fact, 16-0-8 showed greater losses than 10-10-10. This may be attributed to more nutrients inherent to the soil and sod used for the 16-0-8 trials in addition to higher average temperatures occurring during testing at this 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. It should be noted however, that the losses were not significant for either fertilizer type. The small rainfall volume applied resulted in little water collected as either base flow or runoff and therefore less water to wash the nutrients either through or off the test bed.

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 fertilizer resulted in 85.9% less TN lost and 99% less TP lost at 0.25 in/hr.

compared to the combination of A-2-4 soil and Pensacola Bahia sod. This difference can be at least partially attributed to the fact that runoff, which was only generated from A-2-4 soil, was a significant source of these losses. At 0.1 in/hr, there was no significant difference in TN lost; however, 58.3% less TP was lost from A-3 soil and Argentine Bahia sod than the A-2-4 soil and Pensacola Bahia sod, although losses from both soil types were low. The low rainfall volume resulted in not much fertilizer being washed off or through the soil and sod test area. Examination of the 16-0-8 (SR) fertilizer showed that 92.2% less TN was lost and 95% less TP was lost from the A-3 soil and Argentina Bahia sod compared to the A-2-4 soil and Pensacola Bahia sod. This can be attributed to the higher infiltration capacity of the A-3 soil compared with the A-2-4 soil resulting in no runoff being generated for any tests with the A-3 soil as well as possible higher nutrient uptake capacity of Argentine Bahia sod compared with the Pensacola Bahia sod.

A significant difference of this phase of testing from the first is that soil sampling was performed to analyze the total nitrogen and total phosphorus present in the soil as well as the cationic exchange capacity (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 cationic exchange capacity of the soil. As discussed in chapter 4, total nitrogen and total phosphorus tended to increase over time indicating that an unintentional accumulation of nutrients could have occurred. In addition, particularly for the A-3 soil and Argentine Bahia sod combination, the level of nutrients present in the soil prior to testing suggest that the sod placed on the test bed was already heavily fertilized.

The cationic exchange capacity tended to decrease with fertilizer application over time, likely due to exchange sites being utilized by cations introduced to the soil via fertilizer, and/or a decline in soil pH because 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.

Although runoff was found to be a significant source of nutrient loss when it occurred, base flow losses of total nitrogen were also considerable. Total phosphorus losses were observed to be greater from the 10-10-10 fertilizer than the 16-0-8 fertilizer as well as with the A-2-4 soil and Pensacola Bahia sod combination than the A-3 soil and Argentine Bahia sod combination; however, these losses, not taking into account those found in runoff, were low. This suggests that nitrogen tends to be lost from soil rather easily via both pathways of runoff and base flow, while phosphorus has a lower tendency to leach through the soil column but readily runs off from the soil surface. This is likely because phosphorus will tend to be in the form of phosphate, which has a high affinity to be sorbed to particle surfaces while nitrogen will tend to be nitrified to nitrate, which does not have a high affinity for sorption. Table 92 presents the expected TN and TP mass loading rates for the highway cross section with overland flow conditions in the phase #2 study on both soil types.

Table 92: Total Nitrogen and Total Phosphate Losses from Runoff for Phase #2 Testing

Nutrient Losses [lb/ac]	A-3 Soil with Pensacola Bahia Sod				A-2-4 Soil with Pensacola Bahia Sod			
	10-10-10 Fertilizer @ 1 lb/1000 ft^2		16-0-8 Fertilizer @ 0.5 lb/1000 ft^2		10-10-10 Fertilizer @ 1 lb/1000 ft^2		16-0-8 Fertilizer @ 0.5 lb/1000 ft^2	
	0.1 (in/hr)	0.25 (in/hr)	0.1 (in/hr)	0.25 (in/hr)	0.1 (in/hr)	0.25 (in/hr)	0.1 (in/hr)	0.25 (in/hr)
TN Loss from Runoff	0	0	0	0	0	1.55	0	0.68
TP Loss from Runoff	-	0	-	0	-	0.42	-	0.02

9.2 Recommendation for Improvement of BMPs

The experimental findings of this study suggest that the application of slow-release (SR) fertilizers results in overall reduction of nutrient losses, and is thus environmentally beneficial. In addition, the fertilizer application rates can be reduced from 1 lb of N per 1000 ft^2 to 0.5 lb of N per 1000 ft^2, still maintaining acceptable turf quality and preventing soil erosion. As this study focused on one specific type of fertilizer containing sulfur coated urea, research with other types of SR fertilizers is needed for understanding their consequences. Additionally, based on both phases of this study it was observed that new sod can come heavily fertilized from the sod farm. This may allow for lower applications of fertilizer or no application of fertilizer if the sod was recently fertilized prior to harvest. More research into this area is required to understand when forgoing the application of fertilizer may be acceptable.

It was observed in both phases of the study that compared with the AASHTO A-2-4 soil, the AASHTO A-3 soil has resulted in higher infiltration and lower run-off. This lower run-off ratio had resulted in lower loss of nutrients as run-off has higher potential to dissolve and carry away the nutrients. Though it is understood that the choice of soil for highway construction is dependent on local availability and economics, it is suggested that A-3 soil gets preferential use, at least as a surface layer, for increasing base flow and for reducing nutrient losses.

9.3 Suggestions for Further Research

Though the primary and secondary objectives of this research was satisfactorily achieved, namely, quantifying the environmental benefits of two fertilization regimes and soil-turf combinations, the tertiary objective of gaining a better understanding of the influence of slope and rainfall intensity on nutrient losses was not satisfactorily achieved. One of the reasons is conducting 46 tests on just four soil-turf combinations, due to time, equipment, and cost constraints and the requirement of compacting soil and establishing sod on the large test-bed. Mobilization of more resources is required for more detailed testing for understanding these factors, and for developing a scientific basis for evaluation of environmental benefits. This is due to changes in field-practices on a catchment-scale under different topographical and climatic conditions.

The literature review revealed only a few studies on the nutrient uptake capacities of these turf types and the chemical transformations of slow-release fertilizer under typical Florida conditions, namely, soil types and rainfall. Therefore, the mass balance analyses conducted in this study had to depend on limited results from literature. For understanding these transformations, extensive laboratory bench-scale and modeling studies are required, so that they can appropriately supplement the field-scale studies.

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APPENDIX A

WATER BALANCE, TN MASS BALANCE, TP MASS BALANCE, A-3 SOIL WITH ARGENTINE BAHIA SOD, 10-10-10 FERTILIZATION PRACTICE

Table 93: Analysis of Water Balance in the Soil-Sod Combination 1 (A-3 Soil, Argentine Bahia Sod, and 10-10-10 Fertilization Practice)

Avg dry density of soil (pcf)	104.9	Sr. gr. of soil grains	2.58	Porosity	0.34847
Mass of dry soil in test bed (in kg)	11403.7	Volume of water at full saturation (L)	2368.74	Full saturation % (mass basis)	20.77%

	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Rainfall, (in)	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapotrans-piration (mm per day)	Bed Evapotrans-piration (L)	Rainfall Applied [L]	Runoff and Base flow [L]	Seepage + Final Storage [L]
5/27/2009	21%	2368.7	0.000	0.0	0	0.0	78	14.65	4.19	93.1	3393.2	3044.5	2624.2
5/28/2009					0.47	265.1	78	14.67	4.21	93.4			
5/29/2009					0	0.0	80	14.68	4.45	98.9			
5/30/2009					0	0.0	82	14.70	4.70	104.4			
5/31/2009					0	0.0	78	14.72	4.25	94.4			
6/1/2009					0	0.0	79	14.72	4.37	97.0			
6/2/2009					0	0.0	80	14.73	4.50	99.9			
6/3/2009	19.50%	2223.7	0.061	77.6	0	0.0	80.3	14.75	4.55	101.0	3486.4	3021.7	2587.3
6/4/2009					3.5	1973.9	76	14.77	4.06	90.2			
6/5/2009					0.12	67.7	80	14.77	4.53	100.6			
6/6/2009					0.2	112.8	76	14.78	4.07	90.5			
6/7/2009					0.02	11.3	78	14.78	4.31	95.7			
6/8/2009					0.44	248.2	78	14.80	4.33	96.0			
6/9/2009					1.1	620.4	81	14.80	4.68	103.9			
6/10/2009	22.40%	2368.7	0.000	2675.9	0	0.0	84	14.82	5.06	112.2	4851.4	4228.9	2879.0
6/11/2009					0	0.0	85	14.82	5.17	114.9			
6/12/2009					0	0.0	84	14.83	5.07	112.6			
6/13/2009					0.17	95.9	82	14.83	4.83	107.3			
6/14/2009					0	0.0	83	14.83	4.95	110.0			
6/15/2009					0.03	16.9	86	14.85	5.33	118.4			
6/16/2009					1.14	642.9	83	14.85	4.97	110.4			
6/17/2009					0	0.0	83	14.85	4.97	110.4			
6/18/2009					1.42	800.9	81	14.85	4.73	105.0			
6/19/2009					0	0.0	83	14.85	4.97	110.4			
6/20/2009					0	0.0	88	14.85	5.57	123.7			
6/21/2009					0	0.0	90	14.85	5.81	129.1			
6/22/2009	11.40%	1300.0	0.451	1883.5	0	0.0	90	14.85	5.81	129.1	3020.3	2729.2	1462.1
6/23/2009					1.54	868.5	86	14.85	5.33	118.4			
6/24/2009					0	0.0	82	14.85	4.85	107.7			
6/25/2009					0	0.0	84	14.85	5.09	113.0			
6/26/2009					0.19	107.2	82	14.85	4.85	107.7			

	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Rainfall, (in)	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapotrans-piration (mm per day)	Bed Evapotrans-piration (L)	Rainfall Applied [L]	Runoff and Base flow [L]	Seepage + Final Storage [L]
6/27/2009					0.01	5.6	83	14.83	4.95	110.0			
6/28/2009					0	0.0	84	14.83	5.07	112.6			
6/29/2009	15.00%	1710.6	0.278	63.5	0.01	5.6	85	14.83	5.19	115.3	3199.7	3123.0	1677.6
6/30/2009					0.98	552.7	80	14.82	4.58	101.7			
7/1/2009					0.02	11.3	78	14.82	4.34	96.4			
7/2/2009	16.00%	1824.6	0.230	219.0	0.18	101.5	81	14.80	4.68	103.9	3743.6	3281.6	2284.2
7/3/2009					0.02	11.3	84	14.80	5.04	111.9			
7/4/2009					0	0.0	85	14.78	5.14	114.1			
7/5/2009					0.02	11.3	83	14.78	4.90	108.8			
7/6/2009	16.40%	1870.2	0.210	101.8	0.05	28.2	84	14.77	5.00	111.1	3905.4	3379.0	2313.8

Table 94: Mass Balance of Total Nitrogen in the Soil-Sod Combination 1 (A-3 Soil, Argentine Bahia, and 10-10-10 Fertilization Practice)

	BEFORE Fertilizer Application				AFTER Fertilizer 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 Con-tent	Total Day Light Hours	Ammonia Volati-lization per day k_{volati}	Nitrifi-cation per day k_{nitri}	Deni-trifi-cation per day $k_{denitri}$	Grass uptake grams per (day*Test bed)	No. of days to next test	Ammonia volatil-ization loss up to next test
5/27/2009	0	0	60	106.1	106.1	60	78	7.22	0	14.65	0.0042	0	0.002	2.03	7	3.09
6/3/2009	136.3	103	33.3	106.1	209	33.3	80.3	7.52	0.061	14.75	0.007	0.07	0.002	2.08	7	10.24
6/10/2009	190.2	90.2	100	106.1	196.2	100	84	7.45	0	14.82	0.0071	0	0.002	2.12	12	16.79
6/22/2009	185.8	179.4	6.4	106.1	285.5	6.4	90	7.34	0.451	14.85	0.0072	0.2	0.001	2.14	7	14.35
6/29/2009	245.4	0	245.4	106.1	106.1	245.4	85	7.34	0.278	14.83	0.0063	0.16	0.001	2.13	3	2
7/2/2009	301.7	53.7	248	106.1	159.8	248	81	7.28	0.23	14.8	0.0051	0.14	0.001	2.11	4	3.25
7/6/2009	363.2	64.6	298.5	106.1	170.7	298.5	84	7.05	0.21	14.77	0.0037	0.14	0.001	2.09	0	0

Date of Test	Conversion to Nitrate up to next test	Denitrifica-tion 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 see-page since previous test (g)	TN lost in test (irr.+ rain+ flush)	TN lost in test (RAIN only)	% loss in sim rain w.r.to TN after fert. Appli-cation
5/27/2009	0	0.84	14.18	0	0	0	11.64	3.1	1.90%
6/3/2009	108.61	1.75	14.57	77.6	1.78	0.14	25.49	17.37	7.20%
6/10/2009	0	2.4	25.42	2675.9	2.18	5.82	59.97	57.22	19.30%
6/22/2009	271.14	1.17	14.96	1883.5	0.28	0.53	15.47	7.64	2.60%
6/29/2009	50.32	0.93	6.383	63.5	2.31	0.15	40.28	33.15	9.40%
7/2/2009	91.91	1.61	8.436	219	0.8	0.18	31.15	10.24	2.50%
7/6/2009	0	0	0	101.8	2.16	0.22	46.74	27.13	5.80%

All applied N is ammoniacal

Ammonia Volatilization per day (k_{volati}) depends on temperature and pH.

Denitrification rate per day (k_{nitri}) varies inversely with volumetric air content

Grass uptake grams per (day*Test bed) depends on day light duration

Nitrification rate per day (k_{nitri}) depends on volumetric air content

Table 95: Mass Balance of Total Phosphate in the Soil-Sod Combination 1 (A-3 Soil, Argentine Bahia, and 10-10-10 Fertilization Practice)

	BEFORE Fertilizer Application						**AFTER Fertilizer Application**										
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 coefficient 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	X to Y	Y to X	X to P_{buffer}
5/27/2009	0.0	0.0	0.0	0.000	142.1	0.65	92.4	49.7	0.000	14.65	0.0079	0.0014	0.0004	0.0003	0.734	0.071	0.041
6/3/2009	131.5	81.0	50.4	0.041	142.1	0.62	168.7	104.9	0.041	14.75	0.0079	0.0014	0.0004	0.0003	1.340	0.149	0.075
6/10/2009	256.1	149.9	106.1	0.117	142.1	0.59	233.1	165.0	0.117	14.82	0.0079	0.0014	0.0004	0.0003	1.852	0.235	0.104
6/22/2009	308.2	141.3	166.6	0.221	142.1	0.46	206.6	243.5	0.221	14.85	0.0079	0.0014	0.0004	0.0003	1.641	0.347	0.092
6/29/2009	429.3	184.1	244.8	0.313	142.1	0.43	245.1	325.9	0.313	14.83	0.0079	0.0014	0.0004	0.0003	1.948	0.464	0.109
7/2/2009	539.9	212.1	327.4	0.422	142.1	0.39	267.9	413.6	0.422	14.80	0.0079	0.0014	0.0004	0.0003	2.129	0.589	0.120
7/6/2009	661.5	245.7	415.2	0.542	142.1	0.37	298.6	504.5	0.542	14.77	0.0079	0.0014	0.0004	0.0003	2.372	0.719	0.133

Date of Test	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
5/27/2009	0.000	0.41	7.0	2.836	0	0.000	0.00	7.80	0.61	0.7%
6/3/2009	0.000	0.42	7.0	2.914	77.6	0.953	0.07	14.50	7.76	4.6%
6/10/2009	0.000	0.42	12.0	5.084	2675.9	0.193	0.52	84.46	77.88	33.4%
6/22/2009	0.000	0.43	7.0	2.991	1883.5	0.123	0.23	17.81	8.35	4.0%
6/29/2009	0.000	0.43	3.0	1.277	63.5	0.433	0.03	30.19	18.11	7.4%
7/2/2009	0.000	0.42	4.0	1.687	219.0	0.500	0.11	18.74	12.79	4.8%
7/6/2009	0.000	0.42	0.0	0.000	101.8	0.232	0.02	28.51	19.72	6.6%

Partition coefficient R is X/(X+Y)   Rate constants, K_1, K_2, K_3, and K_4 are from literature

Grass uptake grams per (day*Test bed) depends on day light duration

APPENDIX B

WATER BALANCE, TN MASS BALANCE, A-3 SOIL WITH ARGENTINE BAHIA SOD, NO FERTILIZER, 16-0-8 (0.5 LB AND 1LB), AND 10-10-10 FERTILIZATION PRACTICES SEVEN-DAY TEST

Table 96: Analysis of Water Balance in the Soil-Sod Combination 2 (A-3 Soil, Argentine Bahia Sod, and No Fertilizer, 16-0-8 (SR) Fertilization Practice @ 1 lb and 0.5 lb of N per 1000 ft^2, and 10-10-10 Fertilization Practices, Seven-Day Test)

Avg dry density of soil (pcf) 104.9

Mass of dry soil in test bed (in kg) 11405 Sr. gr. of soil grains 2.58 Porosity 0.3484

Volume of water at full saturation (L) 2368.4 Full Saturation % (by mass) 20.77%

	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volumetric Air Content	Seepage Since Previous Test (L)	Rainfall, (in)	Natural Rainfall Volume (L)	Mean Temp. (°F)	Total Day Light Hours	Evapotranspi-ration (mm per day)	Bed Evapo-transpiration (L)	Rainfall Applied [L]	Runoff and Base flow [L]	Final Storage [L]
8/17/2009	18.50%	2110	0.11	0	0.05	28	84	13.92	4.1	91.01	3444	3017	2474
8/18/2009					0.55	310	84	13.9	4.08	90.62			
8/19/2009					0.12	68	82	13.87	3.87	85.86			
8/20/2009	21.60%	2368	0	307	0	0	84	13.83	4.01	89.05	4080	3408	2951
8/21/2009					2.38	1342	84	13.82	3.99	88.65			
8/22/2009					0	0	81	13.78	3.7	82.07			
8/23/2009					0.51	288	82	13.75	3.75	83.27			
8/24/2009	21.90%	2368	0	1958	0.16	90	82	13.73	3.73	82.89	5159	4554	2981
8/25/2009					0.36	203	82	13.7	3.7	82.15			
8/26/2009					0.38	214	84	13.67	3.83	85.12			
8/27/2009	18.10%	2064	0.13	1167	0	0	82	13.65	3.65	81.04	4907	4307	2583
8/28/2009					0	0	84	13.62	3.78	83.94			
8/29/2009					0	0	84	13.58	3.74	83.15			
8/30/2009					0	0	83	13.57	3.65	80.98			
8/31/2009	17.80%	2030	0.14	305	2.02	1139	83	13.53	3.61	80.21	3689	3214	3564
9/1/2009					0.26	147	80	13.5	3.34	74.24			
9/2/2009					0.69	389	78	13.48	3.17	70.45			
9/3/2009	11.10%	1266	0.47	2689	1.16	654	80	13.45	3.3	73.2	3978	3693	2132
9/4/2009					0	0	81	13.42	3.34	74.19			
9/5/2009					0.28	158	80	13.38	3.23	71.82			
9/6/2009					0	0	82	13.37	3.37	74.75			
9/7/2009					0	0	82	13.33	3.33	74.01			
9/8/2009					0	0	80	13.3	3.16	70.08			
9/9/2009					0	0	82	13.28	3.28	72.9			
9/10/2009	15.00%	1711	0.28	141	0	0	82	13.25	3.25	72.16	4114	3488	2264
9/11/2009					0	0	82	13.22	3.22	71.42			
9/12/2009					0.03	17	78	13.18	2.91	64.62			
9/13/2009					0.09	51	81	13.17	3.1	68.81			
9/14/2009	16.90%	1927	0.19	200	0	0	82	13.13	3.13	69.57	3965	3486	2337

	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volumetric Air Content	Seepage Since Previous Test (L)	Rainfall, (in)	Natural Rainfall Volume (L)	Mean Temp. (°F)	Total Day Light Hours	Evapotranspi-ration (mm per day)	Bed Evapo-transpiratio n (L)	Rainfall Applied [L]	Runoff and Base flow [L]	Final Storage [L]
9/15/2009					0	0	82	13.1	3.1	68.83			
9/16/2009					0	0	82	13.08	3.08	68.46			
9/17/2009	16.70%	1905	0.2	295	0	0	82	13.05	3.05	67.72	3883	3524	2196
9/18/2009					0	0	82	13.02	3.02	66.98			
9/19/2009					0	0	83	12.98	3.05	67.62			
9/20/2009					0	0	83	12.97	3.03	67.24			
9/21/2009	16.10%	1836	0.22	158	0	0	82	12.93	2.93	65.13	4020	3495	2296
9/22/2009					0.12	68	84	12.9	3.02	67.03			
9/23/2009					0.01	6	81	12.88	2.82	62.71			
9/24/2009					0.07	39	82	12.85	2.85	63.28			
9/25/2009					0	0	82	12.82	2.82	62.54			
9/26/2009					0.79	446	82	12.78	2.78	61.8			
9/27/2009					0.33	186	82	12.77	2.77	61.43			
9/28/2009					0	0	82	12.73	2.73	60.69			
9/29/2009					0	0	82	12.7	2.7	59.95			
9/30/2009					0	0	74	12.68	2.26	50.24			
10/1/2009					0	0	74	12.65	2.24	49.68			
10/2/2009					0	0	79	12.62	2.47	54.74			
10/3/2009					0	0	79	12.6	2.45	54.4			
10/4/2009					0	0	81	12.57	2.52	55.9			
10/5/2009					0.05	28	82	12.53	2.53	56.25			
10/6/2009					0.01	6	83	12.52	2.56	56.93			
10/7/2009					0	0	83	12.48	2.53	56.17			
10/8/2009					0	0	84	12.45	2.54	56.41			
10/9/2009					0	0	86	12.43	2.61	58.01			
10/10/2009					0	0	81	12.4	2.36	52.32			
10/11/2009					0	0	83	12.38	2.43	53.88			
10/12/2009					0	0	83	12.35	2.39	53.12			
10/13/2009	12.30%	1403	0.41	464	0	0	83	12.32	2.36	52.35	1399	973	1777
10/14/2009					0	0	83	12.3	2.34	51.97			
10/15/2009	12.00%	1369	0.42	356	0.12	68	82	12.27	2.27	50.33	1205	814	1776
10/16/2009					0.03	17	78	12.25	2.09	46.49			
10/17/2009					0	0	65	12.22	1.57	34.87			
10/18/2009					0	0	57	12.18	1.26	27.95			
10/19/2009	12.10%	1380	0.42	304	0	0	63	12.17	1.47	32.73	1311	678	1980
10/20/2009					0	0	68	12.13	1.64	36.36			
10/21/2009					0	0	74	12.12	1.84	40.8			

	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volumetric Air Content	Seepage Since Previous Test (L)	Rainfall, (in)	Natural Rainfall Volume (L)	Mean Temp. (°F)	Total Day Light Hours	Evapotranspi-ration (mm per day)	Bed Evapo-transpiratio n (L)	Rainfall Applied [L]	Runoff and Base flow [L]	Final Storage [L]
10/22/2009					0	0	74	12.08	1.81	40.24			
10/23/2009					0	0	77	12.07	1.9	42.19			
10/24/2009					0	0	79	12.03	1.94	43			
10/25/2009					0	0	73	12.02	1.73	38.43			
10/26/2009	11.40%	1300	0.45	439	0	0	78	11.98	1.86	41.31	3750	3033	1977
10/27/2009					0.19	107	82	11.97	1.97	43.67			
10/28/2009					0	0	80	11.93	1.88	41.63			
10/29/2009	17.00%	1939	0.18	60	0	0	82	11.92	1.92	42.56	4639	4083	2452
10/30/2009					0.06	34	78	11.9	1.79	39.69			
10/31/2009					0	0	79	11.87	1.79	39.64			
11/1/2009					0	0	78	11.85	1.74	38.72			
11/2/2009					0	0	74	11.82	1.61	35.8			
11/3/2009					0.02	11	70	11.8	1.5	33.31			
11/4/2009					0	0	74	11.78	1.59	35.25			
11/5/2009	17.90%	2041	0.14	234	0	0	72	11.75	1.52	33.65	3456	3009	2455
11/6/2009					0	0	68	11.73	1.41	31.36			
11/7/2009					0	0	71	11.72	1.47	32.65			
11/8/2009					0	0	73	11.68	1.49	33.11			
11/9/2009					0	0	77	11.67	1.56	34.69			
11/10/2009					0.33	186	76	11.65	1.53	33.93			
11/11/2009					0	0	74	11.63	1.48	32.75			
11/12/2009	17.30%	1973	0.17	469	0	0	60	11.62	1.19	26.48	3578	3118	2407
11/13/2009					0	0	63	11.58	1.24	27.47			
11/14/2009					0	0	68	11.57	1.32	29.28			
11/15/2009					0	0	68	11.55	1.31	29.07			
11/16/2009					0	0	68	11.53	1.3	28.87			
11/17/2009	16.30%	1859	0.22	433	0	0	72	11.52	1.36	30.09	3964	3485	2308
11/18/2009					0	0	72	11.5	1.34	29.84			
11/19/2009	18.00%	2053	0.13	225	0	0	71	11.48	1.32	29.25	3857	3223	2657
11/20/2009					0.15	85	72	11.47	1.32	29.33			
11/21/2009					0	0	72	11.45	1.31	29.07			
11/22/2009					0	0	72	11.43	1.3	28.82			
11/23/2009	18.30%	2087	0.12	567	0	0	74	11.42	1.31	29.14	4289	3713	2633

Table 97: Mass Balance of Total Nitrogen in the Soil-Sod Combination 2 (A-3 Soil, Argentine Bahia Sod, and No-Fertilizer, 16-0-8 (SR) @ 1 lb and 0.5 lb, and 10-10-10 Fertilization Practices, Seven-Day)

	BEFORE Fertilizer Application				AFTER Fertilizer 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)	Ammoniacal 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 $k_{denitri}$
8/17/2009	55.0	35.0	20.0	0.0	35.0	20.0	84.0	7.61	0.109	13.92	0.0088	0.10	0.002
8/20/2009	48.9	23.7	25.2	0.0	23.7	25.2	84.0	7.40	0.000	13.83	0.0067	0.00	0.002
8/24/2009	41.3	23.0	18.2	0.0	23.0	18.2	82.0	7.27	0.000	13.73	0.0052	0.00	0.002
8/27/2009	32.4	22.7	9.7	106.5	129.2	9.7	82.0	7.57	0.128	13.65	0.0079	0.11	0.002
8/31/2009	119.1	69.6	49.5	106.5	176.1	49.5	83.0	7.50	0.143	13.53	0.0074	0.11	0.001
9/3/2009	119.8	112.2	7.6	106.5	218.7	7.6	80.0	7.38	0.465	13.45	0.0057	0.20	0.001
9/10/2009	64.9	0.0	64.9	106.5	106.5	64.9	82.0	7.25	0.278	13.25	0.0050	0.16	0.001
9/14/2009	103.3	37.0	66.3	106.5	143.5	66.3	82.0	7.18	0.186	13.13	0.0045	0.13	0.001
9/17/2009	148.4	85.9	62.6	106.5	192.4	62.6	82.0	7.45	0.196	13.05	0.0067	0.13	0.001
9/21/2009	185.8	85.0	100.7	106.5	191.5	100.7	82.0	6.60	0.225	12.93	0.0012	0.14	0.001
10/13/2009	153.8	0.0	153.8	106.5	106.5	153.8	83.0	7.14	0.408	12.32	0.0043	0.19	0.001
10/15/2009	205.8	64.5	141.3	0.0	64.5	141.3	82.0	7.11	0.422	12.27	0.0039	0.19	0.001
10/19/2009	159.5	13.2	146.3	0.0	13.2	146.3	63.0	7.29	0.417	12.17	0.0022	0.19	0.001
10/26/2009	121.9	0.0	121.9	53.0	53.0	121.9	78.0	7.34	0.451	11.98	0.0050	0.20	0.001
10/29/2009	117.7	20.2	97.5	53.0	73.2	97.5	82.0	7.73	0.181	11.92	0.0096	0.13	0.001
11/5/2009	126.3	2.8	123.5	53.0	55.9	123.5	72.0	7.03	0.138	11.75	0.0023	0.11	0.001
11/12/2009	151.1	11.4	139.7	53.0	64.4	139.7	60.0	7.45	0.167	11.62	0.0021	0.12	0.001
11/17/2009	174.1	24.3	149.8	53.0	77.3	149.8	72.0	7.28	0.215	11.52	0.0036	0.14	0.001
11/19/2009	186.2	55.2	130.9	53.0	108.3	130.9	71.0	7.02	0.133	11.48	0.0022	0.11	0.002
11/23/2009	217.6	59.9	157.7	53.0	112.9	157.7	74.0	6.94	0.119	11.42	0.0021	0.10	0.002

All applied N is ammoniacal.

Nitrification rate per day (k_{nitri}) depends on volumetric air content

Ammonia Volatilization per day (k_{volati}) depends on temperature and pH.

Denitrification rate per day (k_{nitri}) varies inversely with volumetric air content

Grass uptake grams per (day*Test bed) depends on day light duration

Table 97: continued

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)	TN lost in test (RAIN only)	% loss in sim rain w.r.to TN after fert. Application
8/17/2009	1.62	3.0	0.93	10.41	0.14	4.862	0	0.00	0.00	0.17	0.04	0.07%
8/20/2009	1.57	4.0	0.63	0.00	0.20	6.283	306.9	0.00	0.00	0.50	0.02	0.04%
8/24/2009	1.52	3.0	0.36	0.00	0.11	4.545	1958.2	0.13	0.25	3.62	1.76	4.26%
8/27/2009	1.47	4.0	4.08	55.55	0.40	5.883	1166.5	1.60	1.87	7.61	0.87	0.63%
8/31/2009	1.40	3.0	3.92	59.89	0.48	4.212	304.8	3.55	1.08	96.01	2.21	0.98%
9/3/2009	1.36	7.0	8.75	210.00	0.87	9.518	2689.2	16.28	43.79	98.49	8.98	3.97%
9/10/2009	1.25	4.0	2.13	67.34	0.55	4.995	141.4	21.03	2.97	57.50	11.18	6.52%
9/14/2009	1.18	3.0	1.92	55.74	0.48	3.546	199.9	25.24	5.04	50.34	6.38	3.04%
9/17/2009	1.14	4.0	5.18	102.15	0.85	4.551	295.0	23.10	6.81	51.77	9.13	3.58%
9/21/2009	1.07	22.0	4.85	186.69	7.60	23.57	157.5	22.89	3.61	98.90	7.28	2.49%
10/13/2009	0.73	2.0	0.91	40.65	0.27	1.465	464.3	26.96	12.52	38.86	38.86	14.96%
10/15/2009	0.70	4.0	1.02	50.32	0.51	2.819	356.0	46.55	16.57	25.38	25.38	12.33%
10/19/2009	0.65	7.0	0.20	13.00	0.76	4.545	303.8	43.61	13.25	18.90	18.90	11.85%
10/26/2009	0.54	3.0	0.80	32.05	0.28	1.632	439.3	44.17	19.40	35.11	21.01	12.01%
10/29/2009	0.51	7.0	4.91	65.47	1.53	3.574	59.7	14.69	0.88	33.51	9.72	5.69%
11/5/2009	0.42	7.0	0.91	43.58	1.74	2.914	233.5	12.50	2.92	19.76	2.13	1.19%
11/12/2009	0.34	5.0	0.68	39.46	1.24	1.721	469.4	3.59	1.68	24.70	2.98	1.46%
11/17/2009	0.29	2.0	0.56	21.50	0.42	0.577	433.4	17.10	7.41	31.99	12.55	5.53%
11/19/2009	0.27	4.0	0.95	47.41	1.07	1.066	225.3	12.94	2.92	15.64	4.78	2.00%
11/23/2009	0.23	0.0	0.00	0.00	0.00	0	567.5	16.92	9.60	17.59	4.06	1.50%

APPENDIX C
WATER BALANCE, TN MASS BALANCE, TP MASS BALANCE, A-2-4 SOIL WITH PENSACOLA BAHIA SOD, NO FERTILIZER, 10-10-10 FERTILIZER, 10-10-10 FERTILIZER SEVEN-DAY TEST

Table 98: Analysis of Water Balance in the Soil-Sod Combination 3 (A-2-4 Soil, Pensacola Bahia Sod and 10-10-10 Fertilization Practice, and No Fertilizer)

Avg dry density of soil (pcf) 101.7 Sr. gr. of soil grains 2.65

Mass of dry soil in test bed (in kg) 11056.8 Porosity 0.38498

Volume of water at full saturation (L) 2616.9 Full Saturation % (by mass) 23.67%

	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	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]	Runoff and Base flow [L]	Final Storage [L]
1/14/2010	16.4%	1813.3	0.31	0.00	0.00	0.00	56.00	11.35	1.07	23.66	3586.6	2618.6	2757.7
1/15/2010					0.04	22.56	62.00	11.37	1.14	25.26			
1/16/2010					0.04	22.56	69.40	11.38	1.23	27.36			
1/17/2010					0.09	50.76	71.20	11.40	1.27	28.09			
1/18/2010					0.00	0.00	60.80	11.42	1.14	25.33			
1/19/2010					0.00	0.00	59.70	11.43	1.13	25.12			
1/20/2010					0.04	22.56	62.40	11.45	1.17	26.08			
1/21/2010	17.70%	1957.1	0.25	761.86	0.12	67.68	71.10	11.47	1.31	29.04	3725.9	3031.7	2689.9
1/22/2010					0.37	208.67	72.60	11.48	1.34	29.78			
1/23/2010					0.04	22.56	66.00	11.50	1.25	27.76			
1/24/2010					0.00	0.00	72.60	11.52	1.36	30.31			
1/25/2010					0.38	214.31	65.10	11.53	1.25	27.79			
1/26/2010					0.00	0.00	56.40	11.55	1.11	24.65			
1/27/2010					0.00	0.00	52.90	11.57	1.05	23.34			
1/28/2010	18.90%	2089.7	0.20	882.07	0.00	0.00	54.80	11.60	1.09	24.20	5263.4	3956.5	3372.4
1/29/2010					0.00	0.00	63.00	11.62	1.25	27.77			
1/30/2010					0.08	45.12	68.10	11.63	1.36	30.16			
1/31/2010					0.00	0.00	53.20	11.65	1.07	23.65			
2/1/2010	20.00%	2211.4	0.15	1124.58	0.70	394.79	61.30	11.67	1.24	27.43	3850.9	2962.3	3076.3
2/2/2010					0.42	236.87	66.90	11.70	1.37	30.41			
2/3/2010					0.00	0.00	56.20	11.72	1.14	25.29			
2/4/2010	17.50%	1934.9	0.26	1322.52	0.00	0.00	63.50	11.73	1.31	29.07	5205.3	4090.2	3021.0
2/5/2010					0.25	141.00	70.60	11.77	1.49	33.16			
2/6/2010					0.00	0.00	60.50	11.78	1.26	27.91			
2/7/2010					0.00	0.00	49.50	11.80	0.99	21.93			
2/8/2010	17.50%	1934.9	0.26	1144.10	0.00	0.00	53.80	11.83	1.10	24.40	4190.7	3257.4	2843.8
2/9/2010					0.79	445.55	58.60	11.85	1.23	27.28			
2/10/2010					0.00	0.00	51.70	11.88	1.05	23.25			
2/11/2010	17.20%	1901.8	0.27	1337.08	0.00	0.00	46.10	11.90	0.89	19.77	3754.2	3029.5	2606.7

	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	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]	Runoff and Base flow [L]	Final Storage [L]
2/12/2010					0.91	513.22	50.90	11.92	1.03	22.78			
2/13/2010					0.00	0.00	45.30	11.95	0.86	19.11			
2/14/2010					0.00	0.00	45.50	11.97	0.86	19.19			
2/15/2010					0.00	0.00	57.00	12.00	1.22	27.06			
2/16/2010					0.00	0.00	49.80	12.02	0.99	22.06			
2/17/2010					0.00	0.00	47.90	12.05	0.93	20.67			
2/18/2010					0.00	0.00	50.30	12.07	1.01	22.43			
2/19/2010					0.00	0.00	51.80	12.10	1.06	23.58			
2/20/2010					0.00	0.00	60.40	12.13	1.37	30.38			
2/21/2010					0.00	0.00	63.20	12.15	1.47	32.74			
2/22/2010					0.00	0.00	67.50	12.18	1.65	36.57			
2/23/2010					0.00	0.00	68.30	12.20	1.69	37.44			
2/24/2010					0.37	208.67	60.70	12.23	1.41	31.36			
2/25/2010					0.00	0.00	48.80	12.25	0.95	21.16			
2/26/2010					0.00	0.00	48.80	12.28	0.95	21.14			
2/27/2010					0.13	73.32	46.80	12.32	0.87	19.28			
2/28/2010					0.00	0.00	57.40	12.33	1.31	29.05			
3/1/2010					0.00	0.00	57.70	12.37	1.33	29.51			
3/2/2010					0.33	186.11	60.50	12.40	1.46	32.40			
3/3/2010					0.00	0.00	51.50	12.42	1.07	23.68			
3/4/2010	17.70%	1957.1	0.25	1109.38	0.00	0.00	50.40	12.45	1.02	22.61	3669.2	2850.9	2752.7
3/5/2010					0.00	0.00	50.60	12.48	1.03	22.82			
3/6/2010					0.00	0.00	52.10	12.50	1.10	24.39			
3/7/2010					0.00	0.00	55.20	12.53	1.25	27.74			
3/8/2010	17.50%	1934.9	0.26	742.84	0.00	0.00	61.70	12.57	1.57	34.92	4016.1	3196.0	2720.1
3/9/2010					0.00	0.00	61.00	12.58	1.54	34.29			
3/10/2010					0.00	0.00	67.40	12.62	1.88	41.72			
3/11/2010					2.45	1381.75	69.70	12.65	2.02	44.76			
3/12/2010					0.91	513.22	69.10	12.67	1.99	44.29			
3/13/2010					0.16	90.24	65.90	12.70	1.84	40.96			
3/14/2010					0.00	0.00	64.20	12.73	1.77	39.28			
3/15/2010	17.30%	1912.8	0.27	2547.19	0.00	0.00	63.80	12.75	1.75	38.96	3525.3	2918.7	2480.5
3/16/2010					0.00	0.00	59.20	12.78	1.51	33.59			
3/17/2010					0.00	0.00	61.80	12.82	1.67	37.08			
3/18/2010					0.09	50.76	59.80	12.85	1.57	34.78			
3/19/2010					0.00	0.00	62.50	12.87	1.73	38.39			
3/20/2010					0.00	0.00	64.00	12.90	1.83	40.66			

	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	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]	Runoff and Base flow [L]	Final Storage [L]
3/21/2010					1.66	936.21	66.60	12.93	2.00	44.47			
3/22/2010					0.00	0.00	62.80	12.95	1.78	39.52			
3/23/2010	17.70%	1957.1	0.25	1241.90	0.00	0.00	63.80	12.98	1.86	41.20	1627.0	923.3	2619.5
3/24/2010					0.00	0.00	64.80	13.02	1.93	42.91			
3/25/2010	16.00%	1769.1	0.32	807.51	0.42	236.87	71.20	13.05	2.36	52.36	1514.9	850.7	2617.8
3/26/2010					0.08	45.12	73.40	13.07	2.51	55.76			
3/27/2010					0.00	0.00	67.50	13.10	2.15	47.70			
3/28/2010					1.29	727.54	69.30	13.13	2.29	50.77			
3/29/2010	16.40%	1813.3	0.31	1422.90	0.99	558.34	68.90	13.17	2.28	50.62	1514.9	730.4	3105.5
3/30/2010					0.00	0.00	63.70	13.18	1.93	42.96			
3/31/2010					0.00	0.00	65.40	13.22	2.07	45.89			
4/1/2010	17.30%	1912.8	0.27	1103.81	0.00	0.00	68.00	13.25	2.27	50.31	3638.6	2905.6	2595.4
4/2/2010					0.00	0.00	58.60	13.28	1.61	35.83			
4/3/2010					0.00	0.00	70.00	13.30	2.44	54.12			
4/4/2010					0.01	5.64	70.00	13.33	2.46	54.58			
4/5/2010	16.90%	1868.6	0.29	587.94	0.00	0.00	74.00	13.37	2.78	61.62	4027.9	3173.3	2661.6
4/6/2010					0.00	0.00	73.00	13.40	2.73	60.51			
4/7/2010					0.00	0.00	74.50	13.42	2.85	63.29			
4/8/2010	17.10%	1890.7	0.28	647.09	0.00	0.00	72.20	13.45	2.70	59.94	4783.0	3805.5	2808.2

Table 99: Mass Balance of Total Nitrogen in the Soil-Sod Combination 3 (A-2-4 Soil, Pensacola Bahia, and 10-10-10 Fertilization Practice and No Fertilizer)

	BEFORE Fertilizer Application				AFTER Fertilizer 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 Con-tent	Total Day Light Hours	Ammo-nia Volati-lization per day k_{volati}	Nitrifi-cation per day k_{nitri}	Deni-trifica-tion per day $k_{denitri}$	Grass uptake grams per (day*Test bed)	No. of days to next test	Ammo-nia vola-tilization loss up to next test	Conver sion to Nitrate up to next test	Denitri-fication loss up to next test
1/14/2010	30.0	0.0	30.0	0.0	0.0	30.0	56.0	6.72	0.307	11.35	0.0003	0.17	0.001	0.19	7.0	0.00	0.00	0.20
1/21/2010	23.3	0.0	23.3	0.0	0.0	23.3	71.1	6.56	0.252	11.47	0.0007	0.15	0.001	0.26	7.0	0.00	0.00	0.18
1/28/2010	15.2	0.0	15.2	0.0	0.0	15.2	54.8	6.53	0.201	11.60	0.0001	0.13	0.001	0.33	4.0	0.00	0.00	0.08
2/1/2010	9.5	0.0	9.5	106.1	106.1	9.5	61.3	6.47	0.155	11.67	0.0002	0.12	0.001	0.37	3.0	0.08	37.58	0.20
2/4/2010	71.9	68.4	3.5	106.1	174.5	3.5	63.5	6.66	0.261	11.73	0.0006	0.15	0.001	0.41	4.0	0.41	106.87	0.48
2/8/2010	102.6	67.2	35.4	106.1	173.2	35.4	53.8	6.72	0.261	11.83	0.0002	0.15	0.001	0.46	3.0	0.10	79.59	0.38
2/11/2010	120.7	93.5	27.2	106.1	199.6	27.2	46.1	6.29	0.273	11.90	0.0000	0.16	0.001	0.50	21.0	0.00	199.60	5.03
3/4/2010	138.5	0.0	138.5	106.1	106.1	138.5	50.4	6.43	0.252	12.45	0.0000	0.15	0.001	0.80	4.0	0.00	63.91	0.91
3/8/2010	187.1	42.1	144.9	106.1	148.2	144.9	61.7	6.17	0.261	12.57	0.0000	0.15	0.001	0.87	7.0	0.03	148.17	2.24
3/15/2010	223.3	0.0	223.3	106.1	106.1	223.3	63.8	6.26	0.269	12.75	0.0001	0.16	0.001	0.97	8.0	0.08	105.98	2.81
3/23/2010	283.0	0.0	283.0	106.1	106.1	283.0	63.8	6.45	0.252	12.98	0.0003	0.15	0.001	1.10	2.0	0.06	31.95	0.70
3/25/2010	343.3	74.0	269.3	0.0	74.0	269.3	71.2	6.30	0.324	13.05	0.0002	0.17	0.001	1.14	4.0	0.06	50.57	1.17
3/29/2010	302.6	23.4	279.2	0.0	23.4	279.2	68.9	6.65	0.307	13.17	0.0008	0.17	0.001	1.20	3.0	0.06	11.68	0.84
4/1/2010	260.6	11.7	248.9	0.0	11.7	248.9	68.0	6.22	0.269	13.25	0.0001	0.16	0.001	1.25	4.0	0.00	7.27	1.10
4/5/2010	225.2	4.4	220.8	0.0	4.4	220.8	74.0	6.67	0.286	13.37	0.0011	0.16	0.001	1.31	3.0	0.01	2.12	0.68
4/8/2010	210.4	2.3	208.1	0.0	2.3	208.1	72.2	6.03	0.277	13.45	0.0000	0.16	0.001	1.36	0.0	0.00	0.00	0.00

All applied N is ammoniacal. Nitrification rate per day (k_{nitri}) depends on volumetric air content

Ammonia Volatilization per day (k_{volati}) depends on temperature and pH.

Denitrification rate per day (k_{nitri}) varies inversely with volumetric air content

Grass uptake grams per (day*Test bed) depends on day light duration

Table 99: continued

Date of 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)	TN lost in test (RAIN only)	% loss in sim rain w.r.to TN after fert. Application
1/14/2010	1.3598	0	0.00	0.00	5.18	0.51	1.7%
1/21/2010	1.813	761.9	1.60	1.22	4.82	0.71	3.1%
1/28/2010	1.332	882.1	1.89	1.67	2.60	1.19	7.8%
2/1/2010	1.11	1124.6	1.71	1.93	40.34	20.61	17.8%
2/4/2010	1.628	1322.5	2.30	3.05	69.81	25.12	14.1%
2/8/2010	1.3875	1144.1	1.71	1.96	84.14	38.85	18.6%
2/11/2010	10.49	1337.1	2.66	3.56	69.23	29.58	13.0%
3/4/2010	3.219	1109.4	3.07	3.40	49.95	31.73	13.0%
3/8/2010	6.0865	742.8	11.03	8.19	53.26	34.11	11.6%
3/15/2010	7.77	2547.2	11.42	29.08	6.57	4.01	1.2%
3/23/2010	2.2015	1241.9	4.78	5.94	36.89	36.89	9.5%
3/25/2010	4.551	807.5	19.13	15.45	19.51	19.51	5.7%
3/29/2010	3.6075	1422.9	23.99	34.14	3.32	3.32	1.1%
4/1/2010	4.995	1103.8	18.81	20.76	8.59	3.08	1.2%
4/5/2010	3.9405	587.9	14.25	8.38	1.77	0.45	0.2%
4/8/2010	0	647.1	13.93	9.01	2.88	1.09	0.5%

Table 100: Mass Balance of Total Phosphate in the Soil-Sod Combination 3 (A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice and No Fertilizer)

	BEFORE Fertilizer Application						**AFTER Fertilizer Application**									
Date of Test	Total P - mass (g) in test bed	Extrac-table P (g) **X**	Non-extrac-table P (g) **Y**	P_{Buffer} (g)	Applied P (g)	Partition coefficient R	Extrac-table P (g) **X**	Non-extrac-table 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	X to Y	Y to X
1/14/2010	50.0	50.0	0.0	0.000	0.0	0.65	50.0	0.0	0.000	11.35	0.0079	0.0014	0.0004	0.0003	0.397	0.000
1/21/2010	20.7	20.3	0.4	0.022	0.0	0.98	20.3	0.4	0.022	11.47	0.0079	0.0014	0.0004	0.0003	0.161	0.001
1/28/2010	12.4	11.8	0.6	0.031	0.0	0.95	11.8	0.6	0.031	11.60	0.0079	0.0014	0.0004	0.0003	0.094	0.001
2/1/2010	7.3	6.7	0.7	0.037	142.1	0.91	136.1	13.3	0.037	11.67	0.0079	0.0014	0.0004	0.0003	1.081	0.019
2/4/2010	113.5	99.0	14.4	0.097	142.1	0.87	223.1	32.4	0.097	11.73	0.0079	0.0014	0.0004	0.0003	1.773	0.046
2/8/2010	197.8	163.4	34.1	0.197	142.1	0.83	281.0	58.7	0.197	11.83	0.0079	0.0014	0.0004	0.0003	2.233	0.084
2/11/2010	261.8	200.6	60.8	0.323	142.1	0.77	309.7	93.9	0.323	11.90	0.0079	0.0014	0.0004	0.0003	2.460	0.134
3/4/2010	351.4	254.7	96.2	0.461	142.1	0.73	357.9	135.2	0.461	12.45	0.0079	0.0014	0.0004	0.0003	2.843	0.193
3/8/2010	439.4	300.9	137.9	0.621	142.1	0.69	398.4	182.5	0.621	12.57	0.0079	0.0014	0.0004	0.0003	3.165	0.260
3/15/2010	537.9	351.7	185.4	0.799	142.1	0.65	444.8	234.5	0.799	12.75	0.0079	0.0014	0.0004	0.0003	3.534	0.334
3/23/2010	604.1	365.5	237.7	0.997	142.1	0.61	451.6	293.7	0.997	12.98	0.0079	0.0014	0.0004	0.0003	3.588	0.418
3/25/2010	668.0	370.0	296.9	1.199	0.0	0.55	370.0	296.9	1.199	13.05	0.0079	0.0014	0.0004	0.0003	2.940	0.423
3/29/2010	662.6	361.9	299.4	1.364	0.0	0.55	361.9	299.4	1.364	13.17	0.0079	0.0014	0.0004	0.0003	2.875	0.427
4/1/2010	654.0	350.6	301.8	1.526	0.0	0.54	350.6	301.8	1.526	13.25	0.0079	0.0014	0.0004	0.0003	2.786	0.430
4/5/2010	645.4	339.6	304.2	1.682	0.0	0.53	339.6	304.2	1.682	13.37	0.0079	0.0014	0.0004	0.0003	2.698	0.433
4/8/2010	640.4	332.1	306.4	1.834	0.0	0.52	332.1	306.4	1.834	13.45	0.0079	0.0014	0.0004	0.0003	2.638	0.437

Partition coefficient R is X/(X+Y)   Rate constants, K_1, K_2, K_3, and K_4 are from literature

Grass uptake grams per (day*Test bed) depends on day light duration

Table 100: continued

Date of Test	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
1/14/2010	0.022	0.000	0.04	7.0	0.272	0	0.000	0.00	28.99	3.12	6.24%
1/21/2010	0.009	0.000	0.05	7.0	0.363	761.9	1.713	1.31	6.69	1.65	8.11%
1/28/2010	0.005	0.000	0.07	4.0	0.266	882.1	0.159	0.14	4.64	2.46	20.78%
2/1/2010	0.061	0.000	0.07	3.0	0.222	1124.6	0.224	0.25	35.49	8.42	6.18%
2/4/2010	0.100	0.000	0.08	4.0	0.326	1322.5	0.224	0.30	57.20	24.14	10.82%
2/8/2010	0.125	0.000	0.09	3.0	0.278	1144.1	0.296	0.34	77.48	44.86	15.95%
2/11/2010	0.138	0.000	0.10	21.0	2.098	1337.1	0.224	0.30	50.09	19.97	6.44%
3/4/2010	0.160	0.000	0.16	4.0	0.644	1109.4	0.119	0.13	53.35	30.49	8.51%
3/8/2010	0.178	0.000	0.17	7.0	1.217	742.8	0.154	0.11	42.28	26.04	6.53%
3/15/2010	0.199	0.000	0.19	8.0	1.554	2547.2	0.108	0.27	74.08	39.07	8.77%
3/23/2010	0.202	0.000	0.22	2.0	0.440	1241.9	0.154	0.19	77.59	77.59	17.14%
3/25/2010	0.165	0.000	0.23	4.0	0.910	807.5	0.527	0.43	4.07	4.07	1.10%
3/29/2010	0.162	0.000	0.24	3.0	0.722	1422.9	0.375	0.53	7.39	7.39	2.04%
4/1/2010	0.157	0.000	0.25	4.0	0.999	1103.8	0.221	0.24	7.32	1.95	0.56%
4/5/2010	0.152	0.000	0.26	3.0	0.788	587.9	0.202	0.12	4.15	1.87	0.55%
4/8/2010	0.148	0.000	0.27	0.0	0.000	647.1	0.384	0.25	13.69	4.03	1.21%

APPENDIX D
WATER BALANCE, TN MASS BALANCE, A-2-4 SOIL WITH PENSACOLA BAHIA SOD, 16-0-8 FERTILIZATION PRACTICE

Table 101: Analysis of Water Balance in the Soil-Sod Combination 4 (A-2-4 Soil with Pensacola Bahia Sod and 16-0-8 Fertilization Practice @ 0.5 lb of N per 1000 ft^2)

Avg dry density of soil (pcf)	101.7	Sr. gr. of soil grains	2.65
Mass of dry soil in test bed (in kg)	11057	Porosity	0.38
Volume of water at full saturation (L)	2616.9	Full Saturation % (by mass)	23.67%

	Starting Moisture Content [% of mass]	Initial Bed Water Volume [L]	Volu-metric Air Content	Seepage Since Previous Test (L)	Rainfall, (in)	Natural Rainfall Volume (L)	Mean Temp. °F	Total Day Light Hours	Evapo-transpiration (mm per day)	Bed Evapo-transpi-ration (L)	Rainfall Applied [L]	Run-off and Base flow [L]	See-page + Final Stor-age [L]
5/13/2010	14.91%	1649.0	0.370	0.0	0	0.0	75	14.38	3.64	80.9	3951.2	3037.6	2481.7
5/14/2010					0	0.0	76	14.40	3.76	83.5			
5/15/2010					0	0.0	77	14.42	3.88	86.2			
5/16/2010					0.32	180.5	78	14.45	4.02	89.2			
5/17/2010	14.91%	1649.0	0.370	754.2	0.29	163.6	77	14.47	3.93	87.2	5571.1	4437.9	2858.6
5/18/2010					0	0.0	80	14.48	4.27	94.7			
5/19/2010					0	0.0	80	14.50	4.28	95.1			
5/20/2010	15.62%	1727.6	0.340	941.2	0	0.0	82	14.52	4.52	100.3	3786.0	3054.9	2358.5
5/21/2010					0	0.0	82	14.55	4.55	101.0			
5/22/2010					0	0.0	81	14.57	4.46	98.9			
5/23/2010					0	0.0	80	14.58	4.36	96.8			
5/24/2010	15.36%	1697.9	0.351	363.9	0	0.0	81	14.60	4.49	99.6	4314.4	3591.6	2320.9
5/25/2010					0	0.0	78	14.62	4.16	92.5			
5/26/2010					0	0.0	79	14.63	4.29	95.3			
5/27/2010	16.73%	1849.4	0.293	283.7	0	0.0	81	14.65	4.54	100.7	3717.6	3153.7	2312.6
5/28/2010					1.24	699.3	79	14.67	4.32	96.0			
5/29/2010					0.91	513.2	78	14.68	4.22	93.8			
5/30/2010					0	0.0	79	14.70	4.35	96.7			
5/31/2010					0.28	157.9	82	14.70	4.70	104.4			
6/1/2010	16.15%	1785.7	0.318	1506.7	0.67	377.9	82	14.72	4.72	104.7	3908.7	3073.0	2894.5
6/2/2010					0.32	180.5	82	14.73	4.73	105.1			
6/3/2010					0.11	62.0	82	14.75	4.75	105.5			
6/4/2010	16.66%	1841.8	0.296	1084.6	0.04	22.6	80	14.75	4.52	100.3	4325.2	3590.4	2498.9

Table 102: Mass Balance of Total Nitrogen in the Soil-Sod Combination 4 (A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 Fertilization Practice @ 0.5 lb of N per 1000 ft^2)

	BEFORE Fertilizer Application				AFTER Fertilizer 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 kvolati	Nitri-fication per day knitri	Denitri-fication per day kdenitri	Grass uptake grams per (day*Test bed)	No. of days to next test
5/13/2010	30.0	0.0	30.0	53.1	53.1	30.0	75.0	6.47	0.370	14.38	0.0006	0.18	0.001	1.88	4.0
5/17/2010	47.5	14.2	33.3	53.1	67.3	33.3	77.0	6.32	0.370	14.47	0.0003	0.18	0.001	1.92	3.0
5/20/2010	41.5	30.4	11.1	53.1	83.5	11.1	82.0	7.05	0.340	14.52	0.0035	0.17	0.001	1.95	4.0
5/24/2010	54.4	23.9	30.5	53.1	77.0	30.5	81.0	6.83	0.351	14.60	0.0021	0.18	0.001	2.00	3.0
5/27/2010	69.7	35.5	34.2	53.1	88.6	34.2	81.0	6.47	0.293	14.65	0.0007	0.16	0.001	2.03	5.0
6/1/2010	77.2	16.3	60.9	53.1	69.4	60.9	82.0	6.30	0.318	14.72	0.0003	0.17	0.001	2.06	3.0
6/4/2010	109.8	34.1	75.6	53.1	87.2	75.6	80.0	6.05	0.296	14.75	0.0000	0.16	0.001	2.08	0.0

Date of Test	Ammo-nia 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)	TN lost in test (RAIN only)	% loss in sim rain w.r.to TN after fert. Appli-cation	
5/13/2010	0.12	38.75	0.2184	7.51	0.00	0.00	0.00	27.7	17.6	21.2%	All applied N is ammoniacal.
5/17/2010	0.06	36.85	0.2	5.77	754.18	0.91	0.69	52.5	46.1	45.8%	
5/20/2010	1.17	58.43	0.2	7.81	941.18	0.83	0.78	30.2	17.4	18.4%	
5/24/2010	0.49	41.08	0.2	5.99	363.87	0.68	0.25	30.9	21.7	20.2%	
5/27/2010	0.31	71.93	0.5	10.13	283.71	1.18	0.34	34.2	18.9	15.4%	
6/1/2010	0.06	35.21	0.3	6.19	1506.67	1.42	2.15	11.9	1.5	1.2%	
6/4/2010	0	0	0.0	0.00	1084.57	0.02	0.03	11.2	2.3	1.4%	

APPENDIX E

PHASE #2 STUDY WATER BALANCE, TN MASS BALANCE, TP MASS BALANCE, A-3 SOIL WITH ARGENTINE BAHIA SOD, NO FERTILIZER AND 10-10-10 FERTILIZATION PRACTICE

Table 103: Analysis of Water Balance in the Soil-Sod Combination 1 (A-3 Soil, Argentine Bahia Sod, and No Fertilizer and 10-10-10 Fertilization Practice)

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]
9/7/2013	8.56%	1263.91	0.72099	0	0.02	11.2796	81	12.5667	2.51771	28.0867	449.746	80.7669	1616.08
9/8/2013					0	0	83	12.5333	2.58125	28.7956			
9/9/2013					0	0	83	12.5167	2.56406	28.6039			
9/10/2013					0	0	83	12.4667	2.5125	28.0286			
9/11/2013	8.74%	1289.45	0.71535	224.389	0.01	5.63982	84	12.45	2.54063	28.3424	455.881	101.902	1620.73
9/12/2013					0.01	5.63982	82	12.4167	2.41667	26.9596			
9/13/2013					0.03	16.9194	81	12.4	2.35625	26.2856			
9/14/2013	9.13%	1347.47	0.70254	219.87	0	0	84	12.3667	2.45208	27.3547	298.729	72.4638	1546.38
9/15/2013					0	0	84	12.3333	2.41667	26.9596			
9/16/2013					0	0	82	12.3	2.3	25.6581			
9/17/2013					0.05	28.1991	82	12.2833	2.28333	25.4721			
9/18/2013	9.02%	1331.24	0.70613	137.9	0.02	11.2796	80	12.25	2.17188	24.2287	1365.05	61.1413	2622.2
9/19/2013					0	0	81	12.2333	2.19479	24.4844			
9/20/2013					0	0	80	12.1833	2.10938	23.5315			
9/21/2013					0	0	80	12.1667	2.09375	23.3572			
9/22/2013					0.3	169.194	82	12.1333	2.13333	23.7988			
9/23/2013					1.44	812.134	80	12.1167	2.04688	22.8343			
9/24/2013					0.3	169.194	80	12.0833	2.01563	22.4857			
9/25/2013					0.01	5.63982	79	12.0667	1.96667	21.9395			
9/26/2013					0	0	82	12.0167	2.01667	22.4973			
9/27/2013					0.08	45.1185	77	12	1.84375	20.5683			
9/28/2013					0	0	79	11.9833	1.89115	21.097			
9/29/2013	8.95%	1320.99	0.70839	2262.95	0	0	80	11.9667	1.90625	21.2655	3037.79	125.302	4212.21
9/30/2013					0	0	80	11.9333	1.875	20.9169			
10/1/2013					0	0	88	11.9167	2.08854	23.2991			
10/2/2013	10.13%	1495.66	0.66983	2651.07	0	0	88	11.8667	2.02917	22.6367	3642.33	104.921	5010.43
10/3/2013					0	0	90	11.85	2.0625	23.0086			
10/4/2013					0	0	91	11.8167	2.04635	22.8285			
10/5/2013	9.44%	1393.67	0.69234	3548.28	0	0	90	11.8	2	22.3114	3500.12	80.7669	4790.72
10/6/2013					1.31	738.816	90	11.7667	1.95833	21.8465			
10/7/2013					0.36	203.033	86	11.75	1.84375	20.5683			
10/8/2013					0.03	16.9194	89	11.7167	1.87344	20.8995			
10/9/2013	8.51%	1255.98	0.72274	4407.88	0	0	83	11.6833	1.70469	19.0169	3652.71	92.0894	4797.59
10/10/2013					0	0	86	11.6333	1.7125	19.1041			

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]
10/11/2013					0	0	87	11.6	1.69375	18.8949			
10/12/2013					0	0	86	11.5833	1.65625	18.4766			
10/13/2013					0	0	87	11.55	1.63594	18.25			
10/14/2013					0	0	88	11.5333	1.63333	18.2209			
10/15/2013					0	0	82	11.5	1.5	16.7335			
10/16/2013	9.68%	1428.99	0.68455	3239.9	0	0	87	11.4833	1.55885	17.3901	427.093	82.2766	1756.41
10/17/2013					0	0	88	11.45	1.53438	17.117			
10/18/2013					0	0	90	11.4167	1.52083	16.9659			
10/19/2013					0	0	90	11.4	1.5	16.7335			
10/20/2013					0	0	88	11.3667	1.43542	16.013			
10/21/2013					0.96	541.422	91	11.3333	1.42708	15.9201			
10/22/2013					0	0	90	11.0167	1.02083	11.3881			
10/23/2013	8.31%	1226.72	0.7292	959.591	0	0	83	11.0167	1.01719	11.3474	3605.52	81.5217	4739.36
10/24/2013					0	0	73	11.0167	1.01198	11.2893			
10/25/2013					0	0	81	11.0167	1.01615	11.3358			
10/26/2013					0	0	79	11.0167	1.0151	11.3242			
10/27/2013	9.27%	1367.87	0.69804	3326.2	0	0	80	11.0167	1.01563	11.33	475.656	1262.4	569.796

Table 104: Mass Balance of Total Nitrogen in the Soil-Sod Combination 1 (A-3 Soil, Argentine Bahia, No Fertilizer and 10-10-10 Fertilization Practice)

	BEFORE Fertilizer Application				AFTER Fertilizer 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 $k_{denitri}$	Grass uptake grams per (day*Test bed)	No. of days to next test
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	0.43	4.0
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	0.40	3.0
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	0.38	4.0
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	0.35	11.0
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	0.27	3.0
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	0.24	3.0
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	0.22	4.0
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	0.19	7.0
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	0.13	7.0
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	0.00	4.0
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	0.00	0.0

Date of 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
9/7/2013	13.52	603.02	3.83	1.739	0	20.85	0	1.64	1.64	0.0266
9/11/2013	9.48	467.63	2.92	1.207125	224.4	19.59	4.395996	2.32	2.32	0.037756
9/14/2013	13.22	587.94	6.32	1.517	219.9	20.1	4.41999	1.33	1.33	0.021716
9/18/2013	36.13	573.63	20.08	3.815625	137.9	16.08	2.217432	7.32	0.843	0.013825
9/29/2013	6.86	477.09	3.02	0.80475	2262.9	9.29	21.02234	12.93	1.08	0.017836
10/2/2013	11.92	462.83	3.84	0.7215	2651.1	7.34	19.45907	9.69	0.789	0.013068
10/5/2013	26.3	600.11	4.55	0.888	3548.3	5.65	20.0479	11.86	0.442	0.007343
10/9/2013	29.83	592.94	6.39	1.327375	4407.9	5.09	22.43621	8.96	0.129	0.002156
10/16/2013	25.44	593.16	8.22	0.938875	3239.9	3.23	10.46488	0.244	0.244	0.004107
10/23/2013	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	3326.2	3.12	10.37774	2.18	2.18	0.036968

Table 105: Mass Balance of Total Phosphate in the Soil-Sod Combination 1 (A-3 Soil, Argentine Bahia, No Fertilizer and 10-10-10 Fertilization Practice)

Date of Test	Total P - mass (g) in test bed	Extrac-table P (g) **X**	Non-extrac-table P (g) **Y**	P_{Buffer} (g)	Applied P (g)	Partition coefficient R	Extrac-table 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	X to Y
9/7/2013	2183.56	2183.56	0	0	0	1	2183.56	0	0	12.5667	0.00795	0.00142	0.00045	0.0003	17.3488
9/11/2013	2183.2	2164.88	17.3488	0.97512	0	0.99205	2164.88	17.3488	0.97512	12.45	0.00795	0.00142	0.00045	0.0003	17.2004
9/14/2013	2182.93	2146.47	34.5245	1.9419	0	0.98417	2146.47	34.5245	1.9419	12.3667	0.00795	0.00142	0.00045	0.0003	17.0541
9/18/2013	2182.6	2128.17	51.5294	2.90046	0	0.97636	2128.17	51.5294	2.90046	12.25	0.00795	0.00142	0.00045	0.0003	16.9088
9/29/2013	2181.66	2109.44	68.3648	3.85085	27.2	0.96861	2135.79	69.2186	3.85085	11.9667	0.00795	0.00142	0.00045	0.0003	16.9693
10/2/2013	2207.67	2116.77	86.0893	4.80464	27.2	0.96092	2142.91	87.1523	4.80464	11.8667	0.00795	0.00142	0.00045	0.0003	17.0259
10/5/2013	2233.69	2123.87	104.054	5.76161	27.2	0.9533	2149.8	105.324	5.76161	11.8	0.00795	0.00142	0.00045	0.0003	17.0806
10/9/2013	2259.97	2131	122.255	6.72166	27.2	0.94574	2156.72	123.731	6.72166	11.6833	0.00795	0.00142	0.00045	0.0003	17.1356
10/16/2013	2285.6	2137.23	140.69	7.6848	27.2	0.93824	2162.75	142.37	7.6848	11.4833	0.00795	0.00142	0.00045	0.0003	17.1835
10/23/2013	2312.38	2144.38	159.351	8.65063	0	0.93083	2144.38	159.351	8.65063	11.0167	0.00795	0.00142	0.00045	0.0003	17.0375
10/27/2013	2311.99	2126.22	176.161	9.60825	27.2	0.92349	2151.34	178.242	9.60825	11.0167	0.00795	0.00142	0.00045	0.0003	17.0928

Date of Test	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	0	0.97512	0	0.08695	4	0.3478	0	0.0925	0	0.008	0.008	0.00037
9/11/2013	0.02472	0.96678	0	0.08048	3	0.24143	224.4	0.0845	0.01896	0.008	0.008	0.00037
9/14/2013	0.04919	0.95856	0	0.07585	4	0.3034	219.9	0.0805	0.0177	0.006	0.006	0.00028
9/18/2013	0.07341	0.95039	0	0.06938	11	0.76313	137.9	0.078	0.01076	0.174	0.005	0.00023
9/29/2013	0.09861	0.95379	0	0.05365	3	0.16095	2262.9	0.242	0.54762	0.482	0.035	0.00164
10/2/2013	0.12416	0.95697	0	0.0481	3	0.1443	2651.1	0.0895	0.23727	0.794	0.009	0.00042
10/5/2013	0.15005	0.96005	0	0.0444	4	0.1776	3548.3	0.0625	0.22177	0.519	0.006	0.00028
10/9/2013	0.17627	0.96314	0	0.03793	7	0.26548	4407.9	0.1295	0.57082	0.735	0.005	0.00023
10/16/2013	0.20283	0.96583	0	0.02683	7	0.18778	3239.9	0.0705	0.22841	0.005	0.005	0.00023
10/23/2013	0.22702	0.95763	0	0.00093	4	0.0037	959.6	0.0585	0.05614	0.329	0.329	0.01528
10/27/2013	0.25393	0.96074	0	0.00093	0	0	3326.2	1.07	3.55903	0.866	0.866	0.04007

APPENDIX F
PHASE #2 STUDY WATER BALANCE, TN MASS BALANCE, A-3 SOIL WITH ARGENTINE BAHIA SOD, NO FERTILIZER, 16-0-8 FERTILIZATION PRACTICE (0.5 LB), 16-0-8 FERTILIZATION PRACTICE SEVEN-DAY TEST

Table 106: Analysis of Water Balance in the Soil-Sod Combination 2 (A-3 Soil with Argentine Bahia Sod and No Fertilizer, 16-0-8 (SR) @ 0.5 lb of N per 1000 ft^2, and 16-0-8 Fertilization Practices, Seven-Day Test)

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-transpiration (mm per day)	Bed Evapo-transpiration (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			
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			

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-transpiration (mm per day)	Bed Evapo-transpiration (L)	Rainfall Applied [L]	Collected Runoff and Base flow [L]	Seepage + Final Storage [L]
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 107: Mass Balance of Total Nitrogen in the Soil-Sod Combination 2 (A-3 Soil, Argentine Bahia Sod, and No-Fertilizer, 16-0-8 (SR) @ 0.5 lb, and 16-0-8 Fertilization Practices Seven-Day)

	BEFORE Fertilizer Application				AFTER Fertilizer 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	0.00	0.00	0.00	0	916.8742	3.46	3.172385	0.185	0.185	0.002306

APPENDIX G
PHASE #2 WATER BALANCE, TN MASS BALANCE, TP MASS BALANCE, A-2-4 SOIL WITH PENSACOLA BAHIA SOD, NO FERTILIZER, 10-10-10 FERTILIZATION PRACTICE, 10-10-10 FERTILIZATION PRACTICE SEVEN-DAY TEST

Table 108: Analysis of Water Balance in the Soil-Sod Combination 3 (A-2-4 Soil with Pensacola Bahia Sod and 10-10-10 Fertilization Practice and No Fertilizer)

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]
2/20/2013	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			
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			

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]
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			
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			
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			

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]
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 109: Mass Balance of Total Nitrogen in the Soil-Sod Combination 3 (A-2-4 Soil, Pensacola Bahia, and 10-10-10 Fertilization Practice and No Fertilizer)

	BEFORE Fertilizer Application				AFTER Fertilizer 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	Volumetric Air Content	Total Day Light Hours	Ammonia Volati-lization per day k_{volati}	Nitrification 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 110: Mass Balance of Total Phosphate in the Soil-Sod Combination 3 (A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 Fertilization Practice and No Fertilizer)

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 coefficient 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	X to Y
2/20/2013	333.5	333.5	0	0	0	0.65	333.5	0	0	11.33	0.00795	0.00142	0.00045	0.0003	2.64973
2/23/2013	333.438	330.639	2.64973	0.14893	0	0.99205	330.639	2.64973	0.14893	11.42	0.00795	0.00142	0.00045	0.0003	2.627
2/27/2013	333.323	327.753	5.27295	0.29659	0	0.98417	327.753	5.27295	0.29659	11.53	0.00795	0.00142	0.00045	0.0003	2.60407
3/3/2013	333.151	324.838	7.8695	0.44295	0	0.97635	324.838	7.8695	0.44295	11.63	0.00795	0.00142	0.00045	0.0003	2.58091
3/6/2013	333.03	322.003	10.4392	0.58802	0	0.9686	322.003	10.4392	0.58802	11.72	0.00795	0.00142	0.00045	0.0003	2.55838
3/13/2013	332.715	319.001	12.9827	0.73182	0	0.96089	319.001	12.9827	0.73182	11.92	0.00795	0.00142	0.00045	0.0003	2.53453
3/16/2013	332.554	316.181	15.4987	0.87428	27.22	0.95327	342.129	16.7707	0.87428	12	0.00795	0.00142	0.00045	0.0003	2.71829
3/27/2013	356.988	336.496	19.4651	1.02706	27.22	0.94532	362.227	20.9535	1.02706	12.32	0.00795	0.00142	0.00045	0.0003	2.87797
4/3/2013	380.159	355.169	23.8017	1.18882	0	0.93719	355.169	23.8017	1.18882	12.52	0.00795	0.00142	0.00045	0.0003	2.82189
4/6/2013	378.651	350.714	26.5896	1.34743	27.2	0.92953	375.997	28.5065	1.34743	12.6	0.00795	0.00142	0.00045	0.0003	2.98738
4/10/2013	397.867	364.898	31.4533	1.51534	27.2	0.92064	389.94	33.6118	1.51534	12.7	0.00795	0.00142	0.00045	0.0003	3.09815
5/11/2013	421.008	382.657	36.662	1.68948	27.2	0.91257	407.478	39.0402	1.68948	13.467	0.00795	0.00142	0.00045	0.0003	3.2375

f Test	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	0	0.14893	0	0.01832	3	0.05495	0	0.0455	0	0.00728	0.00728	2.2E-05
2/23/2013	0.00377	0.14766	0	0.02331	4	0.09324	279.5	0.048	0.01342	0.00833	0.00833	0.00252
2/27/2013	0.00751	0.14637	0	0.02942	4	0.11766	662.4	0.0265	0.01755	0.037	0.037	0.01128
3/3/2013	0.01121	0.14506	0	0.03497	3	0.1049	439.3	0.03	0.01318	0.0025	0.0025	0.00077
3/6/2013	0.01487	0.1438	0	0.03996	7	0.27972	151.4	0.0265	0.00401	0.031	0.031	0.00961
3/13/2013	0.0185	0.14246	0	0.05106	3	0.15318	353	0.02	0.00706	0.0006	0.0006	0.00019
3/16/2013	0.02389	0.15279	0	0.0555	11	0.6105	318	0.6165	0.19605	1.98	0.78	0.2274
3/27/2013	0.02985	0.16176	0	0.07326	7	0.51282	3543	0.631	2.23563	1.3	1.3	0.35788
4/3/2013	0.03391	0.15861	0	0.08436	3	0.25308	581.4	0.026	0.01512	1.24	0.0007	0.0002
4/6/2013	0.04061	0.16791	0	0.0888	4	0.3552	2543.6	1.47	3.73909	3.89	3.04	0.80563
4/10/2013	0.04789	0.17414	0	0.09435	31	2.92485	3377.3	0.191	0.64506	0.489	0.382	0.09758
5/11/2013	0.05562	0.18197	0	0.13692	0	0	8681.7	0.039	0.33859	0.0009	0.0009	0.00022

APPENDIX H
PHASE #2 STUDY WATER BALANCE, TN MASS BALANCE, A-2-4 SOIL WITH PENSACOLA BAHIA SOD, 16-0-8 FERTILIZATION PRACTICE

Table 111: Analysis of Water Balance in the Soil-Sod Combination 4 (A-2-4 Soil with Pensacola Bahia Sod and 16-0-8 Fertilization Practice @ 0.5 lb of N per 1000 ft^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			
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 112: Mass Balance of Total Nitrogen in the Soil-Sod Combination 4 (A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 Fertilization Practice @ 0.5 lb of N per 1000 ft^2)

	BEFORE Fertilizer Application				AFTER Fertilizer 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	0.00	0.00	0.00	0	1077.8	18.14	19.55	4.15	4.15	0.32

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