Final Report

# Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions

Work Performed for the Florida Department of Transportation

Submitted by


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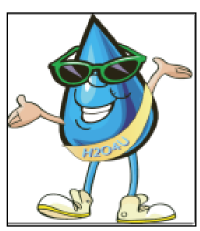


FDOT Project Number: **BDK78**; Work Order #**977-04**
UCF Office of Research Account Number: **16-60-7025**


**February 2011**

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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.

**Technical Report Documentation Page**

| | | |
|---|---|---|
| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>Evaluation of Pollution Levels Due to the Use of Consumer Fertilizers under Florida Conditions | | 5. Report Date<br>August 2010<br>6. Performing Organization Code<br>Stormwater Management Academy |
| 7. Author(s)<br>Manoj Chopra, Marty Wanielista, Sai Kakuturu, Mike Hardin, and Erik Stuart | | 8. Performing Organization Report No. |
| 9. Performing Organization Name and Address<br>Stormwater Management Academy<br>University of Central Florida<br>Orlando, FL 32816 | | 10. Work Unit No. (TRAIS)<br>11. Contract or Grant No. BDK78 #977-04 |
| 12. Sponsoring Agency Name and Address<br>Florida Department of Transportation<br>605 Suwannee Street, MS 30<br>Tallahassee, FL 32399 | | 13. Type of Report and Period Covered<br>Final Report; May 2008 – Feb 2011<br>14. Sponsoring Agency Code |
| 15. Supplementary Notes | | |

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 being 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.

46 tests were 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 for determining the masses 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.

It is concluded 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 nine tests conducted without fertilization confirms 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 was lower than the 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-physico-chemical interactions of the soil-nutrient-turf system with the weather.

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|---|---|---|---|
| 17. Key Word<br>Stormwater, Consumer Fertilizer, Nutrient Loading, Nitrogen, Phosphorus, Rainfall Intensity, Slope, Argentine Bahia, Pensacola Bahia, Best Management Practices (BMPs) | 18. Distribution Statement<br>No Restrictions | | |
| 19. Security Classification (of this report)<br>Unclassified | 20. Security Classification (of this page)<br>Unclassified | 21. No. of Pages<br>200 | 22. Price |

**Form DOT F 1700.7** (8-72) Reproduction of completed page authorized

# ACKNOWLEDGEMENTS

The authors would like to thank the Florida Department of Transportation for their technical assistance and financial support. Without their support, a research project such as this would not be possible. In particular, Rick Renna of FDOT provided highly valuable guidance, support and leadership in the development and conduct of this research study. Eric Livingston of Florida DEP, Joshua Boan of FDOT, and Dr. Harper Harvey of Environmental Research & Design, Inc. provided valuable feedback and timely suggestions. David Saddler, Tim Allen, and David Horhota of FDOT helped us in procurement of soils. The authors also wish to thank Dr. Laurie Trenholm of University of Florida who was very helpful in sharing her expertise on fertilizer leaching.

This work was completed under the guidance of the Stormwater Management Academy located at the University of Central Florida. The staff and students of the Academy provided continued valuable assistance in the conducting of field experiments, collection and chemical analysis of water samples, and compilations and scrutiny of results. Especially, our sincere thanks go to the UCF research students Nicole Runnebaum, Torii Leon, Clayton Bender, Diego Marin, Ken Horner, Jamie Capra, Alicia McDougal, Rafiqul Chowdhury, Matt Goolsby, Rylee Hernandez, and Asaph Mauck for their untiring and timely efforts in completing the material procurement, field-scale experiments, sample collection, chemical analysis, and the data scrutiny.

# 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 water quality restoration targets, also called Total Maximum Daily Loads (TMDLs). This research project was commenced in July 2008 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, videlicet (viz.), rainfall intensity, highway slope, soil type, and sod type, which are unique to Florida due to the 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 ft2, and other corresponding nutrients as 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.

A total of 46 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 $ft^2$. They consisted of three tests on a 25% slope (4 horizontal to 1 vertical), at 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 rainfalls 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, for evaluating 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 a post-rainfall 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 post-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 physico-chemical soil-nutrient-weather interactions, this nutrient accumulation in these four soil-turf combinations were analyzed. The measured losses of nutrients were scrutinized, with and without this modeling basis, and were compared for meeting 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, it was concluded 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 growing even by 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. It was concluded 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, it was determined that it is likely due to the nutrient accumulation in the test bed, the variations in the nutrient uptake by grass, and the physico-chemical soil-nutrient-weather interactions making the nutrients either available or unavailable for leaching. The nutrient mass balance analyses presented in Ch. 4 are limited by the availability of theoretical models and parametric values.

Very low masses of nutrients (4.14 g of TN and 7.29 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.

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# 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 is known cause 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 water quality restoration targets, 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 to successfully implement 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, not only for 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 somewhat unique and considerably different from that in other US states or foreign countries. This is primarily because of Florida's sub-tropical location, receiving several high-intensity rains and storms in summers, being overlaid by erosion-prone sandy soils on cavernous limestone formations, and its ecosystem being 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.

## 1.2 Research Objectives and Experimental Setup

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 1.1), 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 one 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.

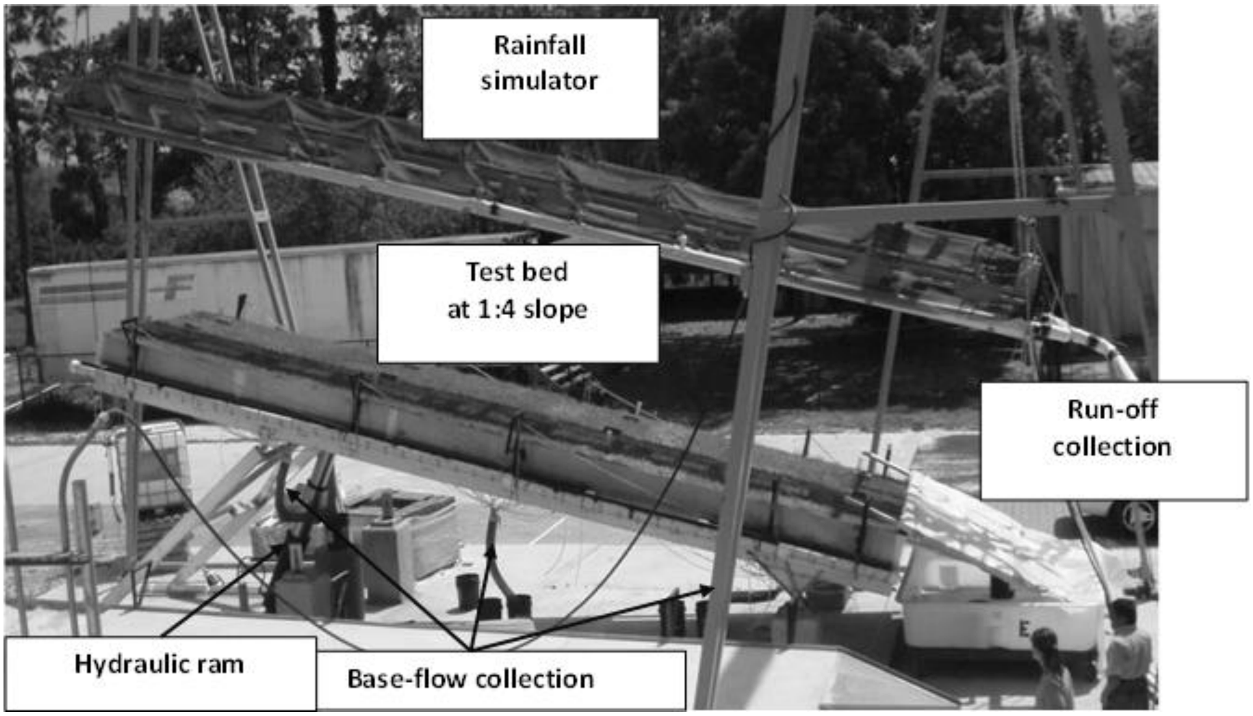


**Figure 1.1: Experiment on a Test Bed Slope of 4:1 (H:V) - Sandy Soil with Argentine Bahia**

The water samples were collected from the run-off and base flow for every test at regular time intervals, and physico-chemical 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 1.2), 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 1.2: 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.  As highway slopes are generally well connected to streams that drain into surface water bodies, 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.

These contentions however have been disputed by several researchers (Hochmuth et al., 2009) of the Institute of Food and Agricultural Sciences at the University of Florida (IFAS-UF), based on the fact that 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 also 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 that are 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. A brief review of existing literature is provided in Chapter 2 for setting the necessary background for the remaining chapters.  The experimental data, discussion of results, and conclusions are presented in Chapters 3 through 8.

# 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. In the next few paragraphs, the important noteworthy points of the reviewed literature are presented.

## 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 state-wide groundwater pollution in Texas due to the use of nitrogen fertilizers. They analyzed the borehole water quality data 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 a 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 strengths and weaknesses of that model and its utility as a short-cut for predicting short-term optimal P requirements of some crops were discussed in that paper.

The same model, after some improvements and making it useful for long-term calculations of phosphorus balance, was presented by Karpinets et al. (2004). 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. Though that 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), 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 de-sorbable 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

The earliest known mechanistic models of nutrient uptake by different plants were presented by Nye and Tinker (1977), and Barber (1984). 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, where the nutrient uptake under the given conditions was examined. 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 home owners in Florida, the MS landscape is a suggested alternative consisting of 12 ornamental species and no turf-grass.

The actual comparison of results from these two alternative residential landscapes was given by Erickson et al. (2001). 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, which are considered better for moisture retention and crop production. Only a few studies focused on clean sands, or sands with minimal silt, which are 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, the mechanistic models found in the literature were appropriately modified and adopted for interpretation of results in the experiments presented in this study.

The details and results of all experimental investigations are presented in Chapter 3. A complete discussion, comparison, and interpretation of results are presented in Chapters 4 through 7.

# 3 EXPERIMENTAL FINDINGS OF THIS STUDY

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 have been 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). The Argentine Bahia sod tiles for this study were supplied by Green Images Nursery in Christmas, FL 32709, and the Pensacola Bahia sod tiles for this study were supplied by Paff Landscape, Inc. in Brooksville FL, 34604. 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. This is not directly accounted for in the current experimental setup but the choice of the range of rainfall intensities is sufficient to account for some of this 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 elemental nitrogen 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 better 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 elemental nitrogen 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. A summary of the experimental parameters is given in Table 3.1. The test series outlined in Table 3.1 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 3.1: Variables in Experiments on Nutrient Losses from Fertilized Highway Slopes**

<table>
<tr><th>Test Series</th><th>Soil-sod Combination</th><th>Slopes (Vertical: Horizontal)</th><th>Rainfall Intensities (inch per hour)</th><th>Fertilizer N-P-K, Application Rate</th></tr>
<tr><td rowspan="10">1</td><td rowspan="10">AASHTO A-3 Soil (clean sand) covered by Argentine Bahia</td><td>1:4</td><td>0.5, 1, and 3</td><td>None</td></tr>
<tr><td>1:4</td><td>0.5, 1, and 3</td><td rowspan="3">10-10-10<br>1 lb of N<br>per 1000 $ft^2$</td></tr>
<tr><td>1:3</td><td>0.5, and 1</td></tr>
<tr><td>1:2</td><td>0.5, and 1</td></tr>
<tr><td>1:4</td><td>0.5, 1, and 3</td><td rowspan="3">16-0-8 (SR)<br>1 lb of N<br>per 1000 $ft^2$</td></tr>
<tr><td>1:3</td><td>0.5, and 1</td></tr>
<tr><td>1:2</td><td>0.5, and 1</td></tr>
<tr><td>1:4</td><td>0.5, 1, and 3</td><td rowspan="3">16-0-8 (SR)<br>0.5 lb of N<br>per 1000 $ft^2$</td></tr>
<tr><td>1:3</td><td>0.5, and 1</td></tr>
<tr><td>1:2</td><td>0.5, and 1</td></tr>
<tr><td rowspan="7">2</td><td rowspan="7">AASHTO A-2-4 Soil (silty sand) covered by Pensacola Bahia</td><td>1:4</td><td>0.5, 1, and 3</td><td>None</td></tr>
<tr><td>1:4</td><td>0.5, 1, and 3</td><td rowspan="3">10-10-10<br>1 lb of N<br>per 1000 $ft^2$</td></tr>
<tr><td>1:3</td><td>0.5, and 1</td></tr>
<tr><td>1:2</td><td>0.5, and 1</td></tr>
<tr><td>1:4</td><td>0.5, 1, and 3</td><td rowspan="3">16-0-8 (SR)<br>0.5 lb of N<br>per 1000 $ft^2$</td></tr>
<tr><td>1:3</td><td>0.5, and 1</td></tr>
<tr><td>1:2</td><td>0.5, and 1</td></tr>
</table>

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 single-day tests, conducted with similar parameters. For serving as a common basis, the fertilizer was applied on the first day only, for both single-day and seven-day tests. The single-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-inches/hour 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 3.2 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 4-7.

**Table 3.2: 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 |
| 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 Tables 3.1 and 3.2, 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% (4:1) and at 0.5, 1.0, and 3.0 inch/hour 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.

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 are presented in Table 3.3. 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 non-linear 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.

The average chemical parameters measured in these three tests are presented in Table 3.4. 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 from7.2 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. While no fertilizer was added to the test beds for this series of tests, the masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flow were measured and are presented in Table 3.5. 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 3.3: Volumes of Rainfall Applied, Runoff and Base Flow**

| | No Fertilizer 4-1 Slope | | |
|---|---|---|---|
| Intended intensity inch/hour | 0.5 in/hr Intensity | 1 in/hr Intensity | 3 in/hr Intensity |
| Avg. actual intensity inch/hour | 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 3.4: Total Solids, pH, Alkalinity, & Turbidity in Tests on A-3 Soil and Argentine Bahia Sod with No Fertilizer**

| Slope and Soil Type | 4-1 Slope A-3 Soil | | |
|---|---|---|---|
| Intended intensity inch/hour | 0.5 in/hr Intensity | 1 in/hr Intensity | 3 in/hr Intensity |
| 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 3.5: Distribution of Nutrient Loss between Runoff & Base Flow: A-3 Soil/Argentine Bahia Sod/No Fertilizer**

| Slope | No Fertilizer 4-1 Slope | | |
|---|---|---|---|
| Rainfall intensity inch/hour | 0.5 in/hr Intensity | 1 in/hr Intensity | 3 in/hr Intensity |
| **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 3.1 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 inch/hr but increased significantly with the 3 inch/hr rainfall intensity. The 3 inch/hr rainfall intensity test was also the only test that produced significant runoff showing the correlation between runoff and nutrient loss from soils. Figure 3.2 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 this 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 4.

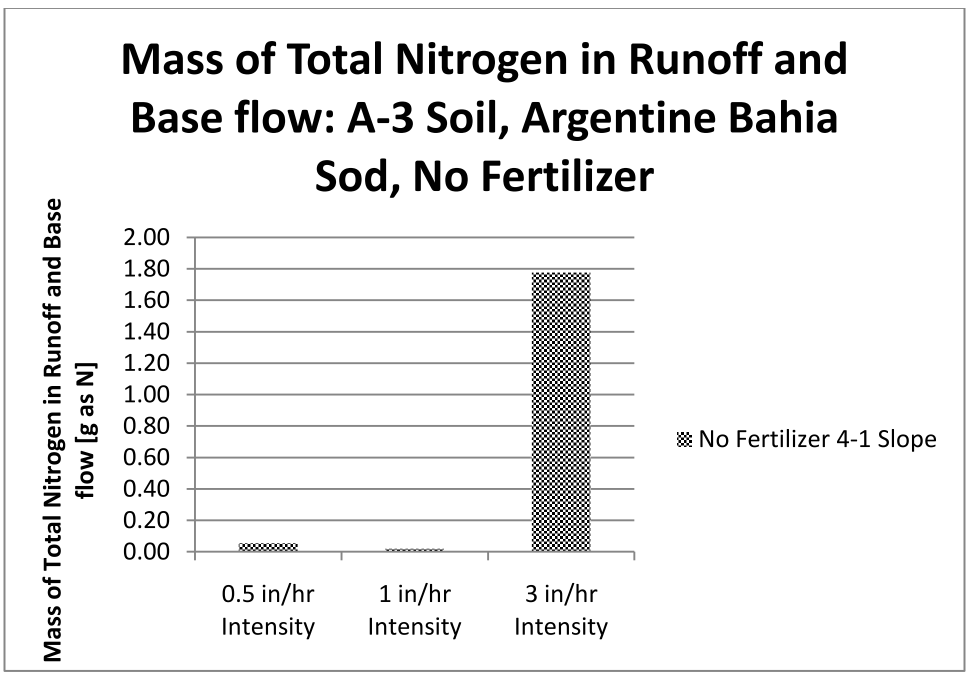


**Figure 3.1: Mass of Total Nitrogen (TN) Collected - A-3 Soil, Argentine Bahia, No Fertilizer**

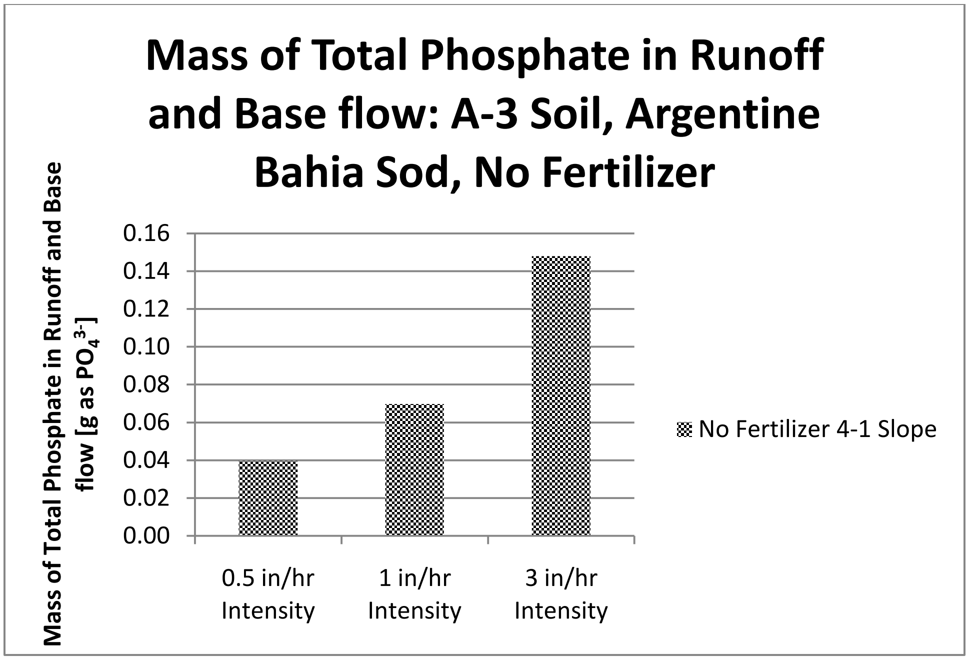


**Figure 3.2: Mass of Total Phosphate (TP) Collected - A-3 Soil, Argentine Bahia Sod, No Fertilizer**

### *3.2.2 10-10-10 N-P-K Fertilizer @ 1 lb of N per 1000 ft$^2$*

Table 3.6 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 non-linear 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. The average chemical parameters measured in the series of seven tests are presented in Table 3.7. 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. The masses of total nitrogen (TN) and total phosphorous (TP) collected in runoff and base flows are presented in Table 3.8. 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 3.6: Volumes of Rainfall Applied, Runoff and Base Flow Collected, 10-10-10 Fertilizer**

| Slope and Soil Type | 4-1 Slope A-3 Soil | | | 3-1 Slope A-3 Soil | | 2-1 Slope A-3 Soil | |
|---|---|---|---|---|---|---|---|
| Intended 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 |
| Avg. actual intensity inch/hour | 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 3.7: Total Solids, pH, Alkalinity, & Turbidity on A-3 Soil and Argentine Bahia Sod with 10-10-10 Fertilizer**

| Slope and Soil Type | 4-1 Slope A-3 Soil | | | 3-1 Slope A-3 Soil | | 2-1 Slope A-3 Soil | |
|---|---|---|---|---|---|---|---|
| Intended 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 |
| 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 3.8: Distribution of Nutrient Loss between Runoff & Base Flow: A-3 Soil/Argentine Bahia Sod/10-10-10 Fertilizer**

| Slope and Soil Type | 4-1 Slope A-3 Soil | | | 3-1 Slope A-3 Soil | | 2-1 Slope A-3 Soil | |
|---|---|---|---|---|---|---|---|
| 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 |
| **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 3.3 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 these trends are the loss of TN in one test at 1 in/hour intensity on the 3-1 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 3.4 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 fertilizer TP losses, in general, 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 4.

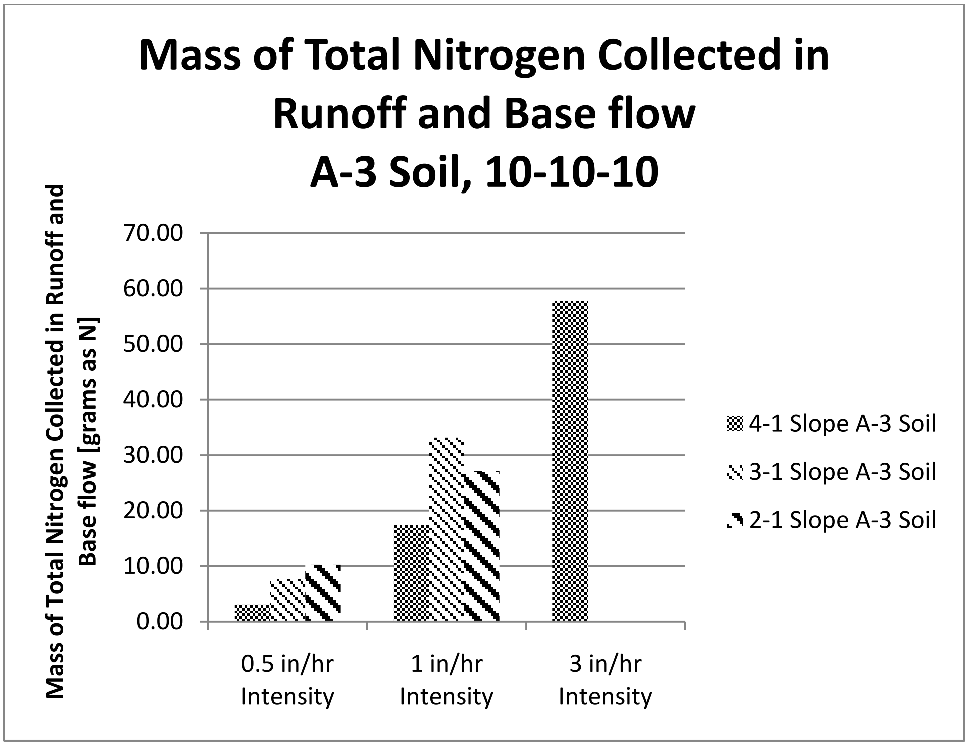


**Figure 3.3: Mass of Total Nitrogen (TN) Collected - A-3 Soil, Argentine Bahia Sod, 10-10-10 Fertilizer**

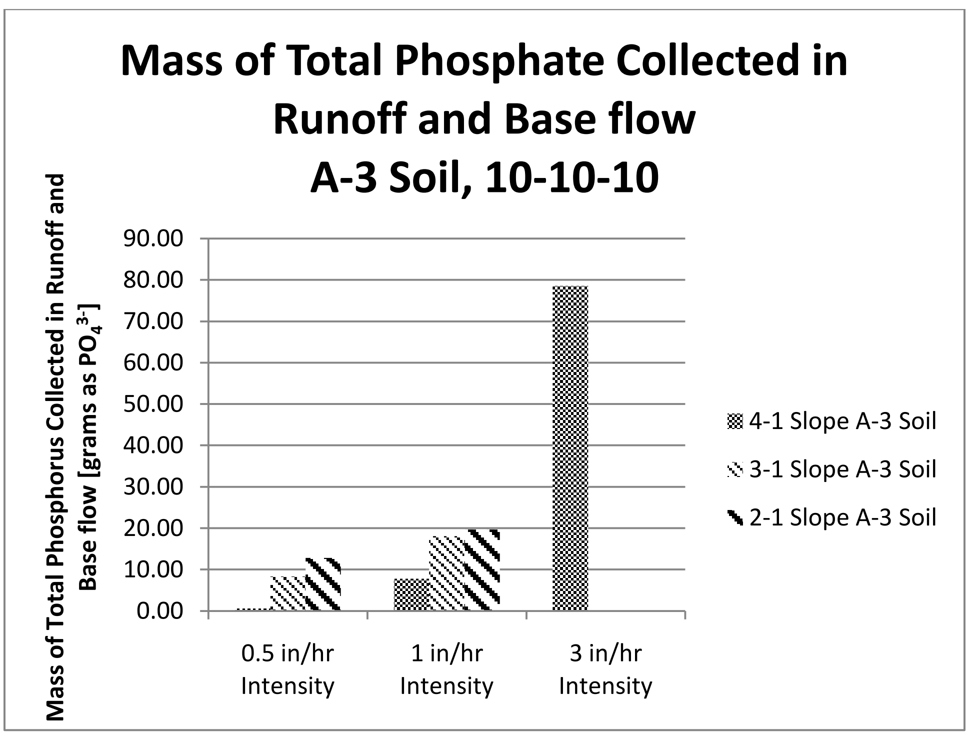


**Figure 3.4: Mass of Total Phosphate (TP) Collected - A-3 Soil, Argentine Bahia Sod, 10-10-10 Fertilizer**

### *3.2.3 10-10-10 N-P-K Fertilizer @ 1 lb of N per 1000 ft$^2$ – Seven-Day Test*

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 are presented in Table 3.9. 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.

The average chemical parameters measured in each of the three tests are presented in Table 3.10. 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. It should be noted that 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. Despite the higher values of total solids, the turbidity values were still quite low and thus would not have resulted in violating 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. The masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flows are presented in Tables 3.11. 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 is highest on 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 as time passes the ammonia is converted to nitrate and then leached out through the base flow, i.e., 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 3.9:  Volumes of Rainfall Applied, Runoff and Base Flow, 10-10-10 Fertilizer, Seven-Day Test**

| | 3-1 Slope (Seven-Day Test) | | |
|---|---|---|---|
| Intended intensity inch/hour | 3 in/hr Intensity, Day One | 3 in/hr Intensity, Day Three | 3 in/hr Intensity, Day Seven |
| Avg. actual intensity inch/hour | 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 | 46.4% | 45.48% | 67.49% |

**Table 3.10: Total Solids, pH, Alkalinity, & Turbidity in Tests on A-3 Soil and Argentine Bahia with 10-10-10 Fertilizer, Seven-Day Test**

| | 3-1 Slope (Seven-Day Test) | | |
|---|---|---|---|
| Intended intensity inch/hour | 3 in/hr Intensity, Day One | 3 in/hr Intensity, Day Three | 3 in/hr Intensity, 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 3.11: Distribution of Nutrient Loss between Runoff & Base Flow: A-3 Soil/Argentine Bahia Sod/10-10-10 Fertilizer/Seven-Day Test**

| | 3-1 Slope (Seven-Day Test) | | |
|---|---|---|---|
| Rainfall intensity inch/hour | 3 in/hr Intensity, Day One | 3 in/hr Intensity, Day Three | 3 in/hr Intensity, 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 3.5 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 TN losses in general decrease with time. Figure 3.6 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 this 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.

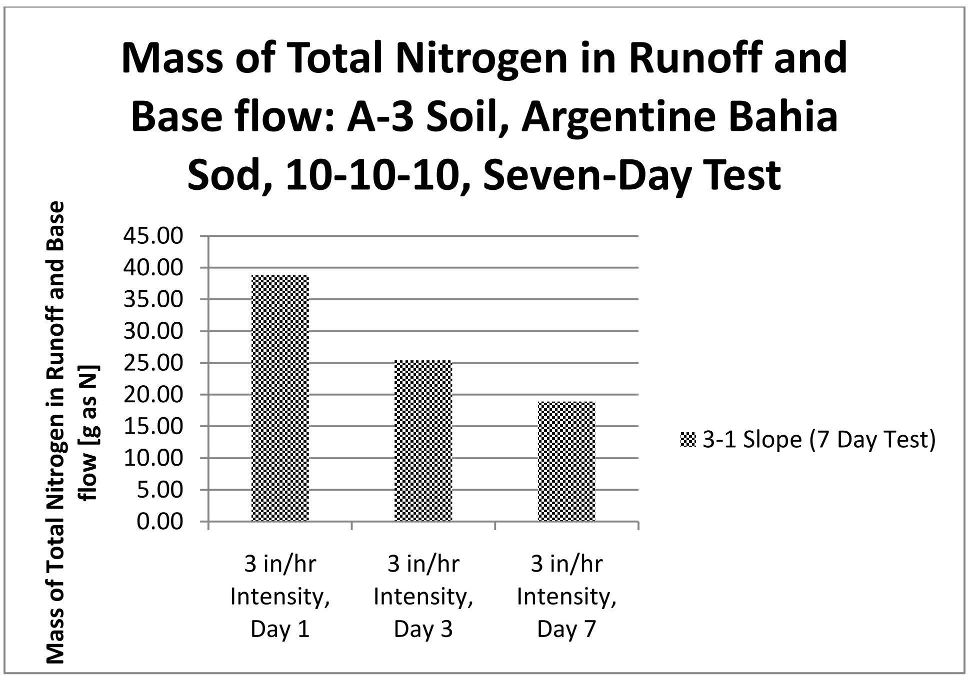


**Figure 3.5: Mass of Total Nitrogen (TN) Collected - A-3 Soil, Argentine Bahia Sod, 10-10-10 Fertilizer, Seven-Day Test**

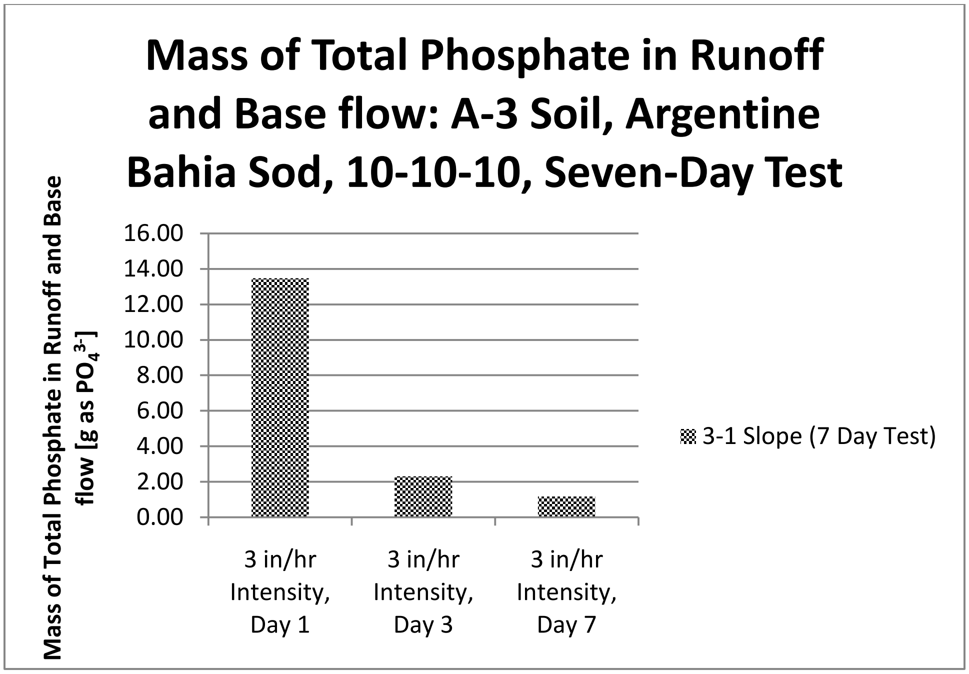


**Figure 3.6: Mass of Total Phosphate (TP) Collected - A-3 Soil, Argentine Bahia Sod, 10-10-10 Fertilizer, Seven-Day Test**

### *3.2.4 16-0-8 (SR) N-P-K Fertilizer @ 1lb of N per 1000ft$^2$*

Table 3.12 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.

The average chemical parameters measured in this series of seven tests are presented in Table 3.13. 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. The masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flows are presented in Table 3.14. 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 4 to 1 slope @ 3 inch/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 due to the fact that all of the tests, except the 3 inch/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 inch/hr. As the 16-0-8 (SR) fertilizer contained no phosphorus, obviously very low masses of TP were collected.

**Table 3.12: Volumes of Rainfall Applied, Runoff and Base Flow, 16-0-8 (SR) @1lb of N per 1000 ft$^2$**

| | 4-1 Slope | | | 3-1 Slope | | 2-1 Slope | |
|---|---|---|---|---|---|---|---|
| Intended 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 |
| Avg. actual intensity inch/hour | 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 3.13: Total Solids, pH, Alkalinity, & Turbidity in Tests on A-3 Soil and Argentine Bahia Sod with 16-0-8 (SR) @ 1lb of N per 1000 ft$^2$**

| | 4-1 Slope | | | 3-1 Slope | | 2-1 Slope | |
|---|---|---|---|---|---|---|---|
| Intended 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 |
| 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 3.14: Distribution of Nutrient Loss between Runoff & Base Flow: A-3 Soil/Argentine Bahia Sod/16-0-8 (SR) Fertilizer @ 1lb of N per 1000 ft$^2$**

| Slope | 4-1 Slope | | | 3-1 Slope | | 2-1 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 |
| **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 3.7 presents the 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 one test at 1 in/hour intensity on the 1 in 2 slope and the loss of TN in the 3 in/hr intensity on the 1 in 4 slope, which 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 4. Figure 3.8 presents the 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 phosphorus in the fertilizer applied for these tests.

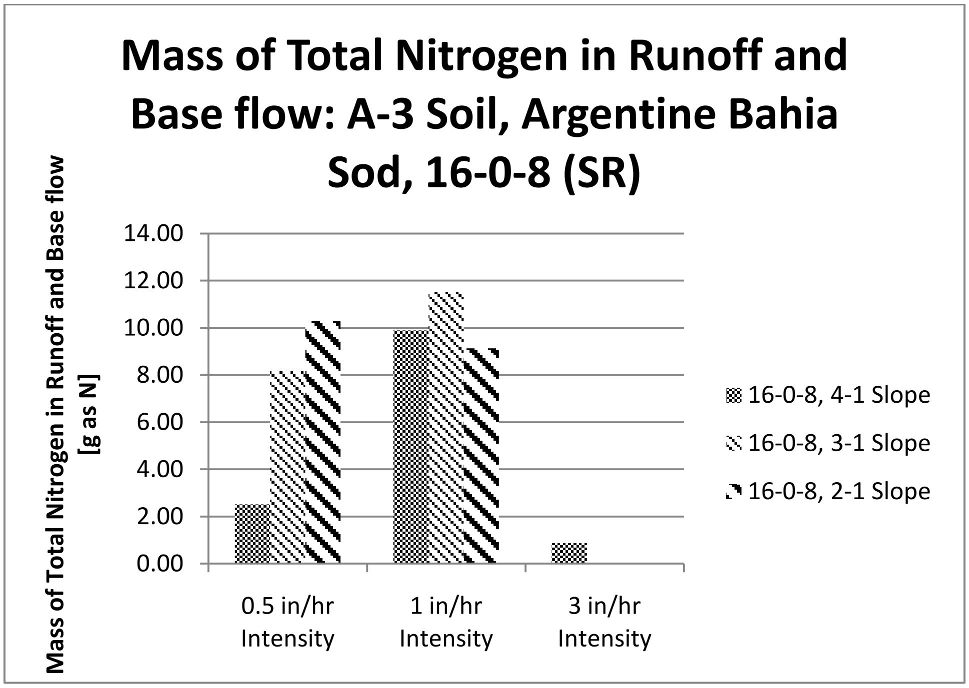


**Figure 3.7: Mass of Total Nitrogen (TN) Collected - A-3 Soil, Argentine Bahia Sod, 16-0-8 (SR) Fertilizer @ 1lb of N per 1000 ft$^2$**

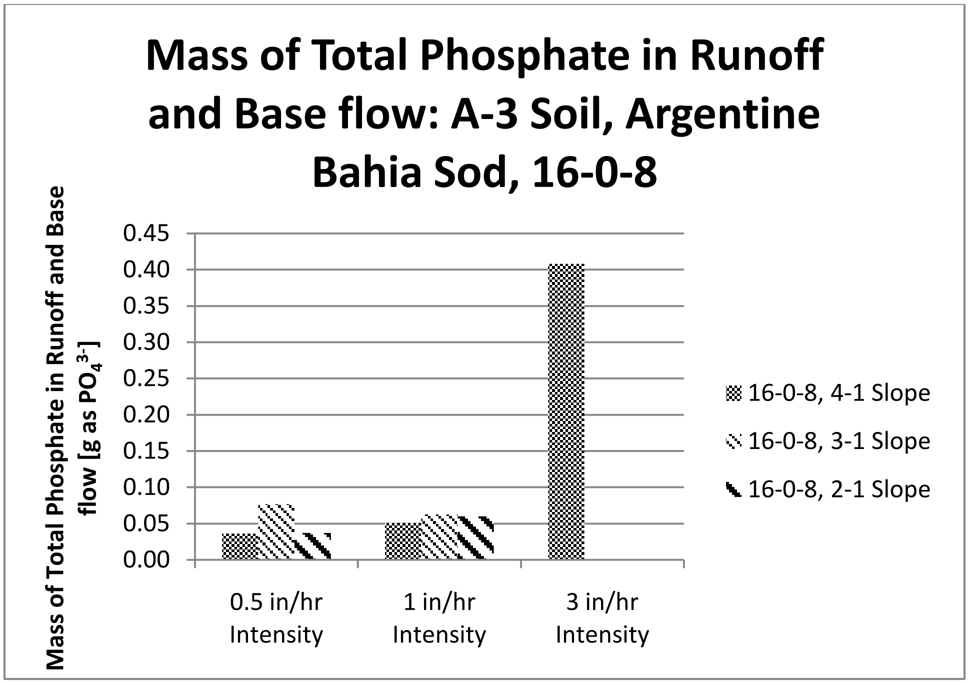


**Figure 3.8: Mass of Total Phosphate (TP) Collected - A-3 Soil, Argentine Bahia Sod, 16-0-8 (SR) Fertilizer @ 1lb of N per 1000ft$^2$**

### *3.2.5 16-0-8 (SR) N-P-K Fertilizer at 0.5lb of N per 1000ft$^2$*

Table 3.15 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 inch/hr 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%.

The average chemical parameters measured in this series of seven tests are presented in Table 3.16. 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.

The masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flows are presented in Table 3.17. 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 inch/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 due to the fact that all of the tests, except the 3 inch/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 3.15: Volumes of Rainfall Applied, Runoff and Base Flow Collected, 16-0-8 (SR) Fertilizer @ 0.5lb of N per 1000 ft$^2$**

| | 4-1 Slope | | | 3-1 Slope | | 2-1 Slope | |
|---|---|---|---|---|---|---|---|
| Intended 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 |
| Avg. actual intensity inch/hour | 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 3.16: Total Solids, pH, Alkalinity, & Turbidity in Tests on A-3 Soil and Argentine Bahia Sod with 16-0-8 (SR) Fertilizer @ 0.5lb of N per 1000 ft$^2$**

| | 4-1 Slope | | | 3-1 Slope | | 2-1 Slope | |
|---|---|---|---|---|---|---|---|
| Intended 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 |
| 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 3.17: Distribution of Nutrient Loss between Runoff & Base Flow: A-3 Soil/Argentine Bahia Sod/16-0-8 (SR) Fertilizer @ 0.5lb of N per 1000 ft$^2$**

| Slope | 4-1 Slope | | | 3-1 Slope | | 2-1 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 |
| **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 3.9 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 three tests, namely: 0.5 in/hour intensity on the 1 in 3 slope, 1.0 in/hour intensity on the 1 in 4 slope, and the 1.0 in/hour intensity on the 1 in 3 slope, which 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 3.10 presents the loss of total phosphate (TP in runoff +

base flow) for all the seven tests in the series.  It can be seen from this 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.

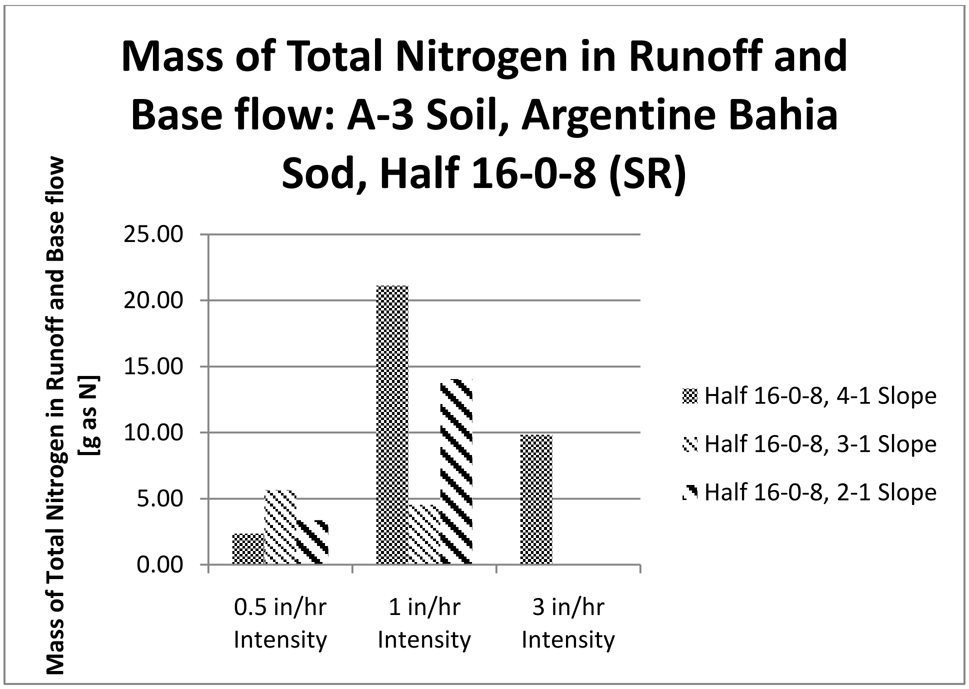


**Figure 3.9:  Mass of Total Nitrogen (TN) Collected - A-3 Soil, Argentine Bahia Sod, 16-0-8 (SR) Fertilizer @ 0.5lb of N per 1000 ft$^2$**

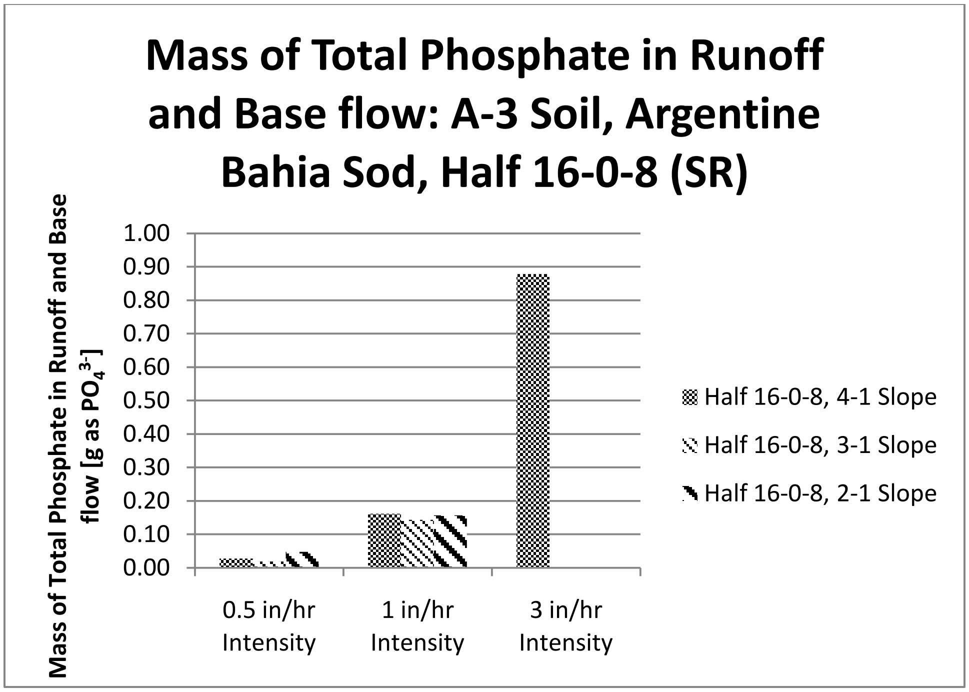


**Figure 3.10: Mass of Total Phosphate (TP) Collected - A-3 Soil, Argentine Bahia Sod, 16-0-8 (SR) Fertilizer @ 0.5lb of N per 1000 $ft^2$**

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

### *3.3.1 No Application of Fertilizer*

As shown in Table 3.2 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 3.18 presents the actual rainfall intensities that were applied to the test bed calculated based on measurement from twelve rain gauges. The volumes of applied rain, runoff and base flow for the three tests in this series are also shown. 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 non-linear 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.

The average chemical parameters measured in these six tests are presented in Table 3.19. 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.

While no fertilizer was added to the test beds for these series of tests, the masses of total nitrogen (TN) and total phosphorous (TP) collected in runoff and base flow were measured and are presented in Table 3.20. 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. This percentage, for both TN and TP, tends 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 3.18: Volumes of Rainfall Applied, Runoff and Base Flow Collected for A-2-4 Soil and Pensacola Bahia Sod, No Fertilizer**

| Slope and Soil Type | 4-1 Slope, A-2-4 Soil (first run) | | | 4-1 Slope, A-2-4 Soil (second run) | | |
|---|---|---|---|---|---|---|
| Intended 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 | 3 in/hr Intensity |
| Avg. actual intensity inch/hour | 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 3.19: Total Solids, pH, Alkalinity, & Turbidity in Tests on A-2-4 Soil and Pensacola Bahia Sod with No Fertilizer**

| Slope and Soil Type | 4-1 Slope, A-2-4 Soil (first run) | | | 4-1 Slope, A-2-4 Soil (second run) | | |
|---|---|---|---|---|---|---|
| Intended 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 | 3 in/hr Intensity |
| 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 3.20: Distribution of Nutrient Loss between Runoff & Base Flow: A-2-4 Soil/Pensacola Bahia Sod/No Fertilizer**

| Slope and Soil Type | 4-1 Slope, A-2-4 Soil (first run) | | | 4-1 Slope, A-2-4 Soil (second run) | | |
|---|---|---|---|---|---|---|
| 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 | 3 in/hr Intensity |
| **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 3.11 presents the loss of total nitrogen (TN in runoff + base flow) for all six tests in this series. It can be seen from this figure that the mass of TN collected did not vary much over any of the intensities but slightly increased with the 3 inch/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 3.12 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 this 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.

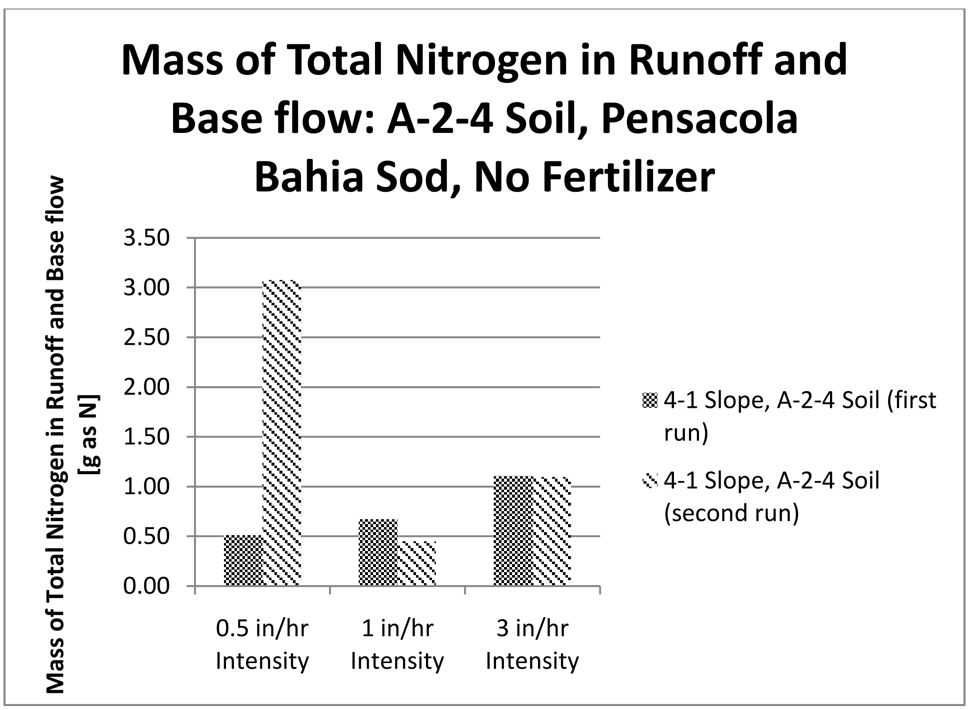


**Figure 3.11: Mass of Total Nitrogen (TN) Collected - A-2-4 Soil, Pensacola Bahia Sod, No Fertilizer**

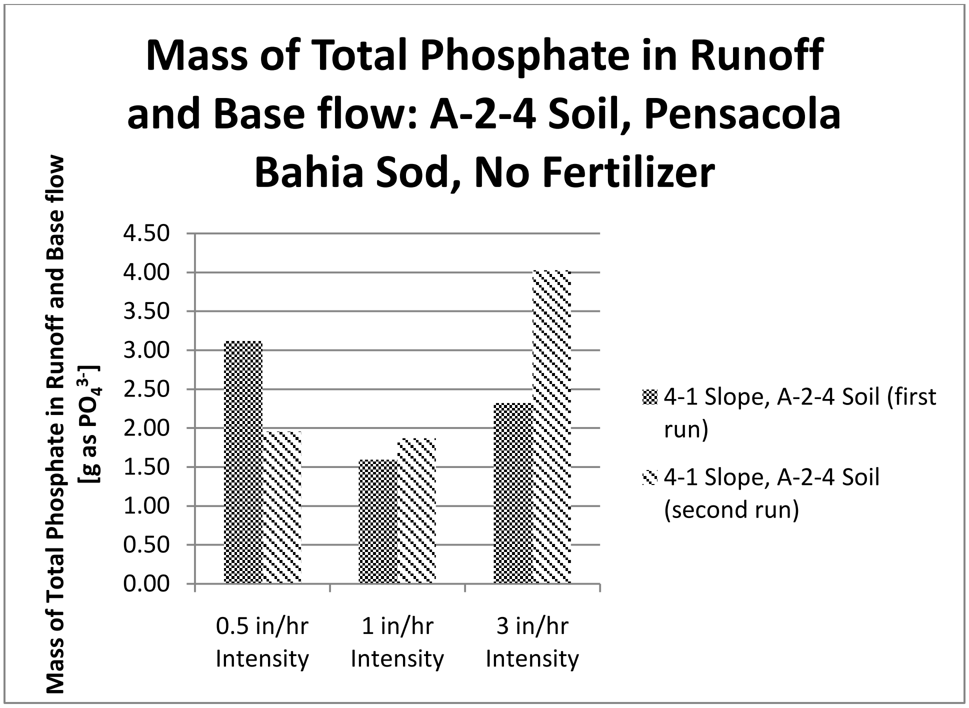


**Figure 3.12: Mass of Total Phosphate (TP) Collected - A-2-4 Soil, Pensacola Bahia Sod, No Fertilizer**

### *3.3.2 10-10-10 N-P-K Fertilizer @ 1lb of N per 1000 ft$^2$*

Table 3.21 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.

The average chemical parameters measured in the series of seven tests are presented in Table 3.22. 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.

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. The masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flows are presented in Table 3.23. 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. Most of the fertilizer particles that could get into the soil either got 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.

**Table 3.21: Volumes of Rainfall Applied, Runoff and Base Flow Collected with 10-10-10 Fertilizer**

| Slope and Soil Type | 4-1 Slope A-2-4 Soil | | | 3-1 Slope A-2-4 Soil | | 2-1 Slope A-2-4 Soil | |
|---|---|---|---|---|---|---|---|
| Intended 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 |
| Avg. actual intensity inch/hour | 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 3.22: Total Solids, pH, Alkalinity, & Turbidity in Tests on A-2-4 Soil and Pensacola Bahia Sod with 10-10-10 Fertilizer**

| Slope and Soil Type | 4-1 Slope A-2-4 Soil | | | 3-1 Slope A-2-4 Soil | | 2-1 Slope A-2-4 Soil | |
|---|---|---|---|---|---|---|---|
| Intended 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 |
| 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 |

**Table 3.23: Distribution of Nutrient Loss between Runoff & Base Flow: A-2-4 Soil/Pensacola Bahia Sod/10-10-10 Fertilizer**

| Slope and Soil Type | 4-1 Slope A-2-4 Soil | | | 3-1 Slope A-2-4 Soil | | 2-1 Slope A-2-4 Soil | |
|---|---|---|---|---|---|---|---|
| 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 |
| **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% |

It can be seen from Table 3.23 above that the TN losses are largely from runoff. Table 3.21 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. Figure 3.13 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/hour test on the 1 in 4 slope. The only exception to this trend is the loss of TN in one test at 1 in/hour 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 3.14 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 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.

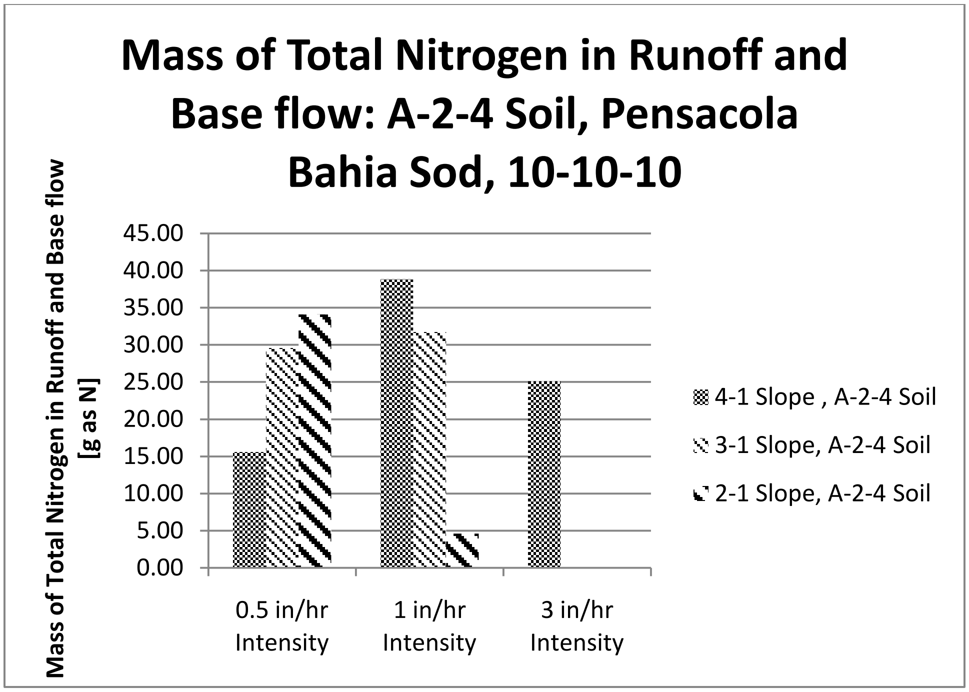


**Figure 3.13: Mass of Total Nitrogen (TN) Collected - A-2-4 Soil, Pensacola Bahia Sod, 10-10-10 Fertilizer**

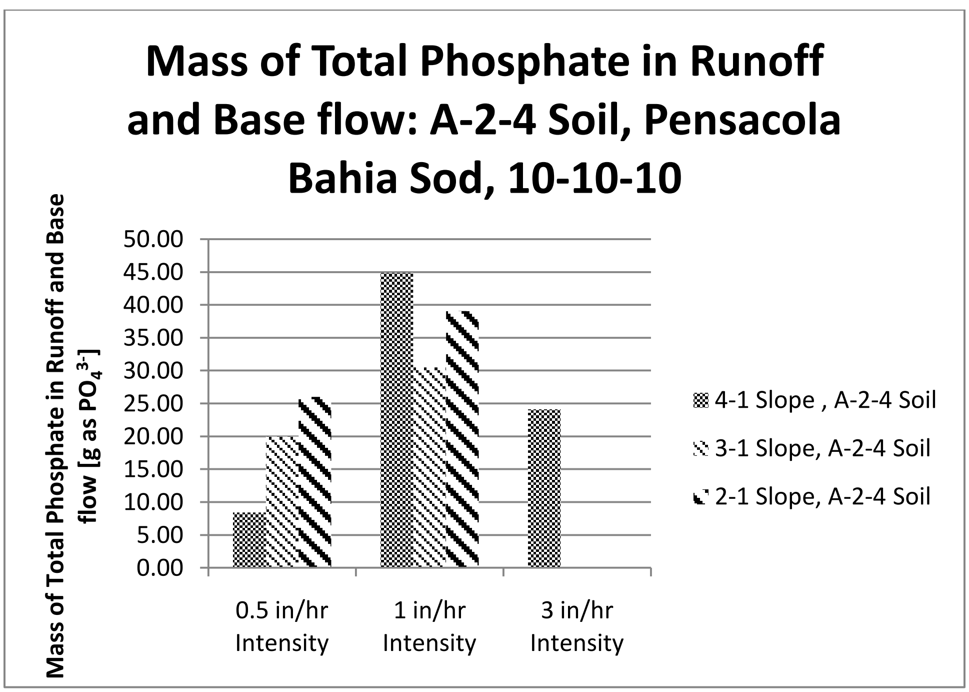


**Figure 3.14: Mass of Total Phosphate (TP) Collected - A-2-4 Soil, Pensacola Bahia Sod, 10-10-10 Fertilizer**

### *3.3.3 10-10-10 N-P-K Fertilizer @ 1lb of N per 1000 $ft^2$ – Seven-Day Test*

Table 3.24 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.

The average chemical parameters measured in each of the three tests are presented in Table 3.25. 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.

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. The masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flows are presented in Table 3.26. 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 3.24: Volumes of Rainfall Applied, Runoff and Base Flow Collected, 10-10-10 Fertilizer, Seven-Day Test**

| Slope and Soil Type | 3-1 Slope, A-2-4 Soil | | |
|---|---|---|---|
| Intended intensity inch/hour | 3 in/hr Intensity, Day One | 3 in/hr Intensity, Day Three | 3 in/hr Intensity, Day Seven |
| Avg. actual intensity inch/hour | 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% | 88.8% | 92.83% |

**Table 3.25: Total Solids, pH, Alkalinity, & Turbidity in Tests on A-2-4 Soil and Pensacola Bahia Sod with 10-10-10 Fertilizer, Seven-Day Test**

| Slope and Soil Type | 3-1 Slope, A-2-4 Soil | | |
|---|---|---|---|
| Intended intensity inch/hour | 3 in/hr Intensity, Day One | 3 in/hr Intensity, Day Three | 3 in/hr Intensity, 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 |

**Table 3.26: Distribution of Nutrient Loss between Runoff & Base Flow: A-2-4 Soil/Pensacola Bahia Sod/10-10-10 Fertilizer/Seven-Day Test**

| Slope and Soil Type | 3-1 Slope, A-2-4 Soil | | |
|---|---|---|---|
| Rainfall intensity inch/hour | 3 in/hr Intensity, Day One | 3 in/hr Intensity, Day Three | 3 in/hr Intensity, 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 3.15 presents the 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 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 3.16 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 this 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.

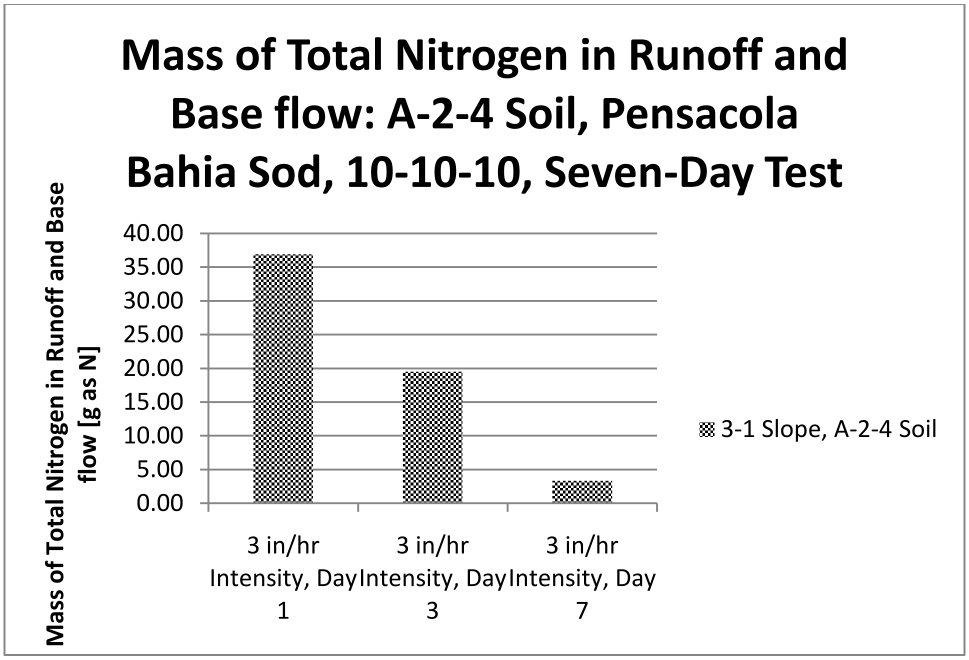


**Figure 3.15: Mass of Total Nitrogen (TN) Collected - A-2-4 Soil, Pensacola Bahia Sod, 10-10-10 Fertilizer, Seven-Day Test**

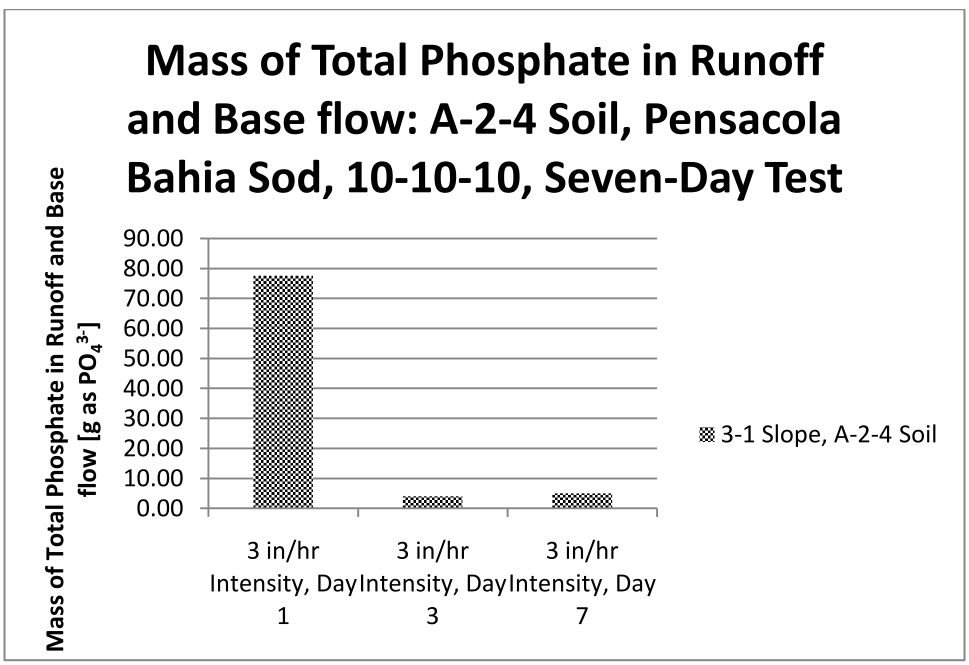


**Figure 3.16: Mass of Total Phosphate (TP) Collected - A-2-4 Soil, Pensacola Bahia Sod, 10-10-10 Fertilizer, Seven-Day Test**

### *3.3.4 16-0-8 (SR) N-P-K Fertilizer at 0.5lb of N per 1000ft²*

Table 3.27 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 non-linear due to the variable nature of the initial moisture content and evapotranspiration conditions.

The average chemical parameters measured in this series of seven tests are presented in Table 3.28. 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.

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. The masses of total nitrogen (TN) and total phosphate (TP) collected in runoff and base flows are presented in Table 3.29. 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 due to the fact that 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 3.27: Volumes of Rainfall Applied, Runoff and Base Flow Collected, 16-0-8 (SR) Fertilizer @ 0.5lb of N per 1000 ft$^2$**

| Slope and Soil Type | 4-1 Slope, A-2-4 Soil | | | 3-1 Slope, A-2-4 Soil | | 2-1 Slope, A-2-4 Soil | |
|---|---|---|---|---|---|---|---|
| Intended 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 |
| Avg. actual intensity inch/hour | 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 3.28: Total Solids, pH, Alkalinity, & Turbidity in Tests on A-2-4 Soil and Pensacola Bahia Sod with 16-0-8 (SR) Fertilizer @ 0.5lb of N per 1000 ft$^2$**

| Slope and Soil Type | 4-1 Slope, A-2-4 Soil | | | 3-1 Slope, A-2-4 Soil | | 2-1 Slope, A-2-4 Soil | |
|---|---|---|---|---|---|---|---|
| Intended 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 |
| 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 |

**Table 3.29: Distribution of Nutrient Loss between Runoff & Base Flow: A-2-4 Soil/Pensacola Bahia Sod/16-0-8 (SR) Fertilizer @ 0.5lb of N per 1000 ft$^2$**

| Slope and Soil Type | 4-1 Slope, A-2-4 Soil | | | 3-1 Slope, A-2-4 Soil | | 2-1 Slope, A-2-4 Soil | |
|---|---|---|---|---|---|---|---|
| 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 |
| **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 3.17 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 3.18 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.

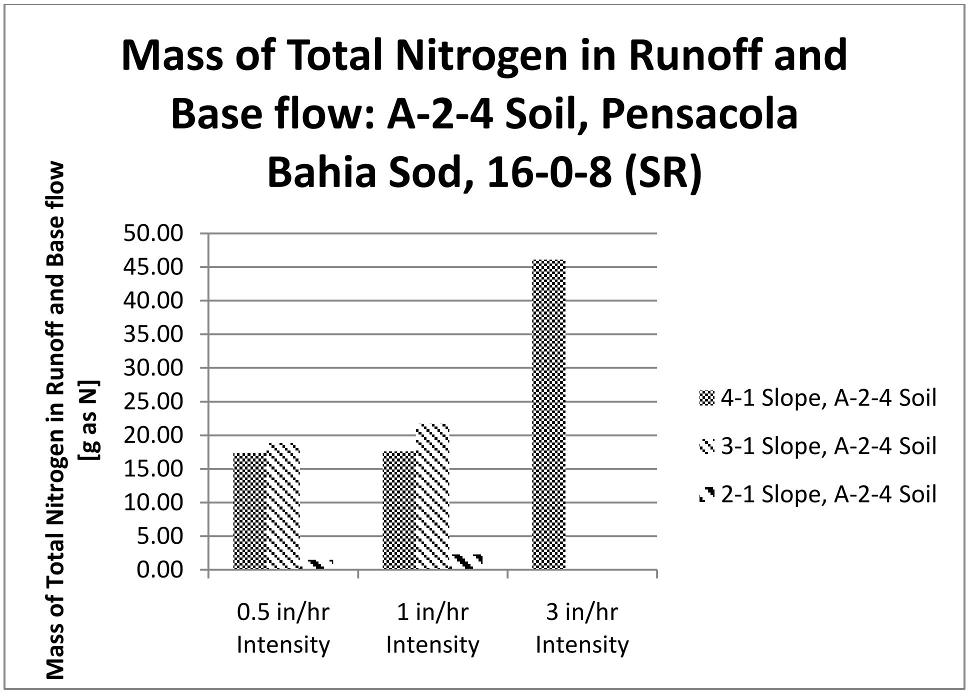


**Figure 3.17: Mass of Total Nitrogen (TN) Collected - A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 (SR) Fertilizer @ 0.5lb of N per 1000 ft$^2$**

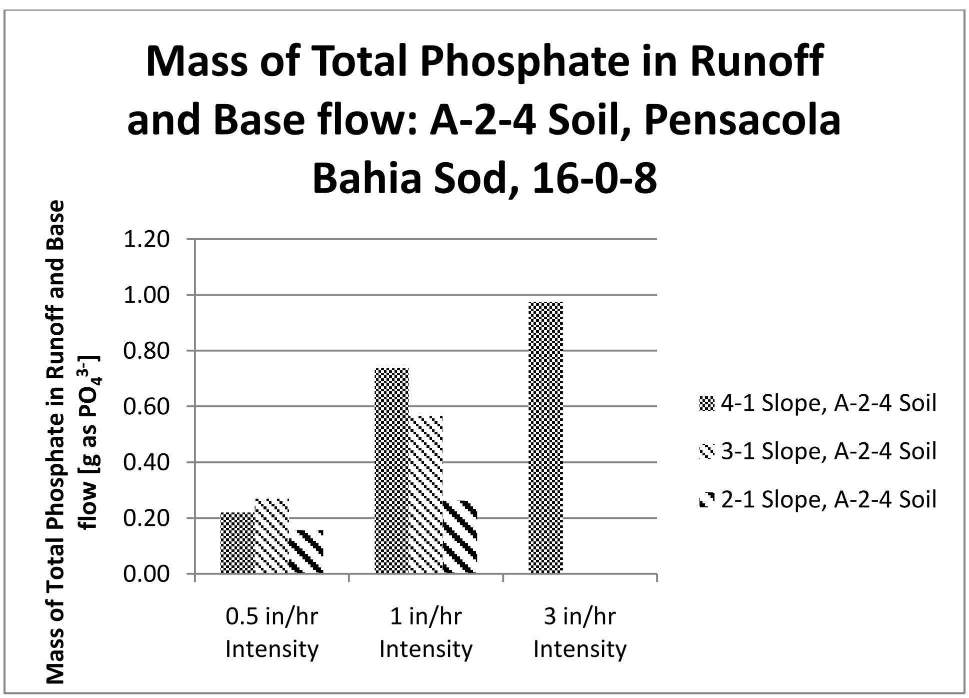


**Figure 3.18: Mass of Total Phosphate (TP) Collected - A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 (SR) Fertilizer @ 0.5lb of N per 1000 ft$^2$**

# 4 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 getting 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.*

## 4.1 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. Also, 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, i.e., 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. A detailed description of the influencing parameters is given in Table 4.1, 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 for maintaining 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 4.1: 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<br>• Increases evaporation from soil pores and grass<br>• May enhance ammonia volatilization of fertilizers<br>• May enhance other nitrogen transformations<br>• Reduces water's viscosity, so increase permeability<br>• 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<br>• Increases evaporation |
| 3. | Longer Daylight Hours | • Increases nutrient uptake by plants due to better photosynthesis |
| 4. | Natural Precipitation | • Increases soil saturation<br>• 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<br>• Decreases the nutrient-soil interactions and increases nutrient loss<br>• Increases ammonia volatilization<br>• 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<br>Result: less aeration of soils, lower root growth.<br>• Reduced infiltration and fertilizer entry into soils. More loss of nutrients in increased run-off.<br>• Anaerobic conditions → denitrification and gaseous N loss |
| 7. | Higher Clay Content | • Increases CEC value, increasing adsorbed $NH_4$and P<br>• Decreases permeability, thus decreasing the infiltration and loss of nutrients including nitrates |
| 8. | Higher Soil Saturation | • Increases runoff and loss of nutrients<br>• Creates anaerobic conditions for denitrification |
| **Pore Water Conditions** | | |
| 9. | pH | • Above 6, increases ammonia volatilization<br>• 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 | • Soil reaches saturation, and increases the run-off |

| | | |
|---|---|---|
| | Duration | |
| **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<br>• The one ft. 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. These processes are shown schematically in Figure 4.1. 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.

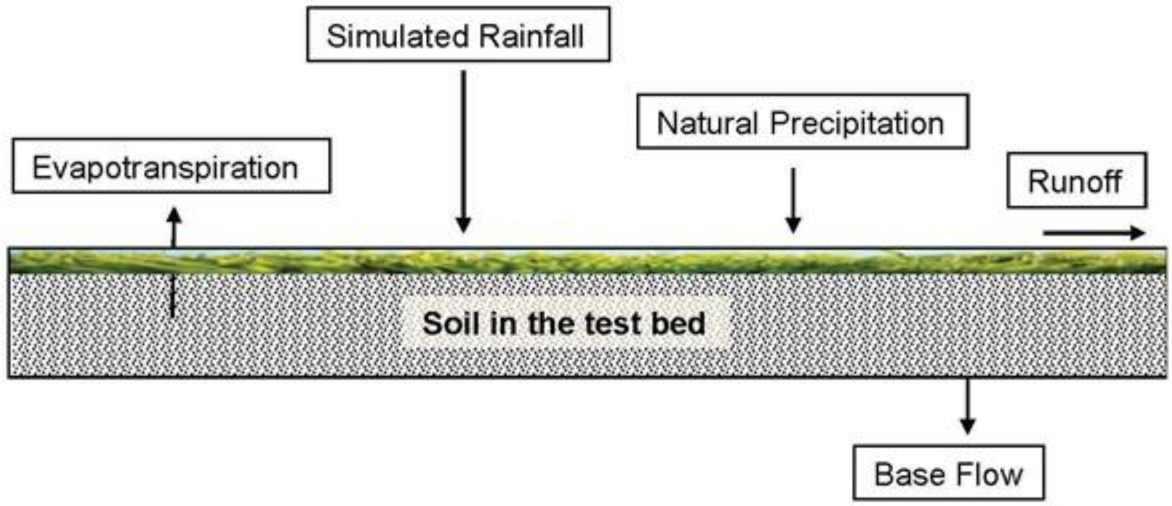


**Figure 4.1: Mass Balance of Moisture in the Test Bed**

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:

$$\mathbf{ET = a + k\,(T - T_{min})^{b}\,(D - D_{min})^{c}} \qquad (4.1)$$

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:

$$\mathbf{ET = 1 + 0.03125\ (T - 50)\ (D-11)} \qquad (4.2)$$

The actual average soil moisture content was measured at the commencement of each test, by collecting several soil samples, oven-drying them, 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) natural precipitation on all days, (3) 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.

## 4.2 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. These processes are shown schematically in Figure 4.2.

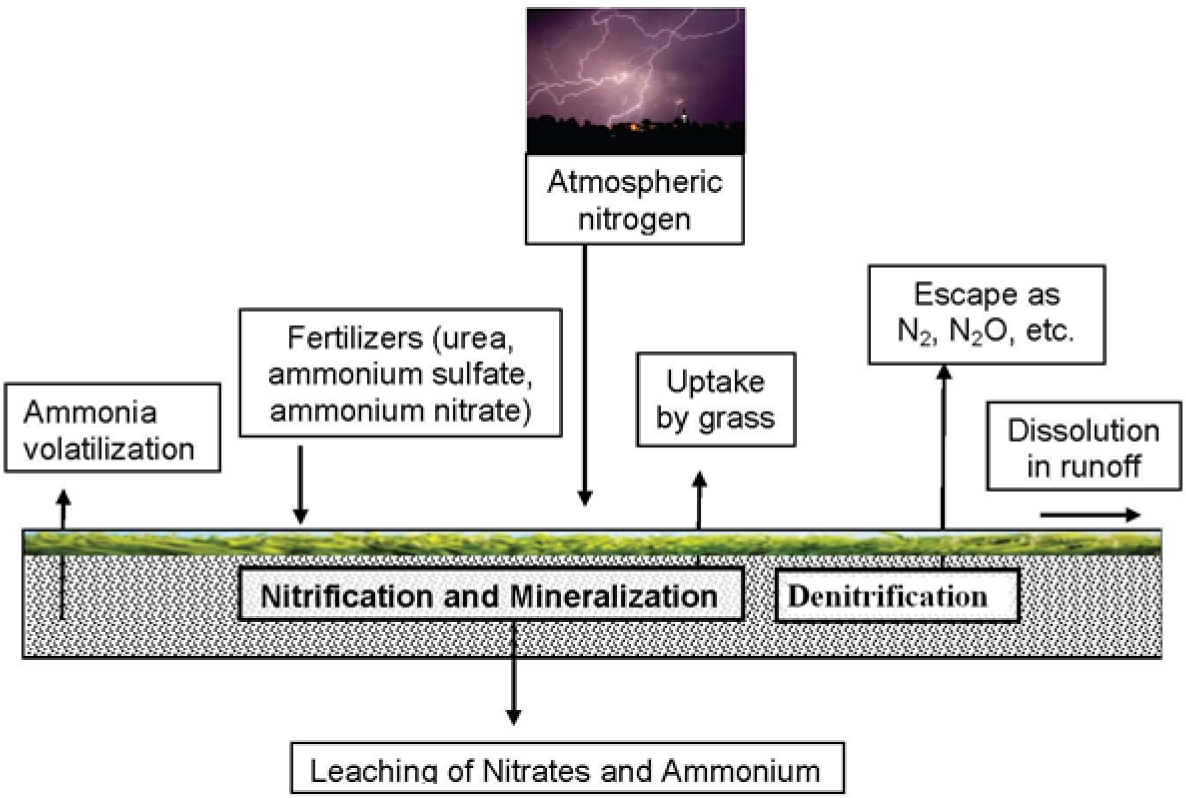


**Figure 4.2: Mass Balance of Nitrogen in the Test Bed**

The Leaching Estimation And Chemistry Models (LEACHM), originally proposed and developed by Wagenet and Hutson (1989) was successfully adopted in several subsequent research studies, including Paramasivam et al. (2000) and Singh and Sondhi (2002).

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 (2002) 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 physicochemical 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 (2002), 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:

$$\mathbf{k_{volati} = 0} \qquad \text{for pH} \leq 6 \qquad (4.3a)$$

$$\mathbf{k_{volati} = 0.0001(pH\text{-}6)^{2}(T\text{-}50)} \qquad \text{for pH} > 6 \qquad (4.3b)$$

where T is the daily mean temperature ($^{o}$F) with its minimum being 50 $^{o}$F, 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:

$$\mathbf{k_{nitri} = \alpha\, \theta_{air}^{\,n}} \qquad (4.4)$$

$$\mathbf{k_{denitri} = \beta\, (1 - \theta_{air})^{d}} \qquad (4.5)$$

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:

$$\mathbf{U_{TN\text{-}Bahia} = 0.555\ (D - D_{min})} \qquad (4.6)$$

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.

## 4.3 Transformations and Transport of Phosphate

Relevant publications on the plant uptake of phosphorus, soil-phosphorus interactions, and leaching of phosphorus were made by 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 get strongly adsorbed to soil surfaces depending on the pore water chemistry and soil's physico-chemical 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 gets 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. The interactions between these three pools and the environment are shown schematically in Figure 4.3.

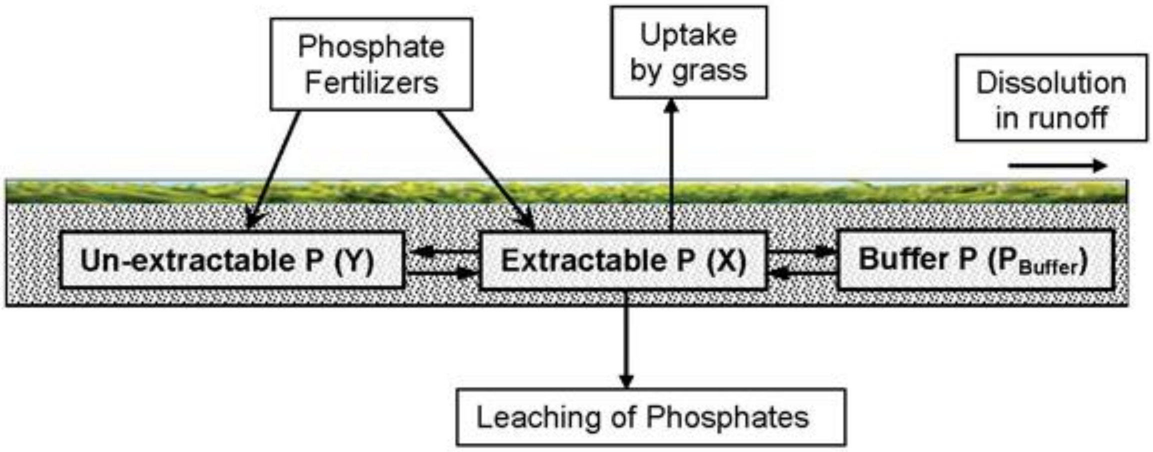


**Figure 4.3: Mass Balance of Phosphate in the Test Bed**

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, 1985; 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:

$$\mathbf{U_{TP\text{-}Bahia} = 0.111\ (D - D_{min})} \tag{4.6}$$

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.

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

### *4.4.1 Soil-sod combination 1 for 10-10-10 fertilizer*

The seven tests that were conducted on the soil-sod combination 1 are reproduced from Table 3.2 and are listed in Table 4.2. As described before, the moisture balance of this combination was analyzed and is presented in Appendix A as Table 9.1. The mass balance of total nitrogen (TN) and total phosphate (TP) are also presented in Appendix A as Tables 9.2 and 9.3, respectively.

**Table 4.2: Chronological Sequence of Tests on Soil-Sod Combination 1**

| 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 |

The total nitrogen mass balance and Figure 4.4 revealed a few trends about the nitrogen in the system and its fate. This 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. Examination of Figure 4.5 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. The percentage of TN mass lost to the total available is shown in Figure 4.6. The mass of TN lost from the system increases with rainfall intensity. There was no observable trend with TN mass loss and soil slope.

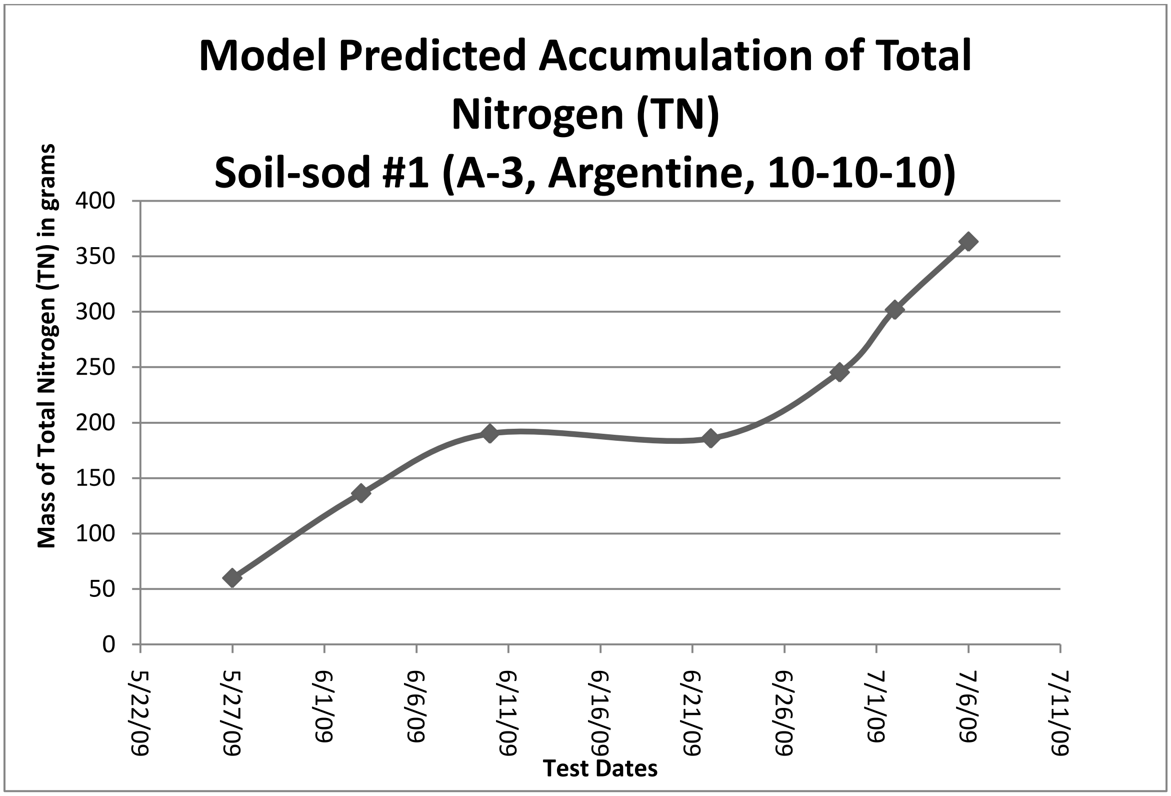


**Figure 4.4: Model Predicted Accumulation of TN in Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, 10-10-10 Fertilizer)**

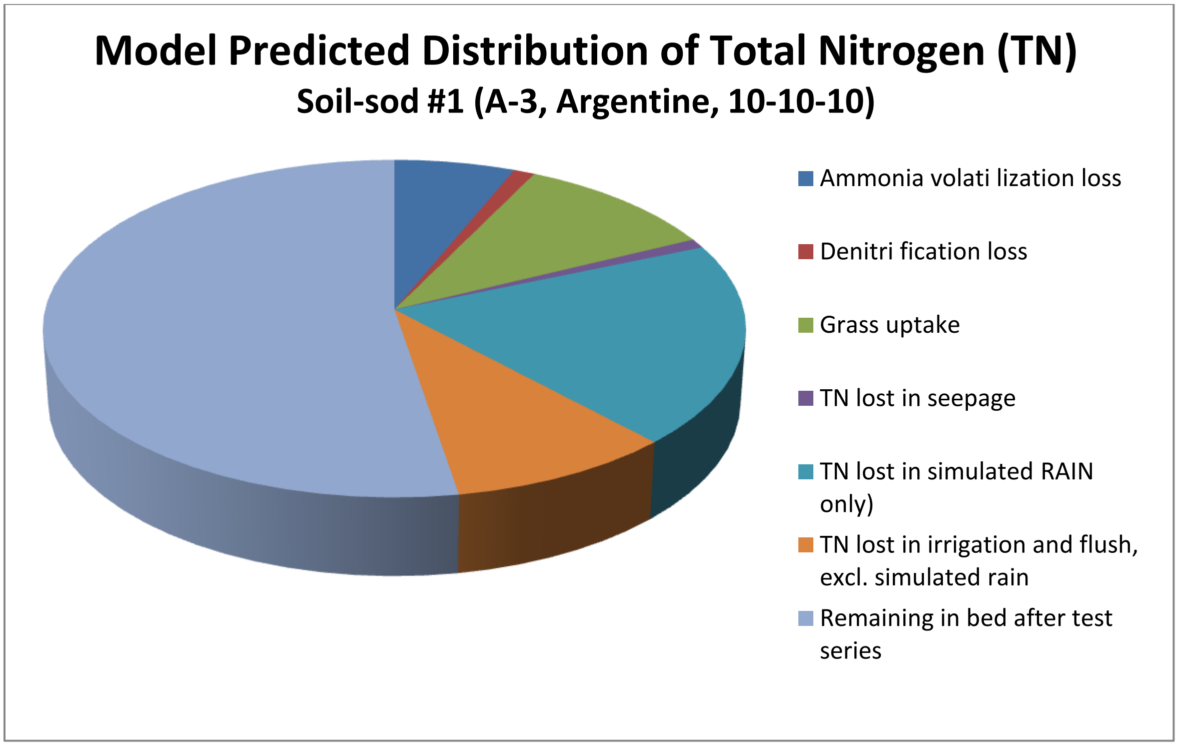


**Figure 4.5: Model Predicted Distribution of TN for Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, 10-10-10 Fertilizer)**

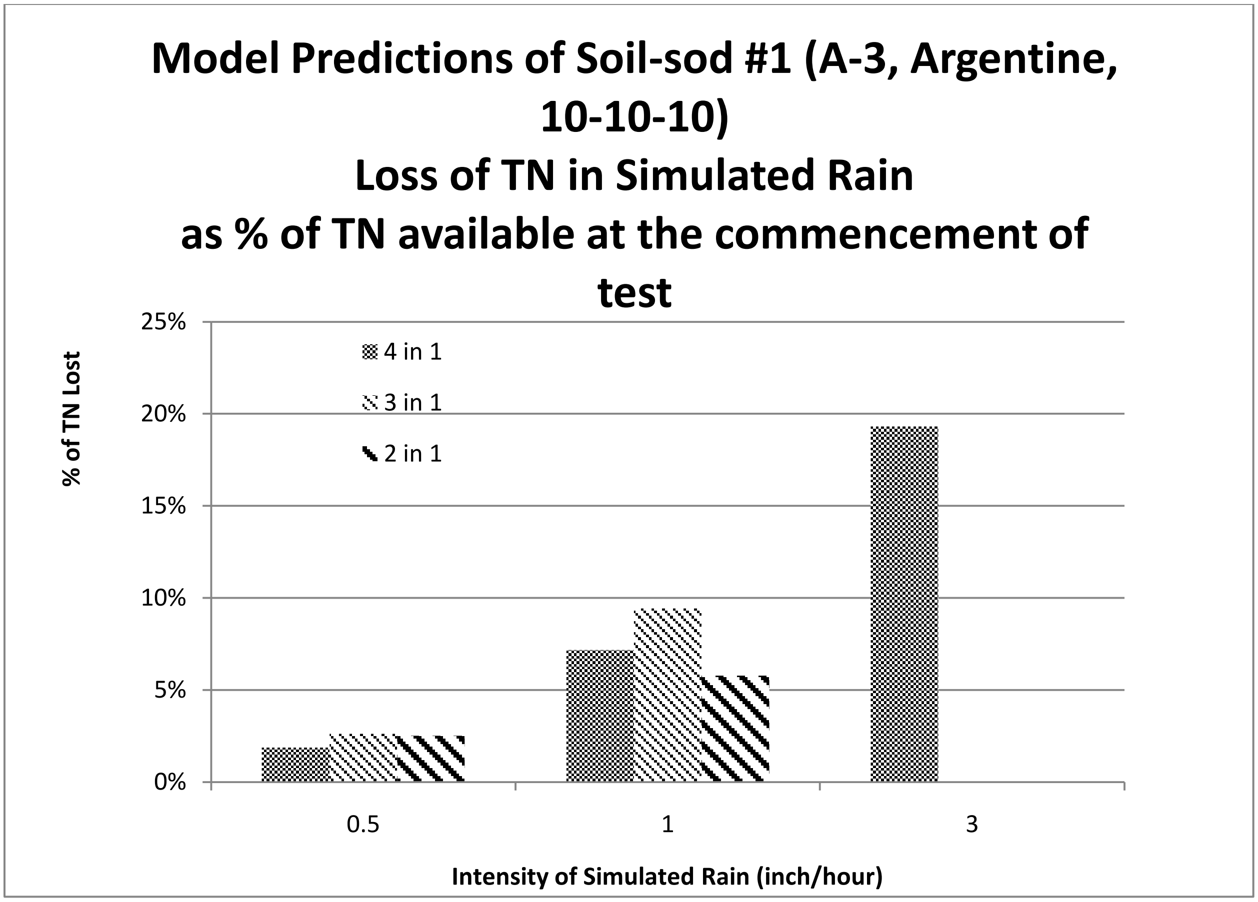


**Figure 4.6: Model Predictions of Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, 10-10-10 Fertilizer) Loss of TN in Simulated Rain as a % of TN Available at the Commencement of the Test**

The following observations can be made from Figures 4.7, 4.8, and 4.9, 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 4.7). 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 4.8). 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 4.9 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.

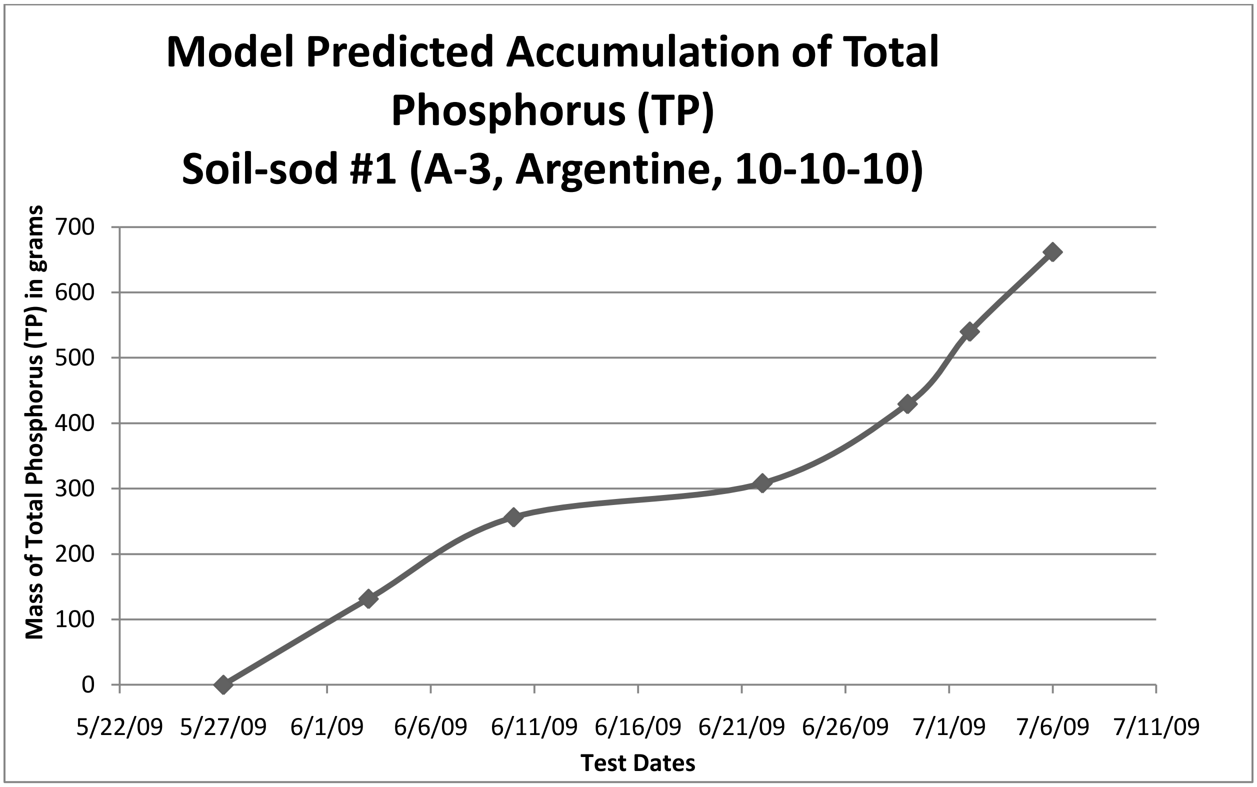


**Figure 4.7: Model Predicted Accumulation of Total Phosphate (TP) Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, 10-10-10 Fertilizer)**

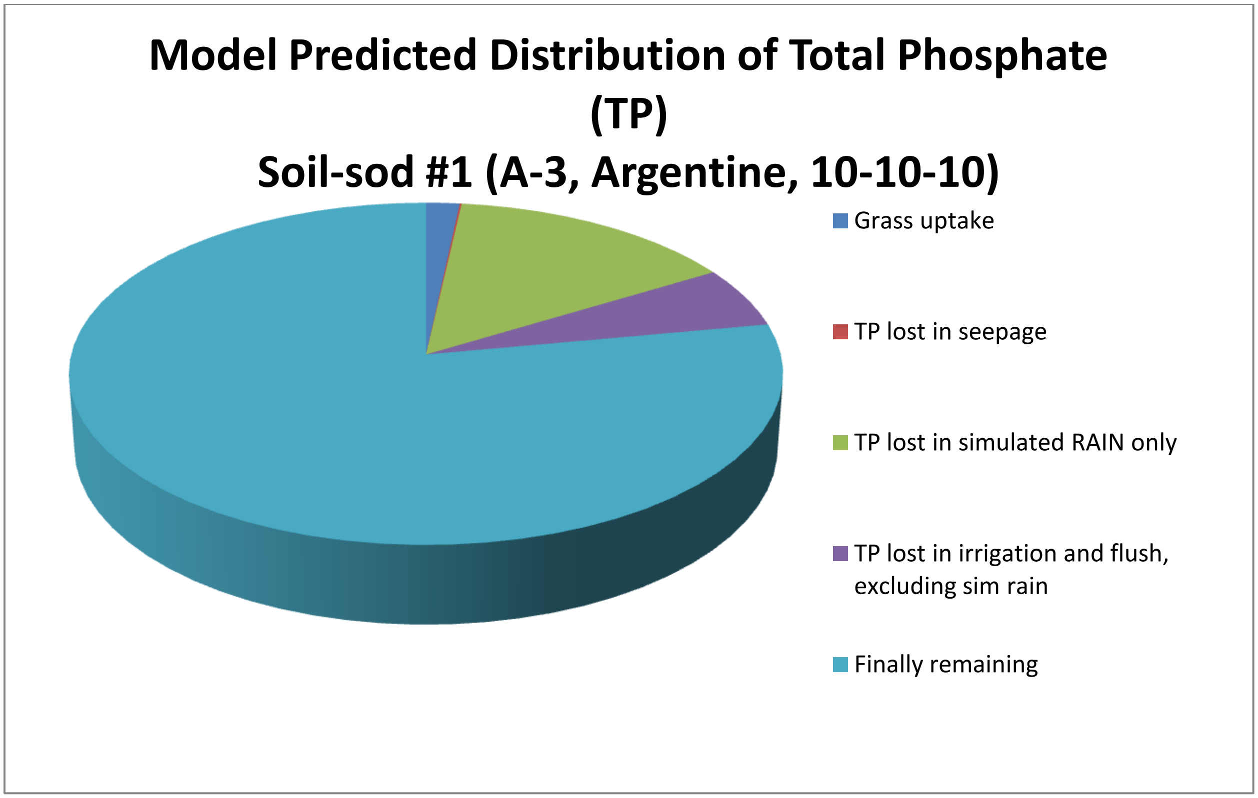


**Figure 4.8: Model Predicted Distribution of Total Phosphate (TP) for Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, 10-10-10 Fertilizer**

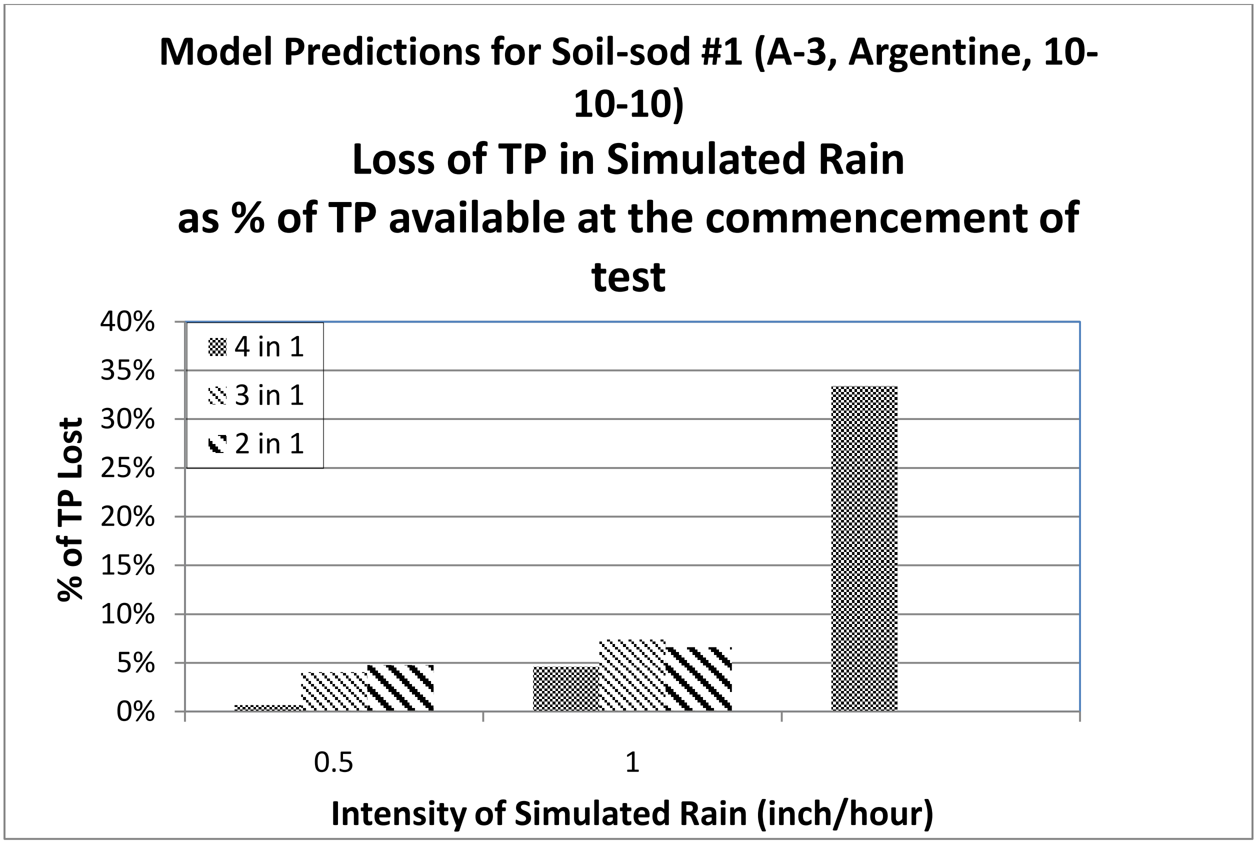


**Figure 4.9: Model Predictions for Soil-Sod Combination #1 (A-3 Soil, Argentine Bahia Sod, 10-10-10 Fertilizer) Loss of TP in Simulated Rain as a % of TP Available at the Commencement of Test**

### *4.4.2 Soil-sod combination 2 for no-fertilizer, 16-0-8 (SR), and 10-10-10 seven-day*

The 18 tests that were conducted on the soil-sod combination 2 are reproduced from Table 3.2 and are listed in Table 4.3. The moisture balance of this combination was analyzed as per models described before and using a spreadsheet and presented in Appendix B as Table 10.1. The mass balance of total nitrogen (TN) is also presented in Appendix B as Table 10.2. Figures 4.10 through 4.15 show a summary of the results of this mass balance. Figure 4.10 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 4.3: Chronological Sequence of Tests on Soil-Sod Combination 2**

| Test # | Soil | Bahia Sod | Fertilizer | Slope | inch/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 4.11 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.

In Figure 4.12, the percent of TN lost in the simulated rain event with respect to what is available for the no-fertilizer test series is shown. The no-fertilizer tests indicated no real tread with respect to TN mass lost except it is insignificant. This is due to the fact that no fertilizer was added to the system making the dominant form of TN mass loss sod uptake.

Figure 4.13 illustrates this same comparison but with the 16-0-8 (SR) fertilizer applied at 1lb 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 4.14 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.

In Figure 4.15, the percent of TN lost in the simulated rain event are shown and compared to the total available at the time of the test for the 16-0-8 (SR) fertilizer applied at 0.5lb of N per 1000 $ft^2$. The TN lost is insignificant and that there are no obvious trends. It should be noted that the 4 to 1 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.

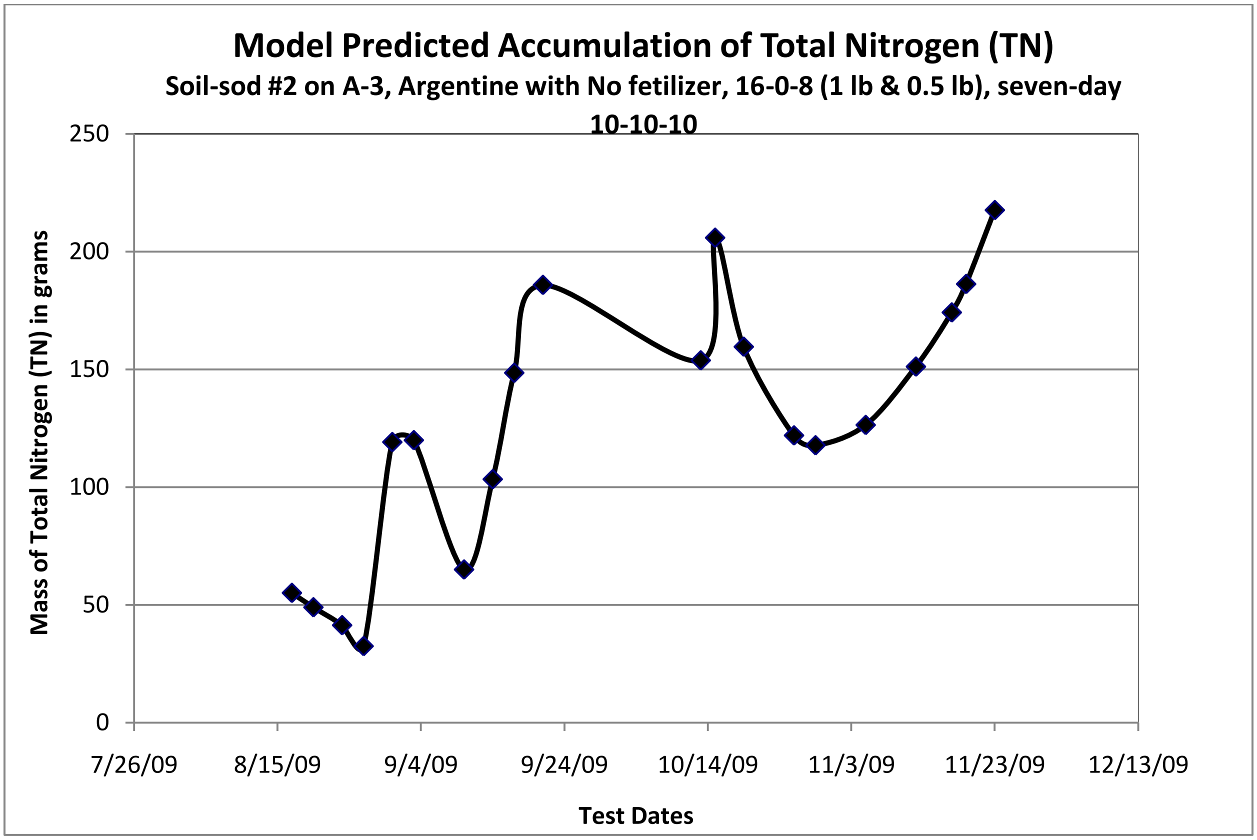


**Figure 4.10: Model Predicted Accumulation of Total Nitrogen (TN) on Soil-Sod Combination #2 (A-3 Soil, Argentine Bahia Sod with No Fertilizer, 16-0-8 (SR) Fertilizer at 1lb and 0.5lb, Seven-Day 10-10-10 Fertilizer)**

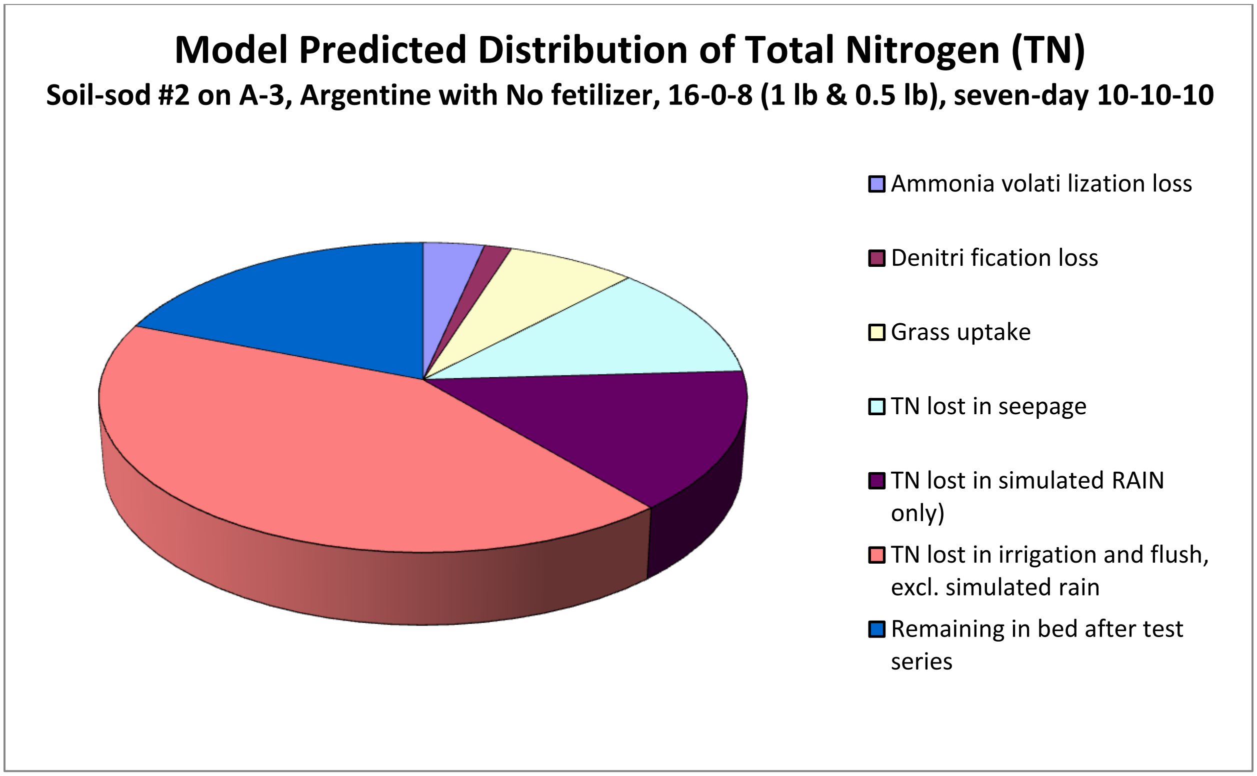


**Figure 4.11: Model Predicted Distribution of Total Nitrogen (TN) on Soil-Sod Combination #2 (A-3 Soil, Argentine Bahia Sod with No Fertilizer, 16-0-8 (SR) Fertilizer applied at 1lb and 0.5lb, Seven-Day 10-10-10 Fertilizer)**

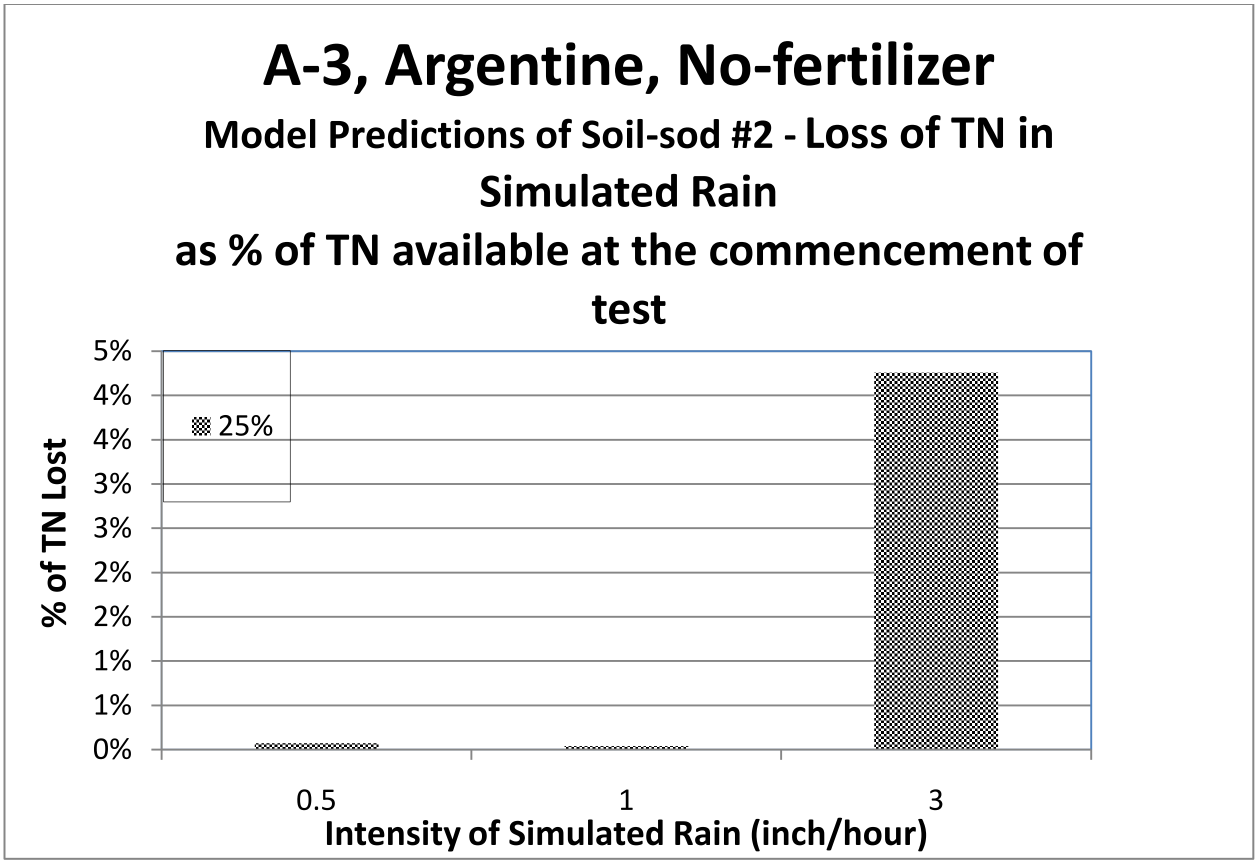


**Figure 4.12: A-3 Soil, Argentine Bahia Sod, No Fertilizer Model Predictions of Soil-Sod Combination #2 - Loss of TN in Simulated Rain as a % of TN Available at the Commencement of Test**

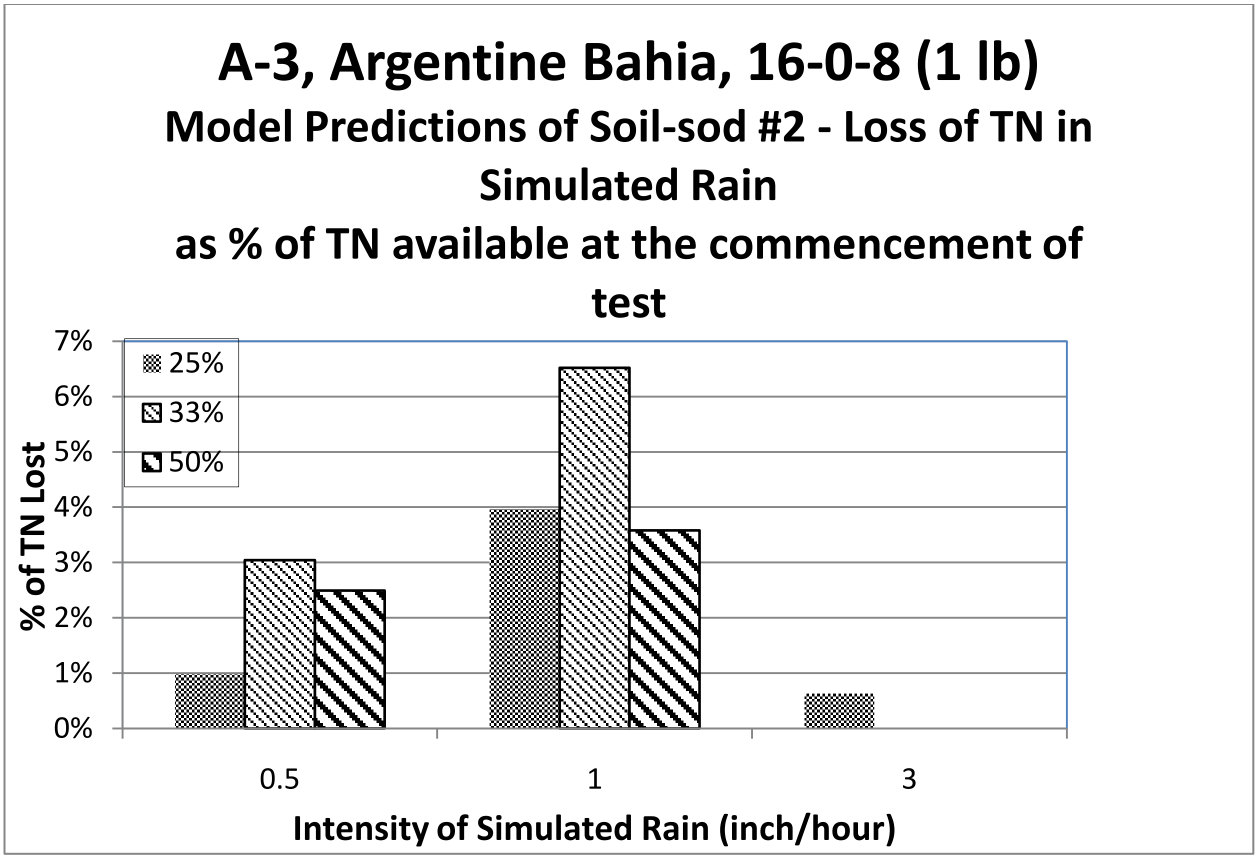


**Figure 4.13: A-3 Soil, Argentine Bahia Sod, 16-0-8 (1lb) Model Predictions of Soil-Sod Combination #2 - Loss of TN in Simulated Rain as a % of TN Available at the Commencement of Test**

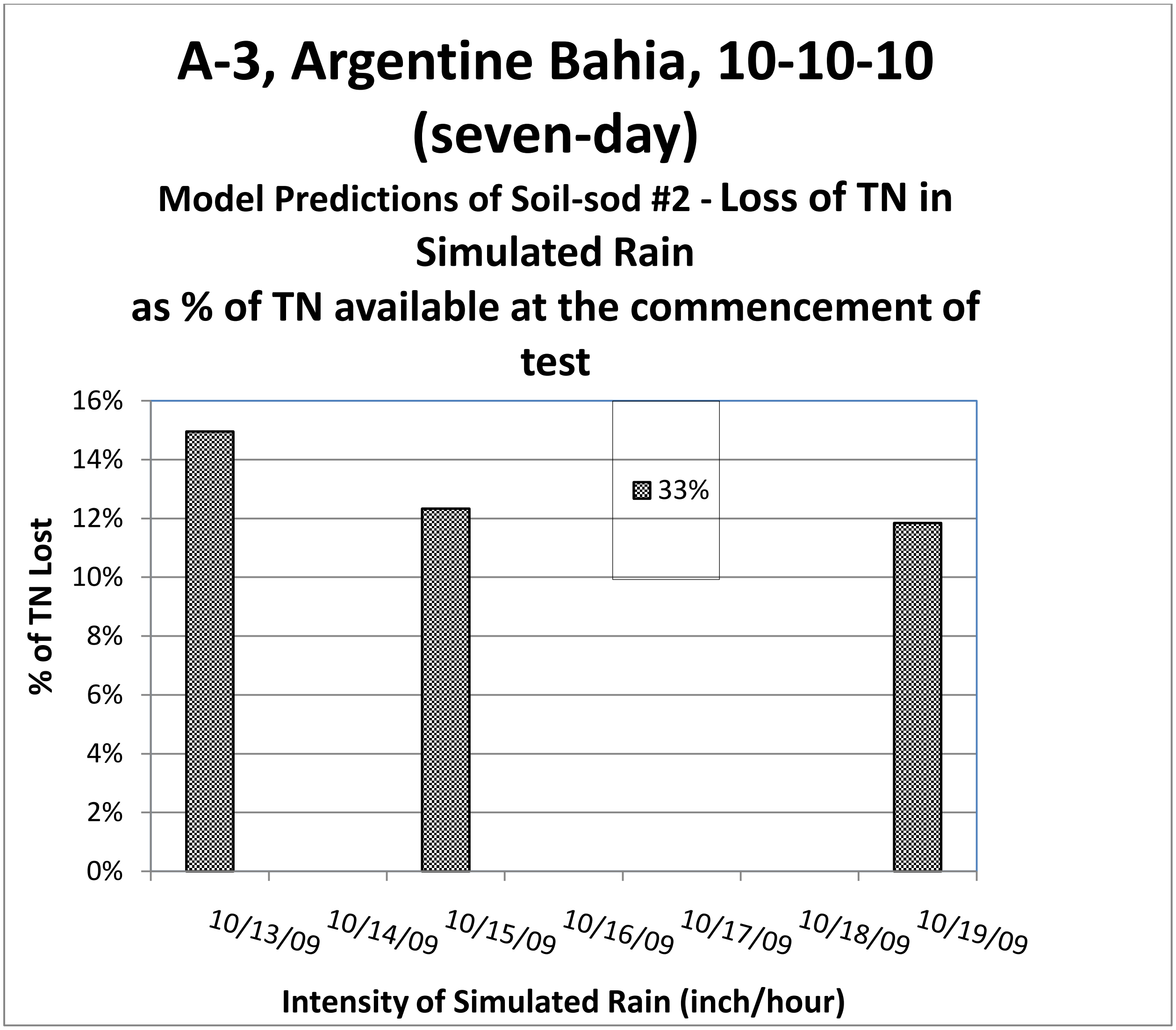


**Figure 4.14: A-3 Soil, Argentine Bahia Sod, 10-10-10 (Seven-Day) Model Predictions of Soil-Sod Combination #2 - Loss of TN in Simulated Rain as a % of TN Available at the Commencement of Test**

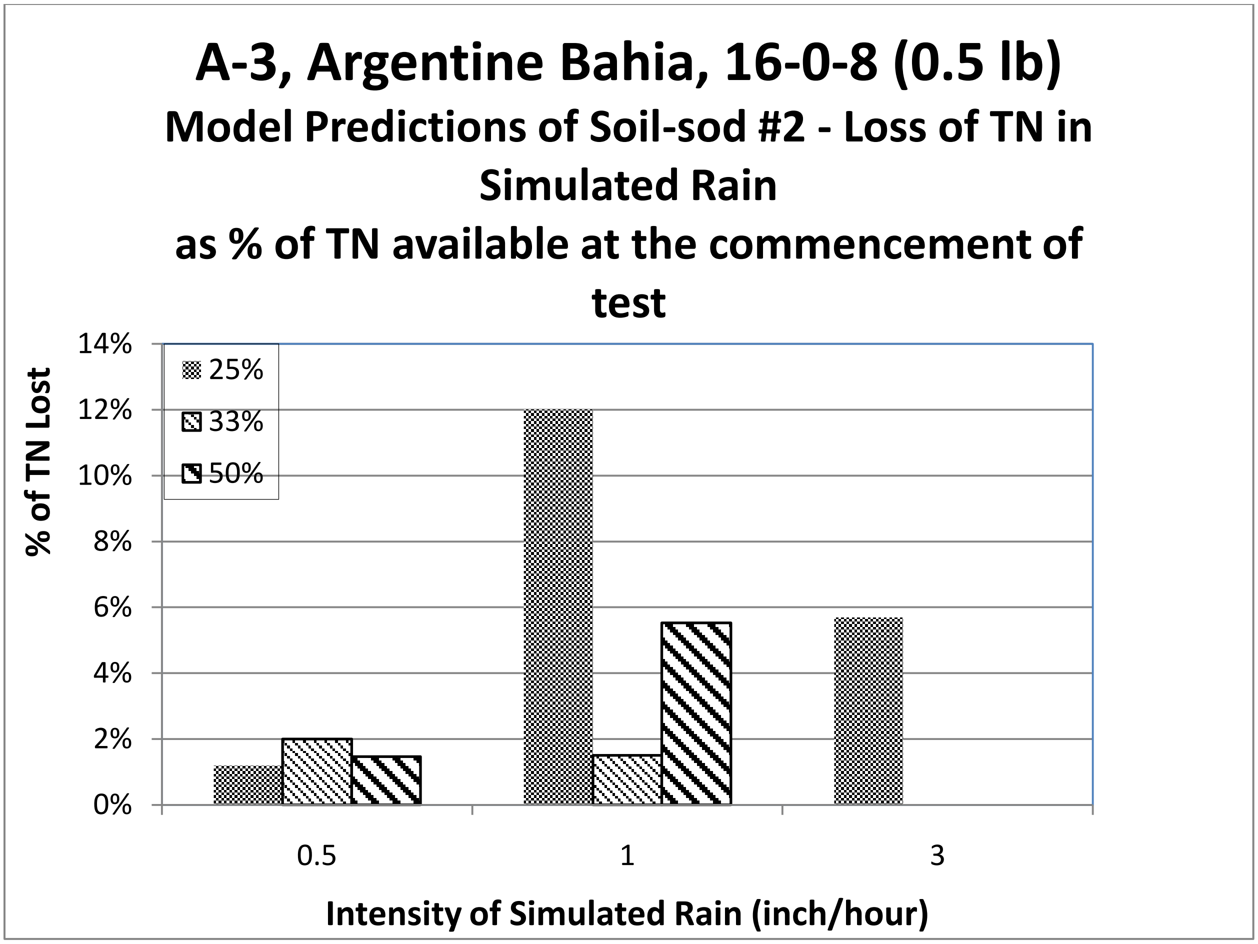


**Figure 4.15: A-3 Soil, Argentine Bahia Sod, 16-0-8 (0.5lb) Model Predictions of Soil-Sod Combination #2 - Loss of TN in Simulated Rain as a % of TN Available at the Commencement of Test**

## 4.5 AASHTO A-2-4 Soil with Pensacola Bahia

### *4.5.1 Soil-sod combination 3 for no-fertilizer and 10-10-10 (single-day and seven-day)*

The 16 tests that were conducted on the soil-sod combination 3 are reproduced from Table 3.2 and are listed in Table 4.4. The moisture balance of this combination was analyzed as per models described before and is presented in Appendix C as Table 11.1. The mass balance of total nitrogen (TN) and total phosphorus (TP) is presented in Appendix C as Table 11.2 and 11.3, respectively.

**Table 4.4: Chronological Sequence of Tests on Soil-Sod Combination 3**

| Test # | Soil | Bahia Sod | Fertilizer | Slope | inch/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 4.16 shows the accumulation of TN in the test bed. It can be seen from this 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 11.2 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.

The distribution of TN mass pathways in the system is shown in Figure 4.17. 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.

In Figure 4.18, 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 4.19 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 2 to 1 slope at 1 in/hr (suspiciously low). There were no observable trends with this data, however.

In Figure 4.20, 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.

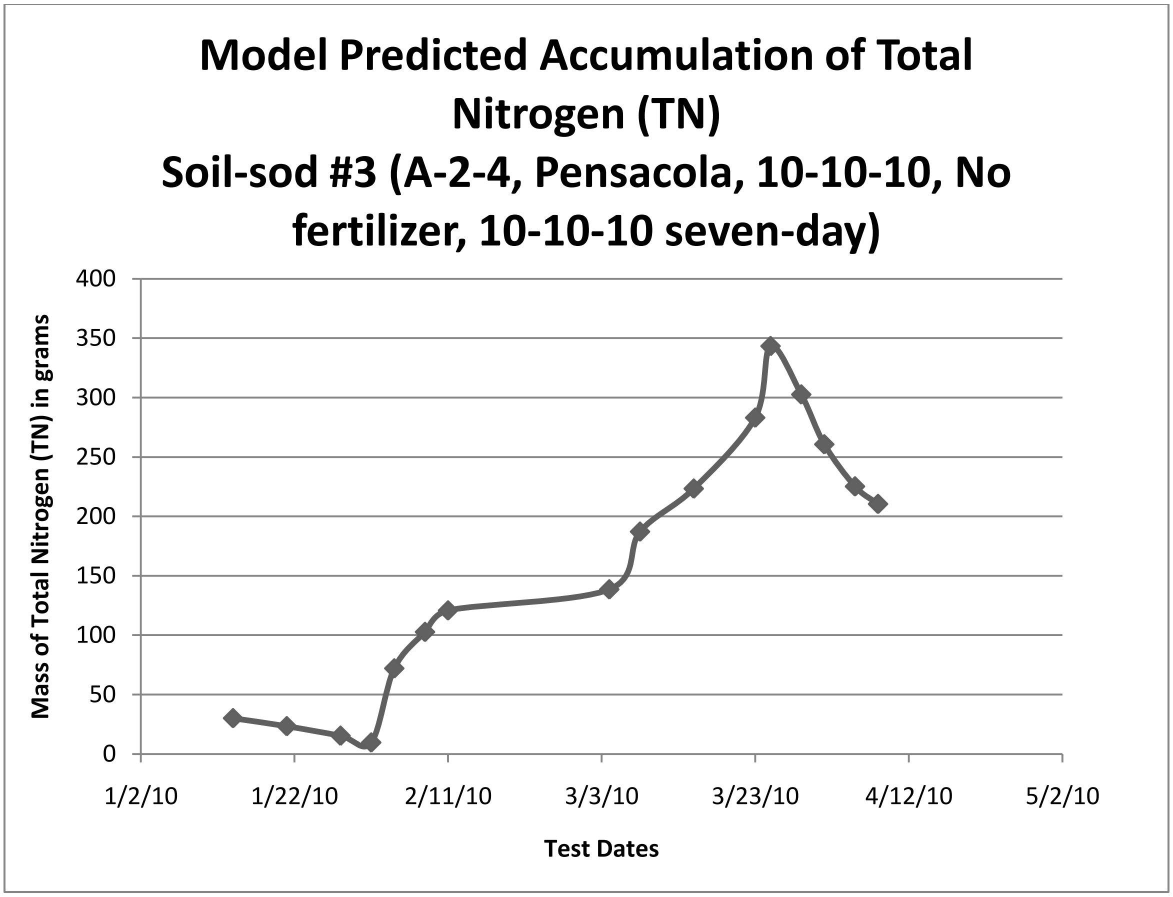


**Figure 4.16: Model Predicted Accumulation of Total Nitrogen (TN) for Soil-Sod Combination #3 (A-2-4 Soil, Pensacola Bahia Sod, 10-10-10 Fertilizer, No-Fertilizer, 10-10-10 Fertilizer Seven-Day Test)**

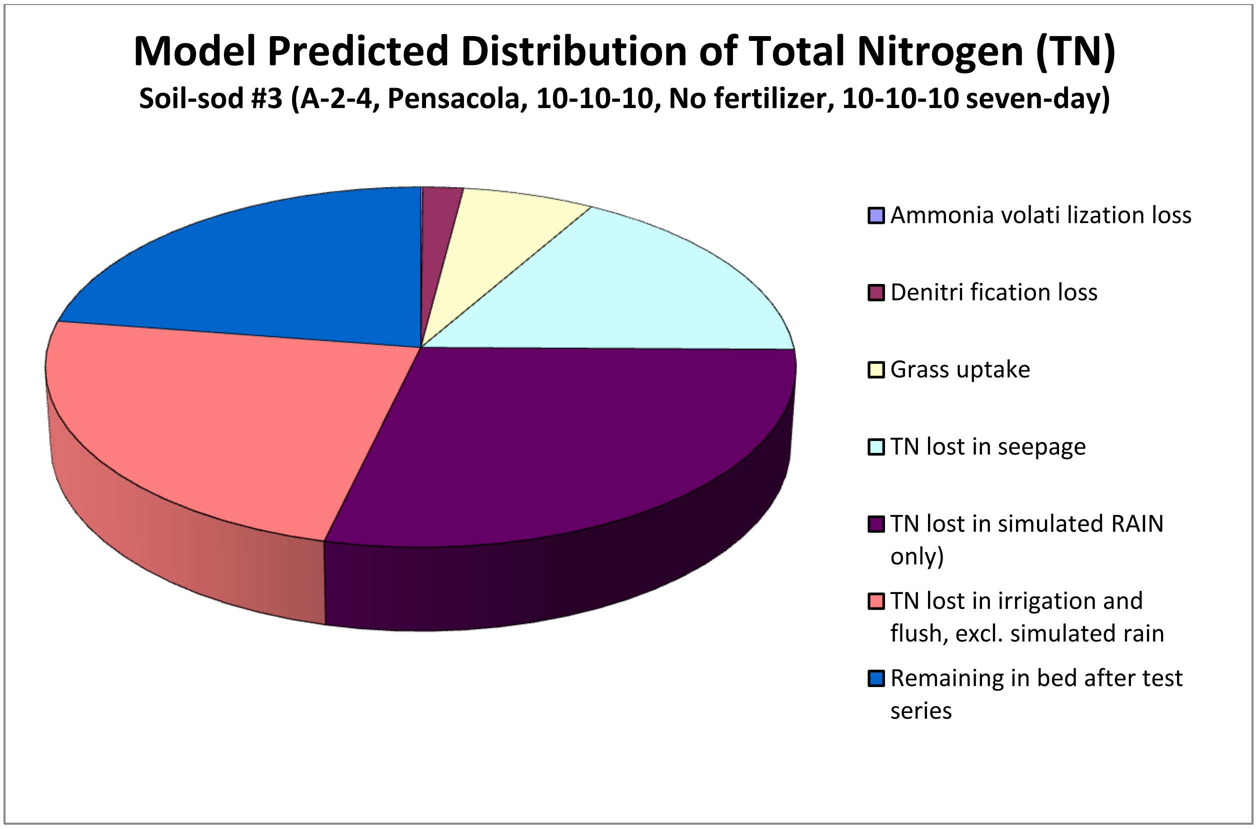


**Figure 4.17: Model Predicted Distribution of Total Nitrogen (TN) for Soil-Sod Combination #3 (A-2-4 Soil, Pensacola Bahia Sod, 10-10-10 Fertilizer, No-Fertilizer, 10-10-10 Fertilizer Seven-Day Test)**

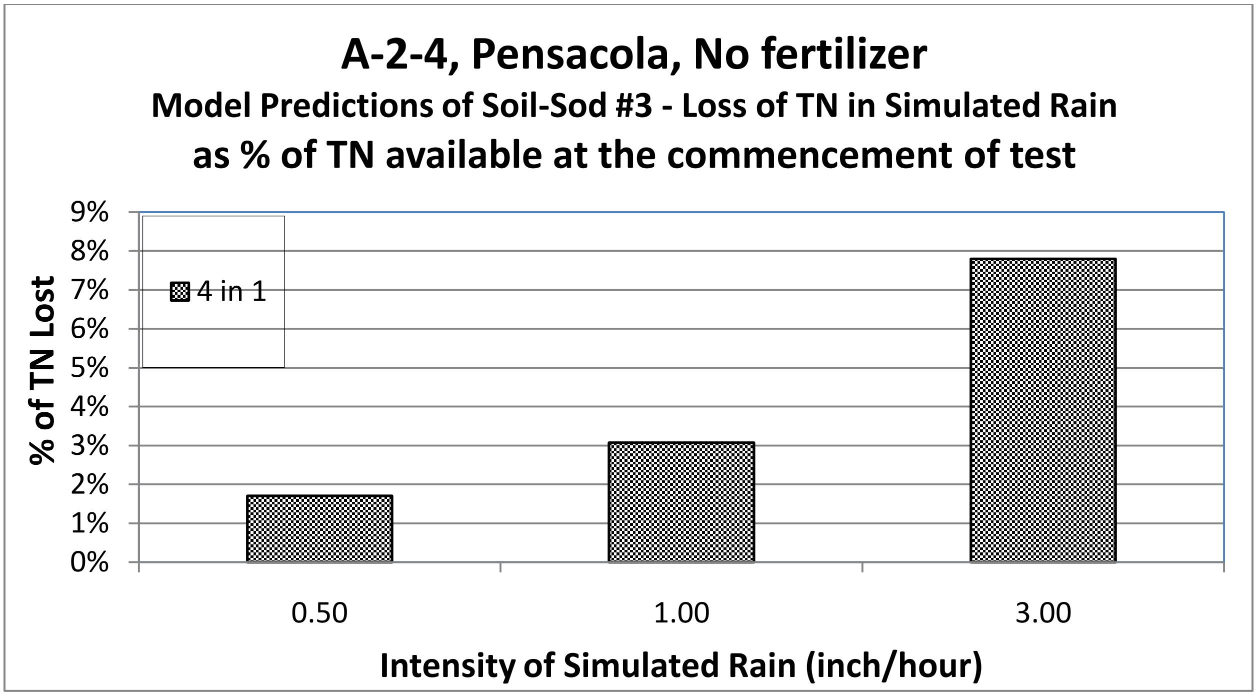


**Figure 4.18: A-2-4 Soil, Pensacola Bahia Sod, No-Fertilizer Model Predictions of Soil-Sod Combination #3 - Loss of TN in Simulated Rain as a % of TN Available at the Commencement of Test**

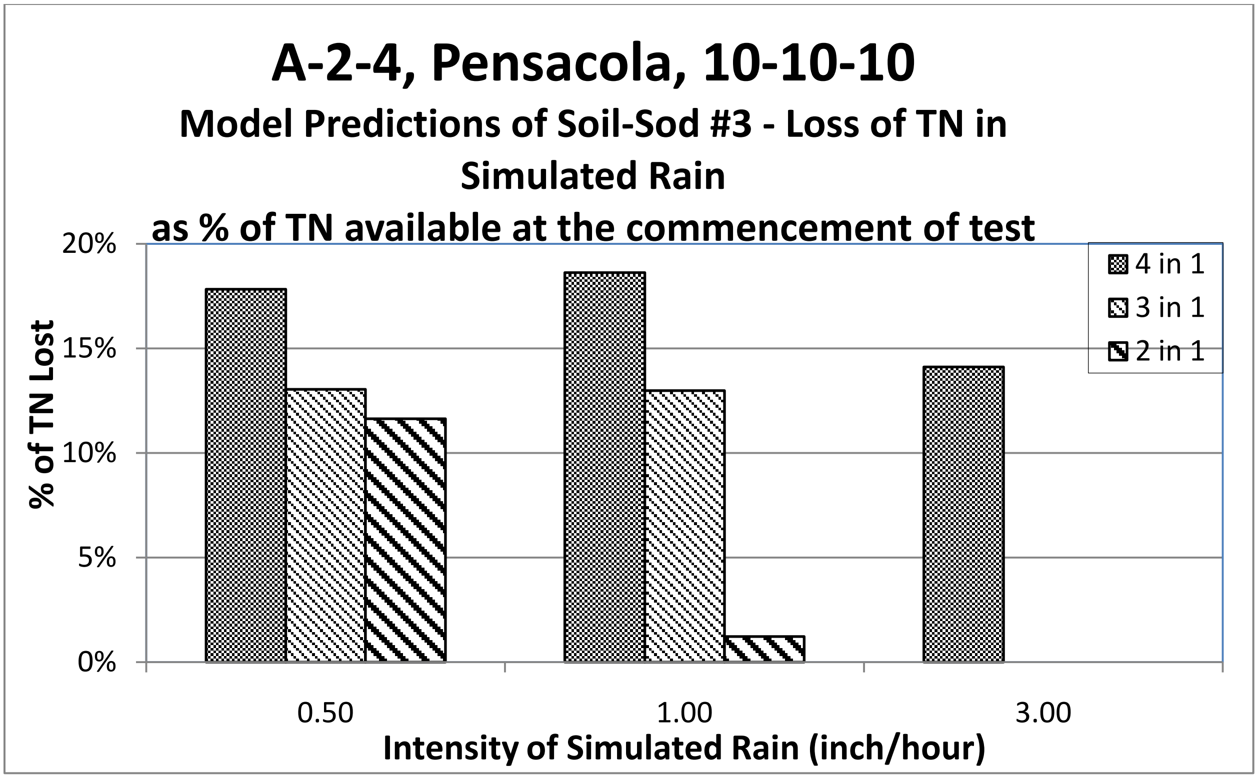


**Figure 4.19: A-2-4 Soil, Pensacola Bahia Sod, 10-10-10 Fertilizer Model Predictions of Soil-Sod Combination #3 - Loss of TN in Simulated Rain as a % of TN Available at the Commencement of Test**

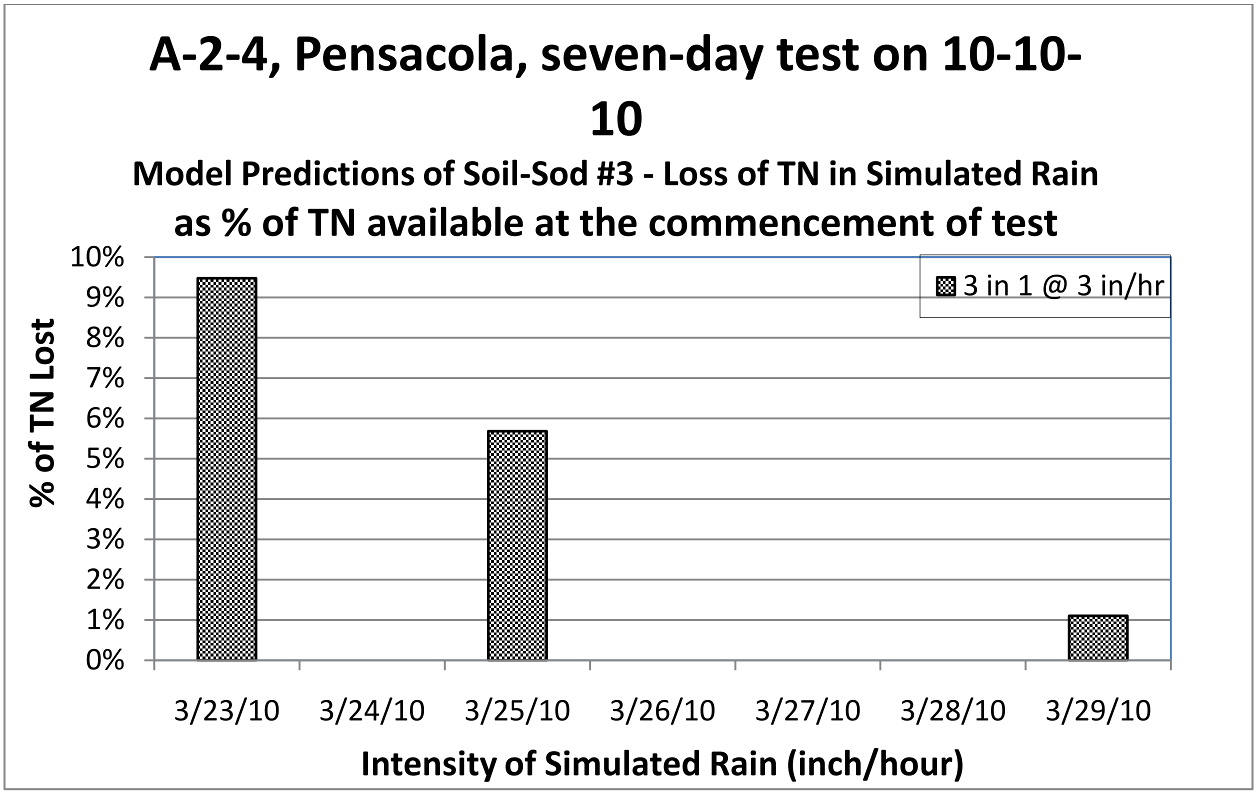


**Figure 4.20: A-2-4 Soil, Pensacola Bahia Sod, Seven-Day Test on 10-10-10 Model Predictions of Soil-Sod Combination #3 - Loss of TN in Simulated Rain as a % of TN Available at the Commencement of Test**

In Figure 4.21 the accumulation of TP in the system over time is displayed. From this 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 11.3 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 4.22 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 4.23 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 4.24 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.

Lastly, Figure 4.25 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.

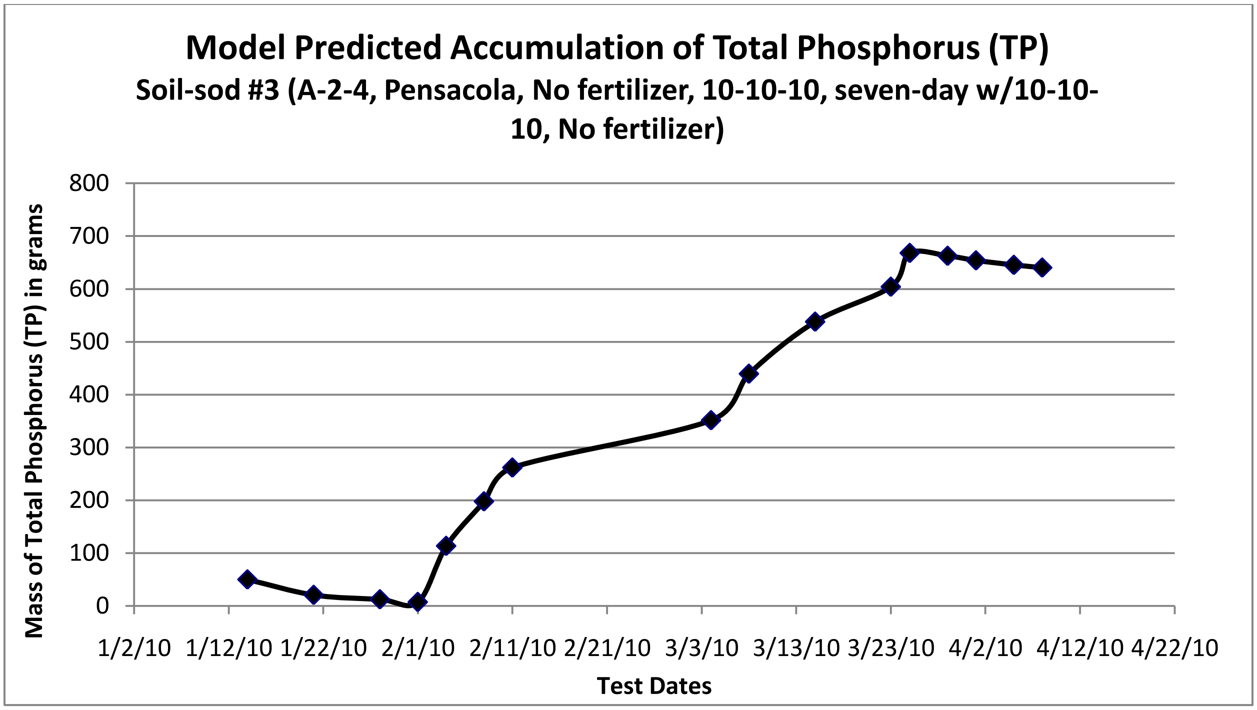


**Figure 4.21: Model Predicted Accumulation of Total Phosphorus (TP) for Soil-Sod Combination #3 (A-2-4 Soil, Pensacola Bahia Sod, No-Fertilizer, 10-10-10 Fertilizer, Seven-Day with 10-10-10 Fertilizer, No Fertilizer)**

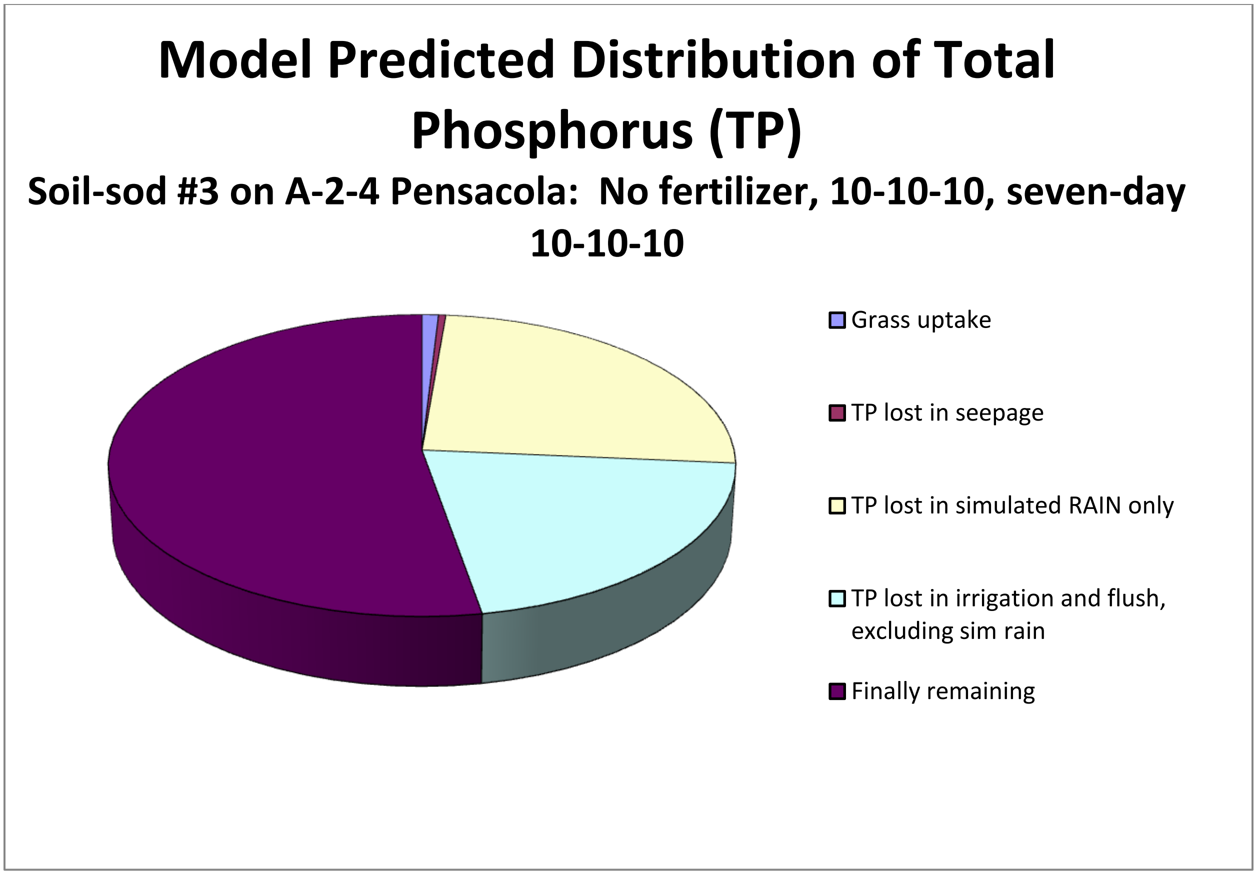


**Figure 4.22: Model Predicted Distribution of Total Phosphorus (TP) in Soil-Sod Combination #3 on A-2-4 Pensacola Bahia Sod: No-Fertilizer, 10-10-10 Fertilizer, Seven-Day Test with 10-10-10 Fertilizer, No-Fertilizer**

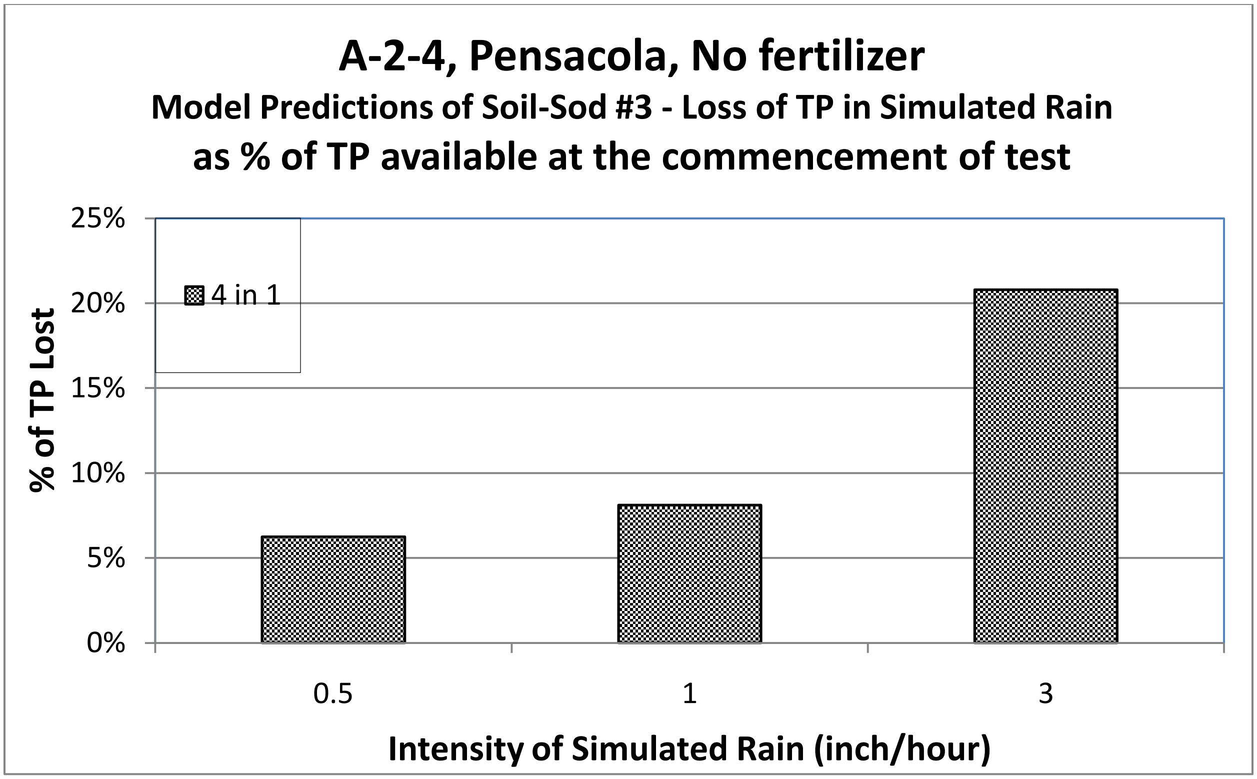


**Figure 4.23: A-2-4 Soil, Pensacola Bahia Sod, No-Fertilizer Model Predictions of Soil-Sod Combination #3 - Loss of TP in Simulated Rain as a % of TP Available at the Commencement of Test**

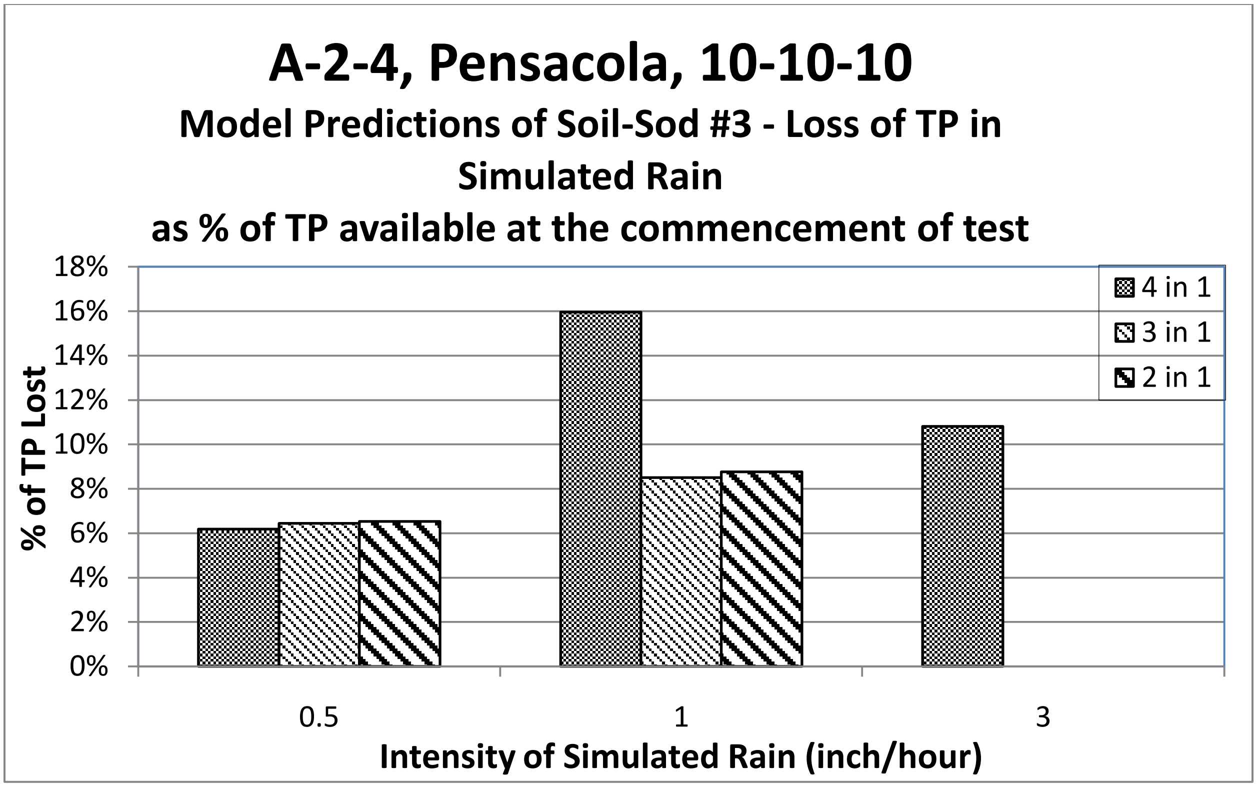


**Figure 4.24: A-2-4 Soil, Pensacola Bahia Sod, 10-10-10 Fertilizer Model Predictions of Soil-Sod Combination #3 - Loss of TP in Simulated Rain as a % of TP Available at the Commencement of Test**

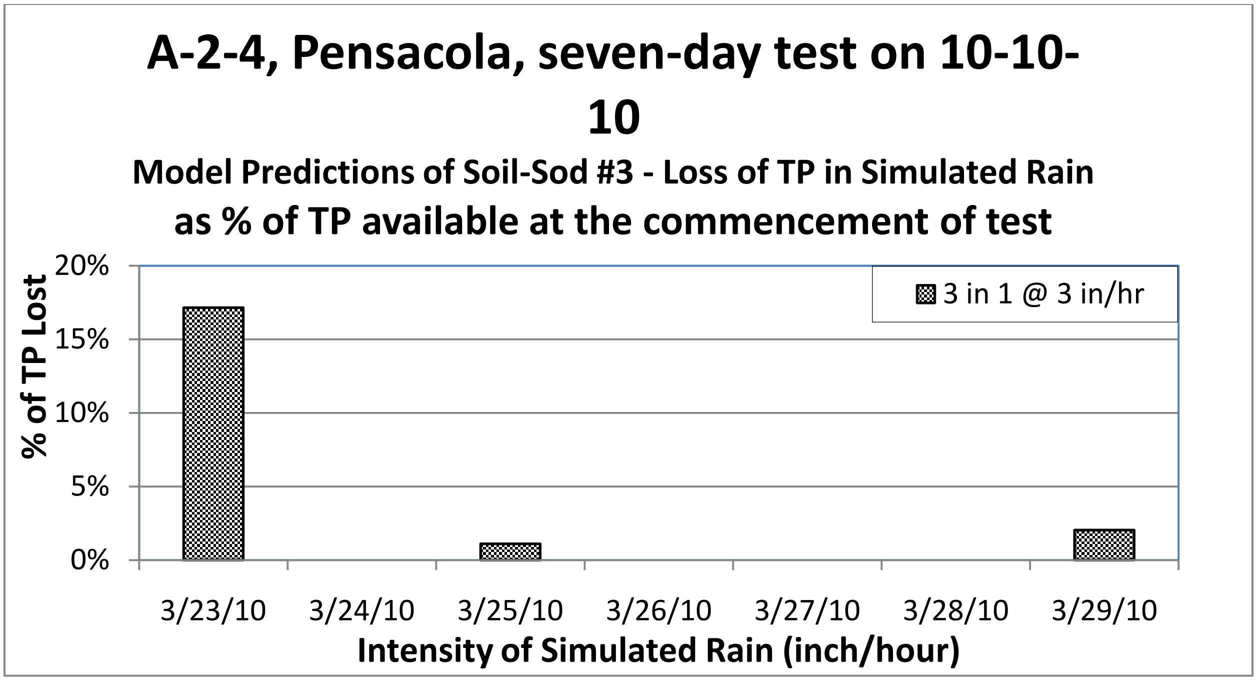


**Figure 4.25: A-2-4 Soil, Pensacola Bahia Sod, Seven-Day Test on 10-10-10 Fertilizer Model Predictions of Soil-Sod Combination #3 - Loss of TP in Simulated Rain as a % of TP Available at the Commencement of Test**

### *4.5.2 Soil-sod combination 4 for 16-0-8 (SR) fertilizer*

The seven tests that were conducted on the soil-sod combination 4 are reproduced from Table 3.2 and are listed in Table 4.5. The moisture balance of this combination was analyzed as per models described before and using a spreadsheet and presented in Appendix D as Table 12.1. The mass balance of total nitrogen (TN) is also presented in Appendix D as Table 12.2.

Figure 4.26 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. In Figure 4.27, the distribution of TN pathways in this system is shown. 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.

**Table 4.5: Chronological Sequence of Tests on Soil-Sod Combination 4**

| Test # | Soil | Bahia Sod | Fertilizer | Slope | inch/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 |

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 4.28 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 2 to 1 slope, the TN mass loss was significant and tended to increase with rainfall intensity. The tests run on the 2 to 1 slope seem too low to be reasonable.

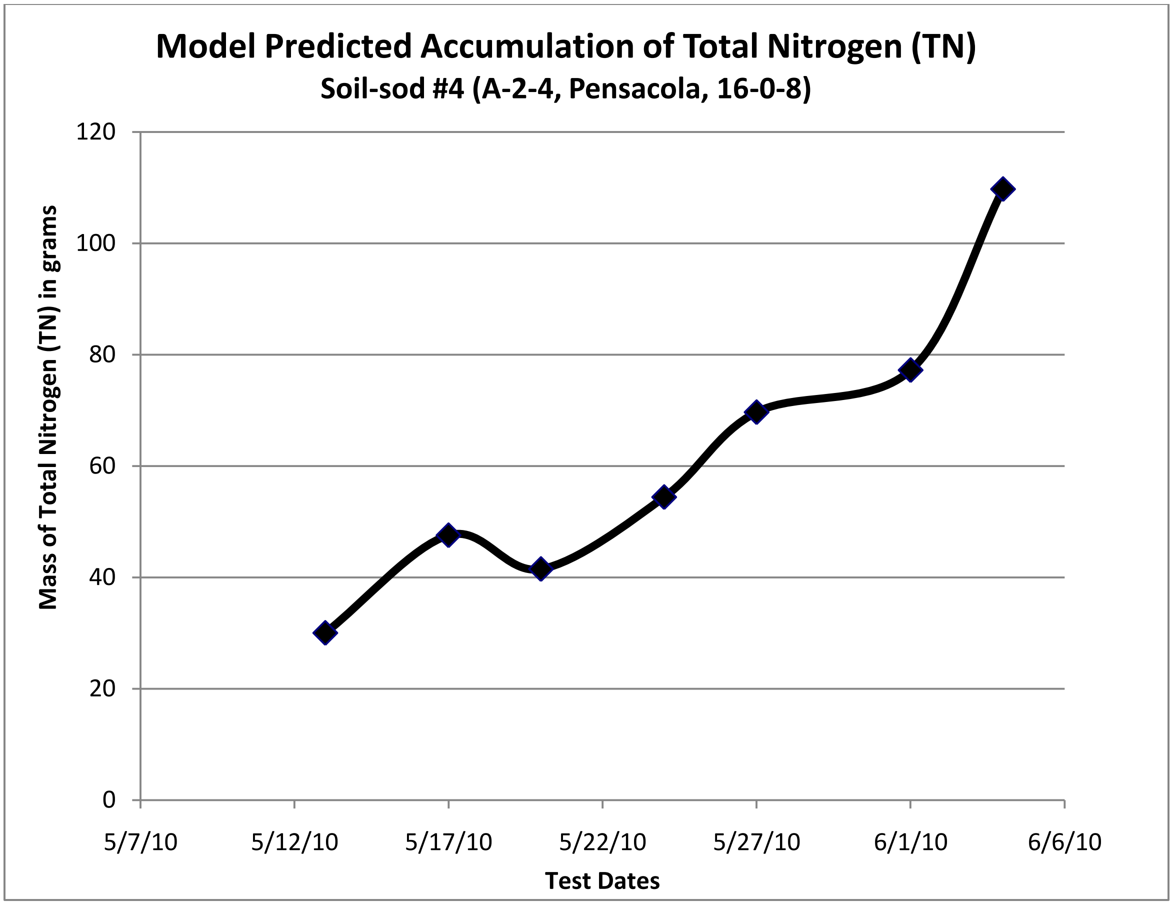


**Figure 4.26: Model Predicted Accumulation of Total Nitrogen (TN) for Soil-Sod Combination #4 (A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 (SR) Fertilizer**

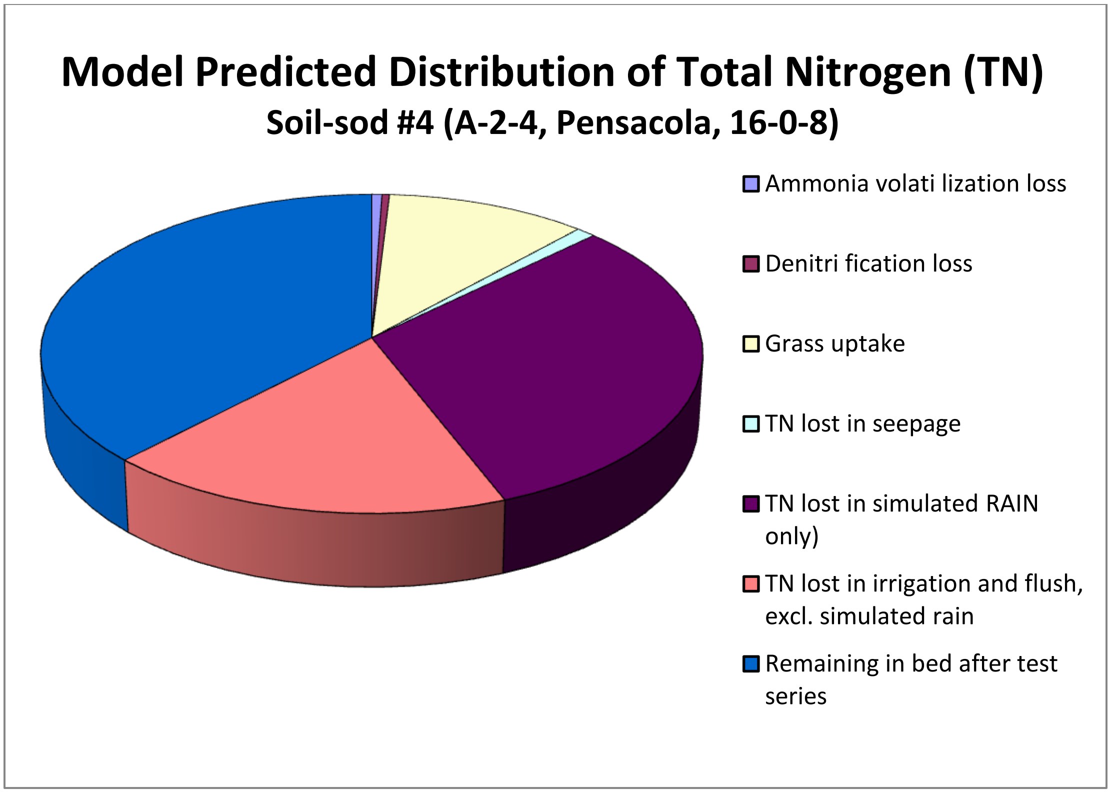


**Figure 4.27: Model Predicted Distribution of Total Nitrogen (TN) Soil-Sod Combination #4 (A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 (SR) Fertilizer**

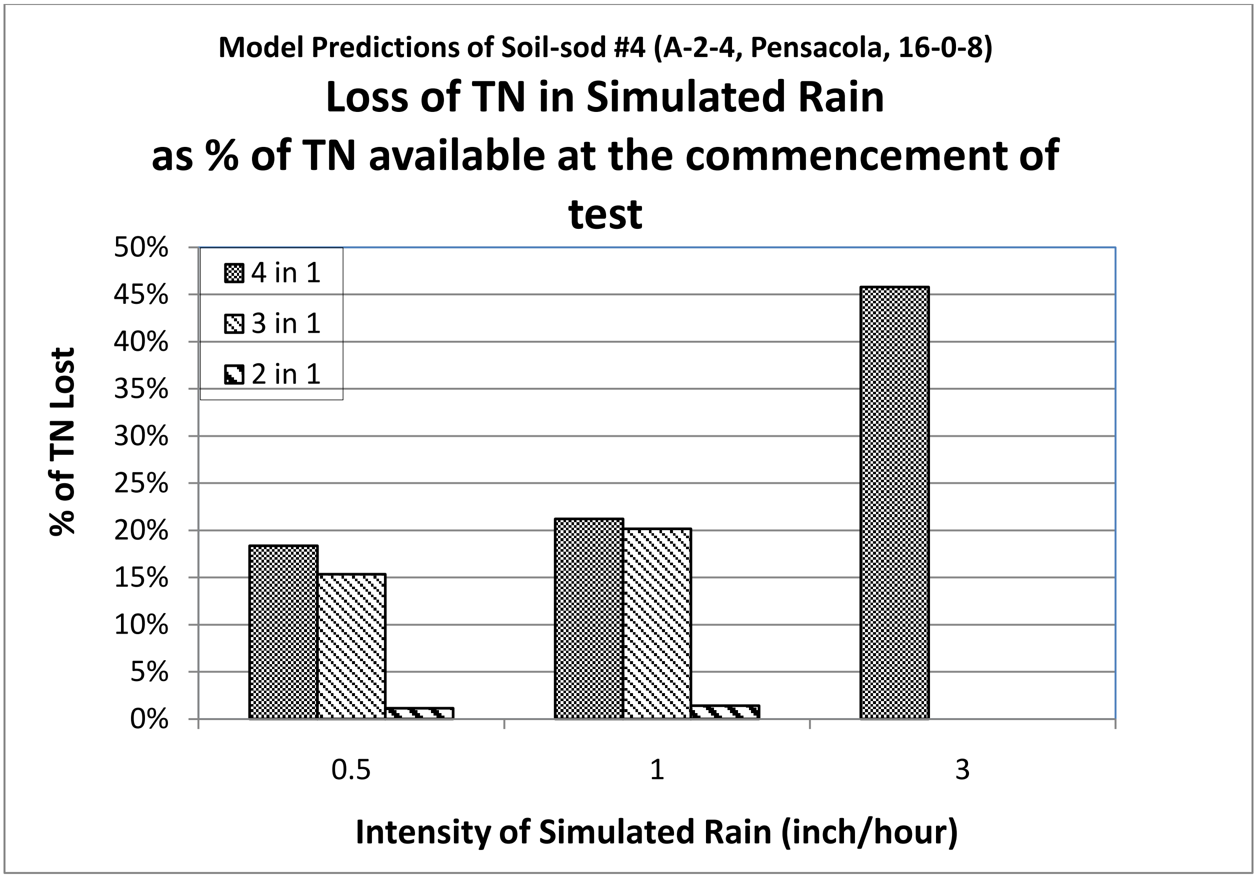


**Figure 4.28: Model Predictions of Soil-Sod Combination #4 (A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 (SR) Fertilizer) Loss of TN in Simulated Rain as a % of TN Available at the Commencement of Test**

# 5 SINGLE-DAY TESTS COMPARED TO SEVEN-DAY TESTS, 10-10-10 FERTILIZER

As described in Chapter 3, two seven-day tests were also conducted using the 10-10-10 fertilizer at 3 inch/hour rainfall intensity, one each on A-3 soil and A-2-4 soil. These tests were in addition to the two tests conducted as single-day tests with the same fertilizer and soils at 3 inch/hour 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 single-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 single-day and seven-day tests; the differences being only in the number and timing of rainfall application. The comparisons between these tests are analyzed and presented in this section.

## 5.1 AASHTO A-3 Soil with Argentine Bahia

The comparison of TN and TP losses for the single day test at the 3 inch/hour rainfall intensity (on 4 to 1 slope) to the seven-day test at the same rainfall intensity (on 3 to 1 slope) is shown in Table 5.1. From this table, it is seen that while the losses of TN and TP for the seven-day tests are lower than in the single-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. There were several factors that might have influenced these results, such as the seven-day test was preceded by several 16-0-8 (SR) fertilizer tests, while the single-day test was 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 single-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 5.1: Comparison of 10-10-10 Single-Day and Seven-Day Tests, TN and TP Losses (in grams)**

| | Single-Day Test | Seven-Day Test | | |
|---|---|---|---|---|
| | 4-1 Slope, 10-10-10 (6-10-2009) | 3-1 Slope, 10-10-10, Day One (10-13-2009) | 3-1 Slope, 10-10-10, Day Three (10-15-2009) | 3-1 Slope, 10-10-10, Day Seven (10-20-2009) |
| Rainfall intensity inch/hour | 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 3.2, the single-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 single-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 single-day tests.

## 5.2 AASHTO A-2-4 Soil with Pensacola Bahia

The comparison of the 10-10-10 fertilizer single-day test to the seven-day test is shown in Table 5.2. Once again, while the losses of TN and TP for the seven-day test were higher than the single-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 5.2: Comparison of 10-10-10 Single-Day Test with Seven-Day Test, TN and TP Losses (in grams)**

| | Singel-Day Test | Seven-Day Test | | |
|---|---|---|---|---|
| | 4-1 Slope, 10-10-10 (2-4-2010) | 3-1 Slope, 10-10-10, Day One (3-23-2010) | 3-1 Slope, 10-10-10, Day Three (3-25-2010) | 3-1 Slope, 10-10-10, Day Seven (3-29-2010) |
| Rainfall intensity inch/hour | 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 3.2, the single-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 single-day test.  Also, 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 single-day tests.

# 6 COMPARISON OF 10-10-10 AND 16-0-8 (SR) FERTILIZERS

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 1000ft$^2$ (former practice), to the current practice of using 16-0-8 (slow-release) fertilizer @ either 1 lb or 0.5 lb of N per 1000ft$^2$. 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 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. Detailed comparisons are presented below.

## 6.1 A-3 Soil and Argentine Bahia

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 Figures 6.1 and 6.2). 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.

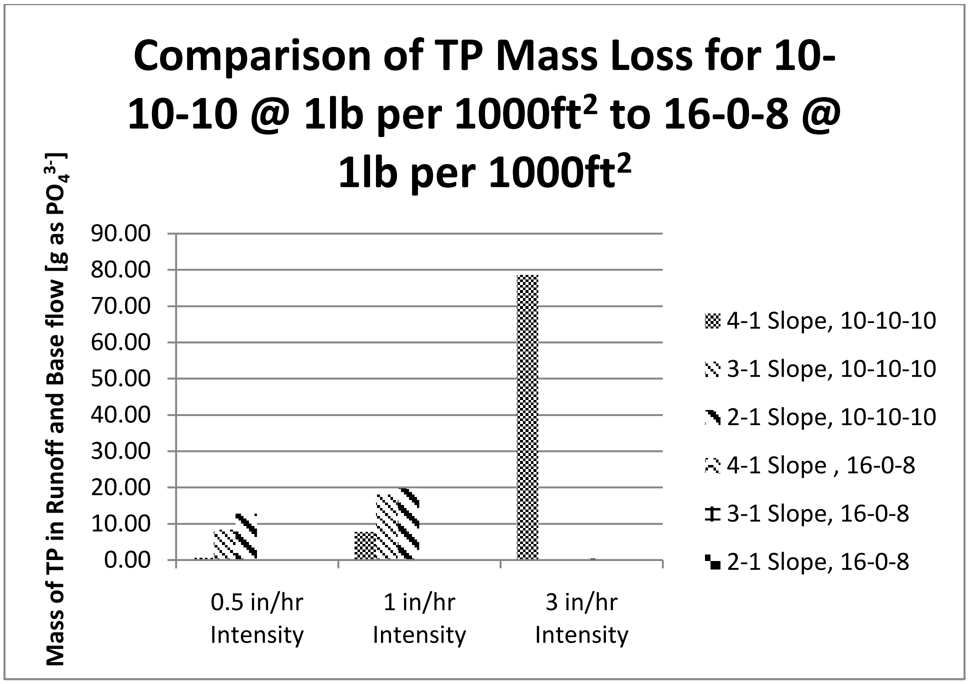


**Figure 6.1: Comparison of TP Loss for 10-10-10 and 16-0-8 (SR) @ 1 lb of N/1000 ft$^2$**

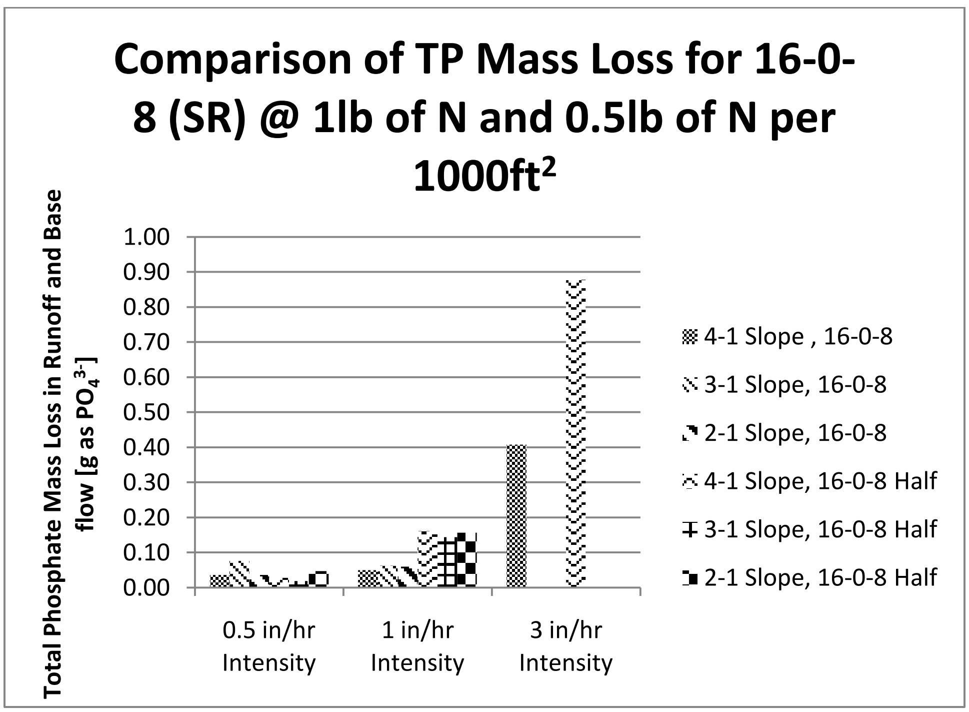


**Figure 6.2: Comparison of TP Losses for 16-0-8 (SR) at (1 lb and 0.5 lb of N per 1000 ft$^2$)**

Comparing the TN mass loss from the 10-10-10 fertilizer at an application rate of 1 lb of N per 1000 ft$^2$ to the 16-0-8 (SR) fertilizer at an application rate of 1 lb of N per 1000 ft$^2$ on the A-3 soil (Figure 6.3), 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, 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).

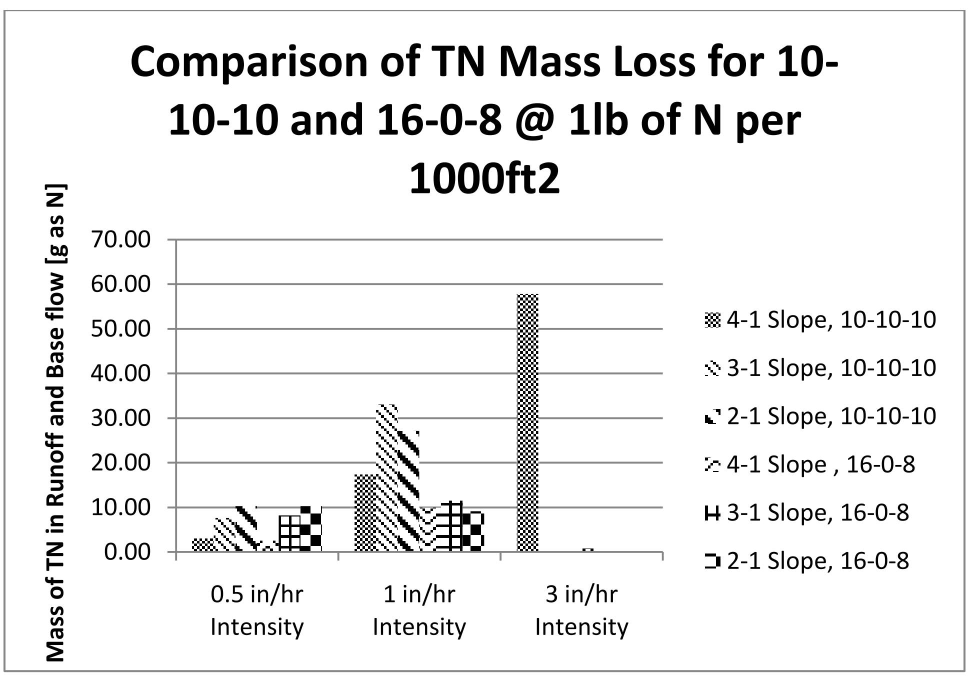


**Figure 6.3: Comparison of TN Loss for 10-10-10 and 16-0-8 Fertilizer @ 1lb of N per 1000 ft$^2$**

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 3.6 in Chapter 3).  The low value, 8.91% was from the 4-1 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 3 to 1 slope.  This difference of 27.5% is significant and likely due to starting soil moisture content as well as other environmental conditions.  The 1 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 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 3.12 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 3 to 1 slope which was only slightly higher, about 1%, than the 2 to 1 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 6.1). 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 6.1: Comparison of 10-10-10 and 16-0-8 (SR) Fertilizer TN Concentrations in Runoff and Base Flow**

| | 10-10-10 | | | | | | | 16-0-8 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4-1 Slope | | | 3-1 Slope | | 2-1 Slope | | 4-1 Slope | | | 3-1 Slope | | 2-1 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 being 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 3.8 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 3.14 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 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 6.4). The 1.0 in/hr rainfall intensity showed a similar results but had a few abnormal data points, namely the 4 to 1 slope and the 2 to 1 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 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.

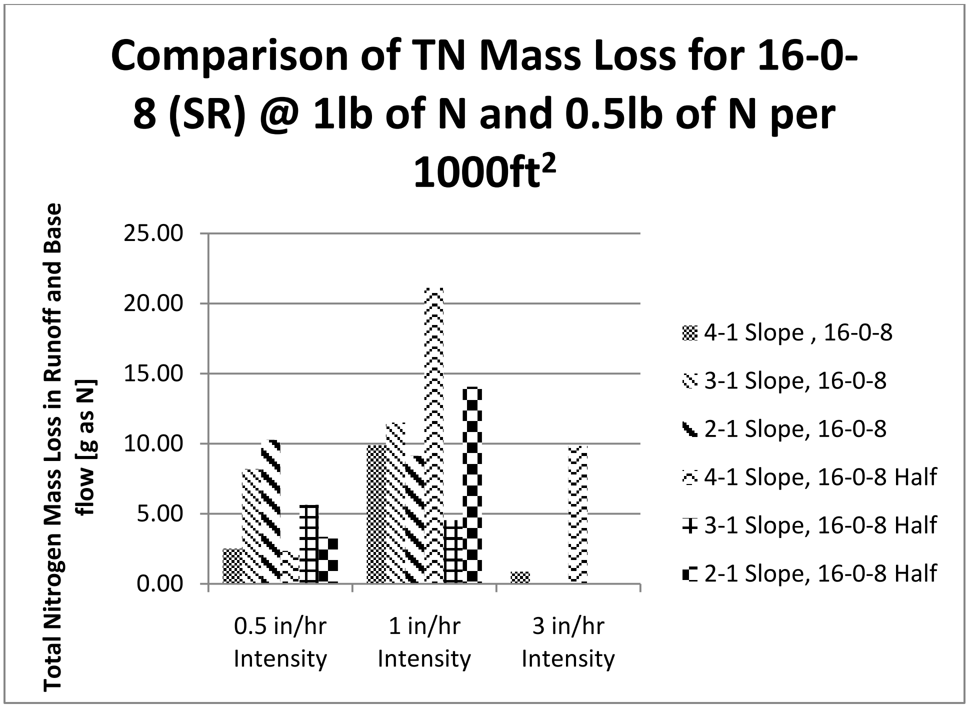


**Figure 6.4: Comparison of TN Mass Loss for 16-0-8 (SR) Fertilizer at Two Application Rates (1lb and 0.5lb of N per 1000 ft$^2$)**

Analyzing the percentage of runoff to total water volume collected, it was observed that no real difference exists (see Tables 3.12 and 3.15 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 Tables 3.14 and 3.17 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 lb of N application and the TN concentrations were slightly higher in runoff than base flow, as seen in Table 6.2.

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 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 4.  More detailed modeling studies are needed for accurate analysis and interpretation.

## Table 6.2: Comparison of 16-0-8 (SR) and Half 16-0-8 (SR) Fertilizer TN Concentrations in Runoff and Base Flow

| | 16-0-8 | | | | | | | Half 16-0-8 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4-1 Slope | | | 3-1 Slope | | 2-1 Slope | | 4-1 Slope | | | 3-1 Slope | | 2-1 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 | | | | |

## 6.2 A-2-4 Soil and Pensacola Bahia

Both the 10-10-10 fertilizer and 16-0-8 (SR) fertilizer, applied at 1 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 6.5). 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.

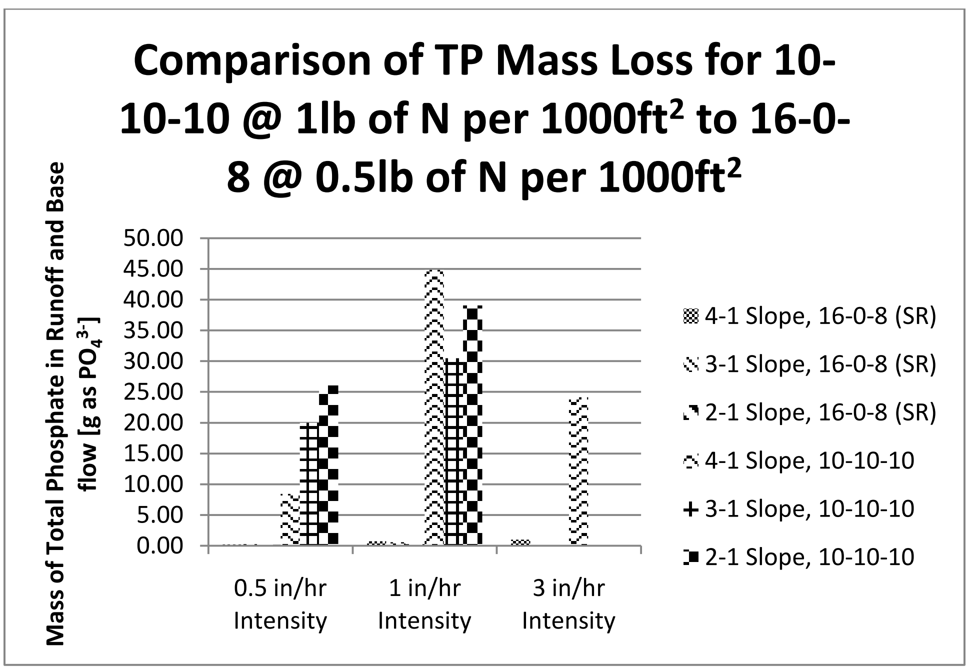


**Figure 6.5: Comparison of TP Losses for 10-10-10 @ 1 lb with 16-0-8 (SR) @ 0.5 lb of N per 1000 ft$^2$**

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 6.6). 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.

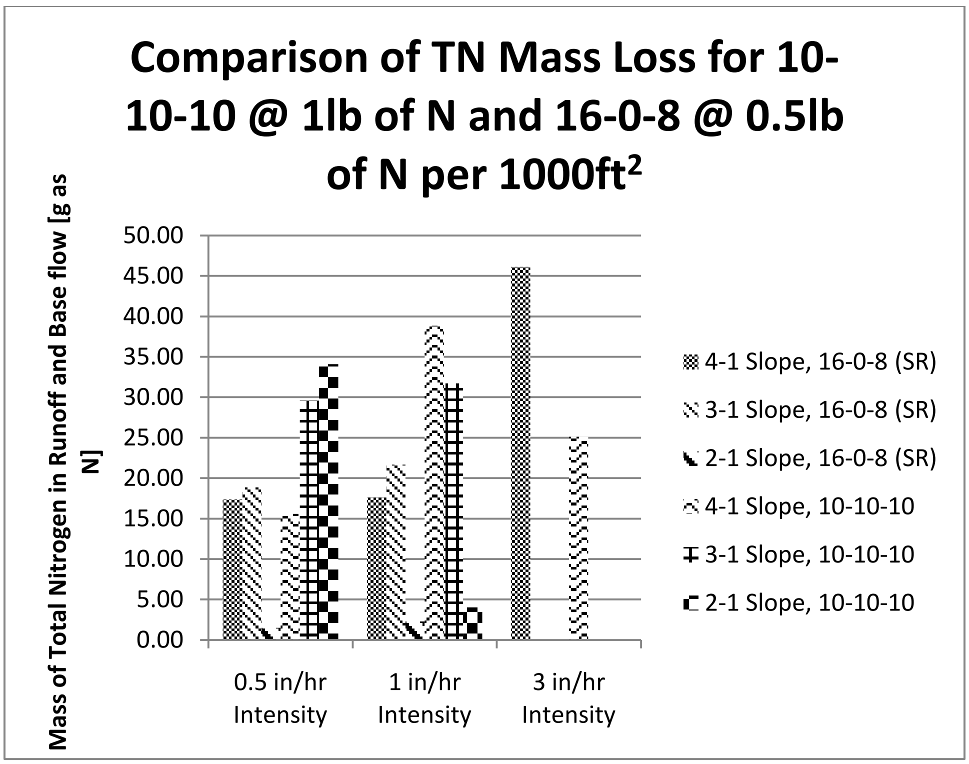


**Figure 6.6: Comparison of TN Mass Loss for 10-10-10 and 16-0-8 Fertilizers at 1lb and 0.5lb of N, Respectively, per 1000 ft$^2$**

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 3.21 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 3.27 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 3.23 in Chapter 3).  The 91.17% loss was from the 2 to 1 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 in/hr at 2 to 1 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 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 6.3.  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 6.3: Comparison of 10-10-10 and Half 16-0-8 (SR) Fertilizer TN Concentrations in Runoff and Base Flow

| | 10-10-10 | | | | | | | Half 16-0-8 (SR) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4-1 Slope | | | 3-1 Slope | | 2-1 Slope | | 4-1 Slope | | | 3-1 Slope | | 2-1 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 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.

## 7.1 No Fertilizer Comparison

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 7.1 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.

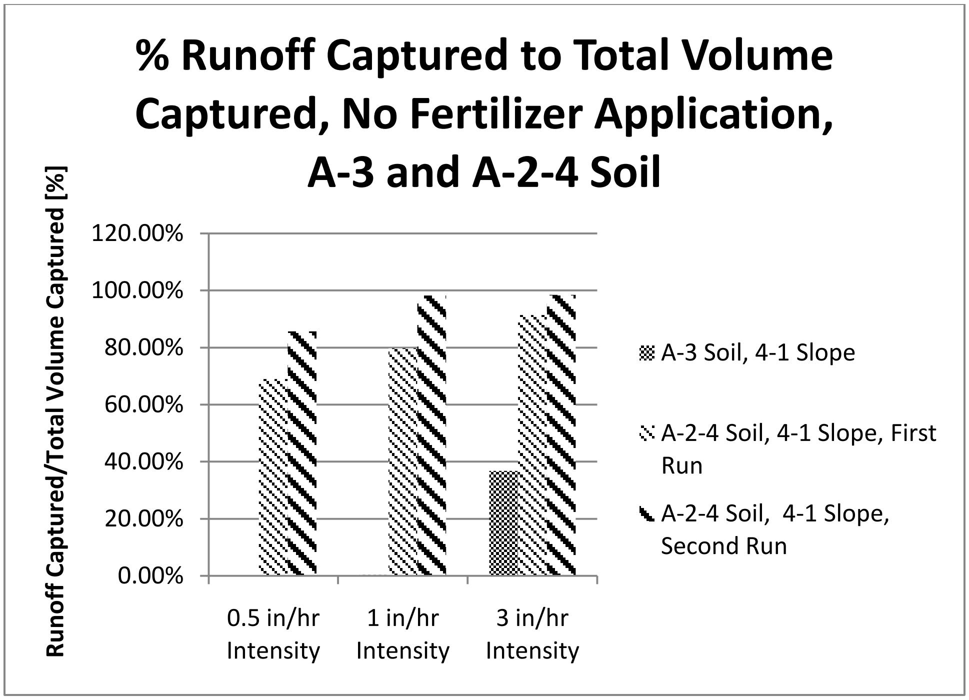


**Figure 7.1: Comparison of the Percent of Runoff Captured to the Total Volume Captured, No Fertilizer Application, A-3 and A-2-4 Soils**

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 7.2. The average alkalinity is presented in Figure 7.3. 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.

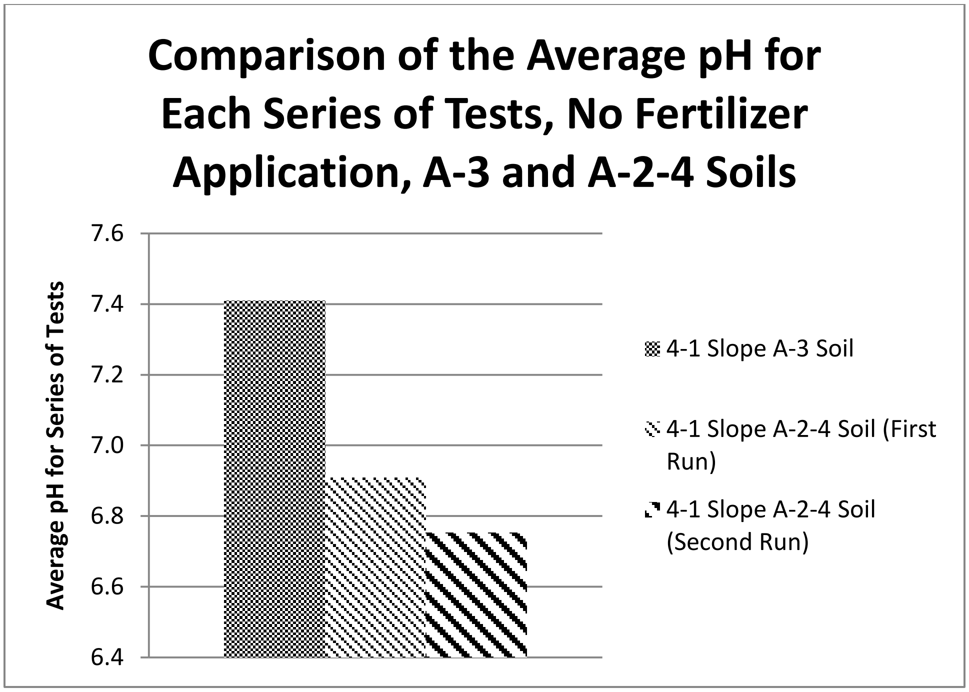


**Figure 7.2: Comparison of the Average pH for Each Series of Tests, No Fertilizer Application, A-3 and A-2-4 Soils**

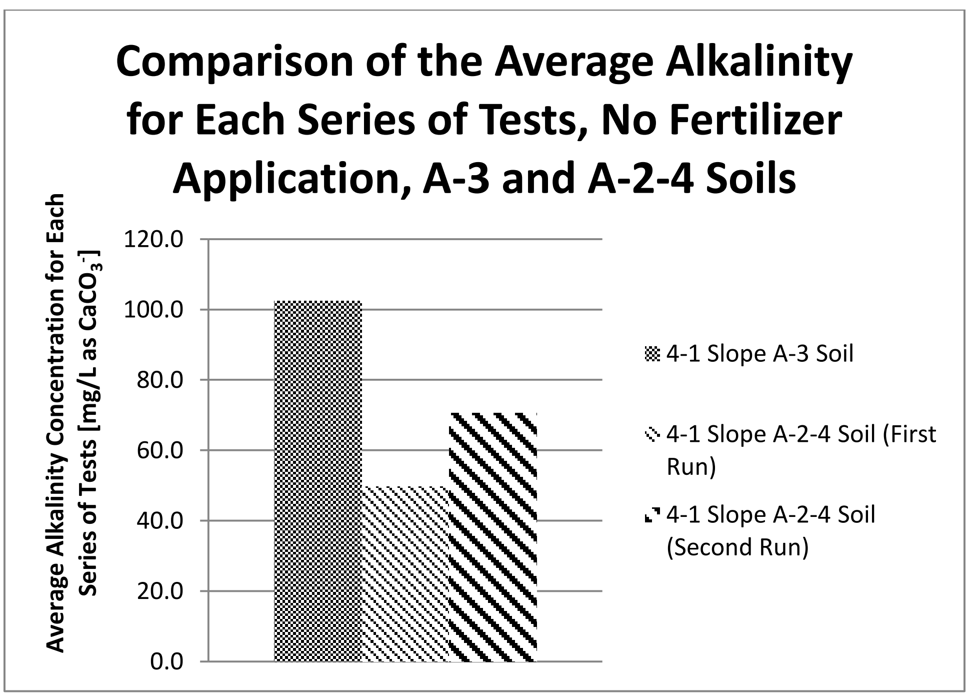


**Figure 7.3: Comparison of the Average Alkalinity for Each Series of Tests, No Fertilizer Application, A-3 and A-2-4 Soils**

A comparison of the total mass of nitrogen collected in runoff and base flow is shown in Figure 7.4. From this 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 4 to 1 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 7.5 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. No other trends were observed. Overall this analysis suggests that the A-2-4 soil has a higher initial TP mass content compared to the A-3 soil.

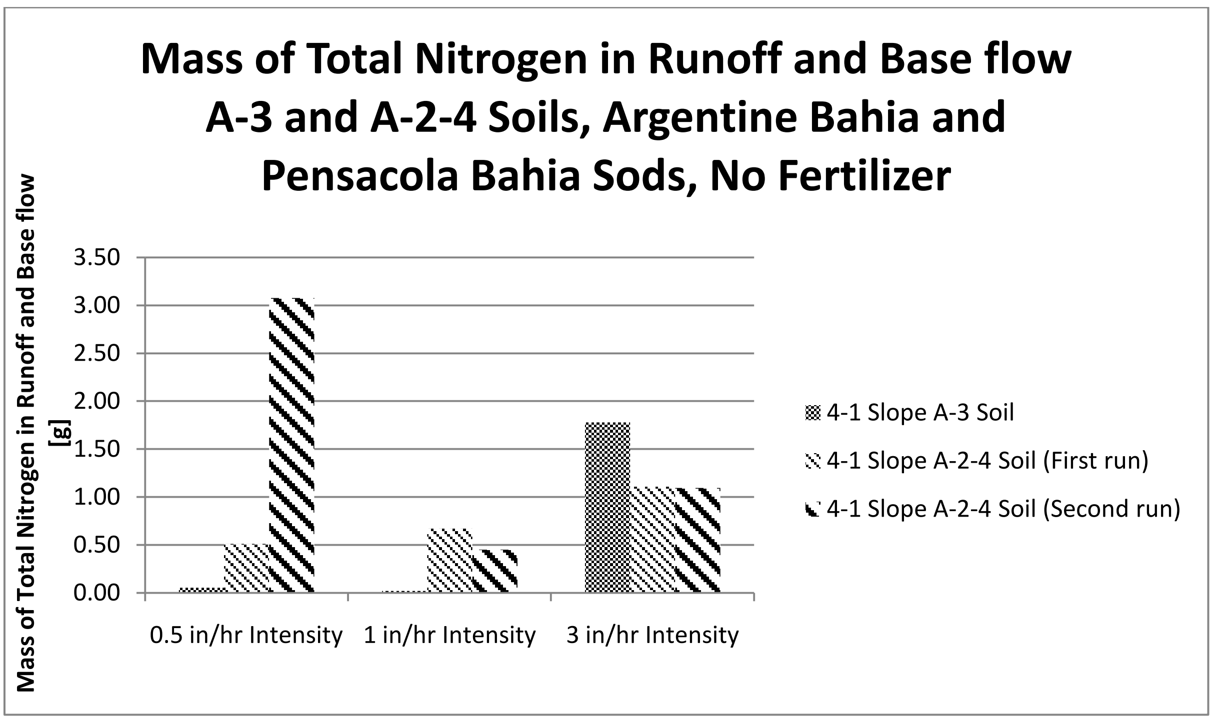


**Figure 7.4: Comparison of Total Nitrogen Mass Lost in Runoff and Base Flow for A-3 and A-2-4 Soils and No Fertilizer Application**

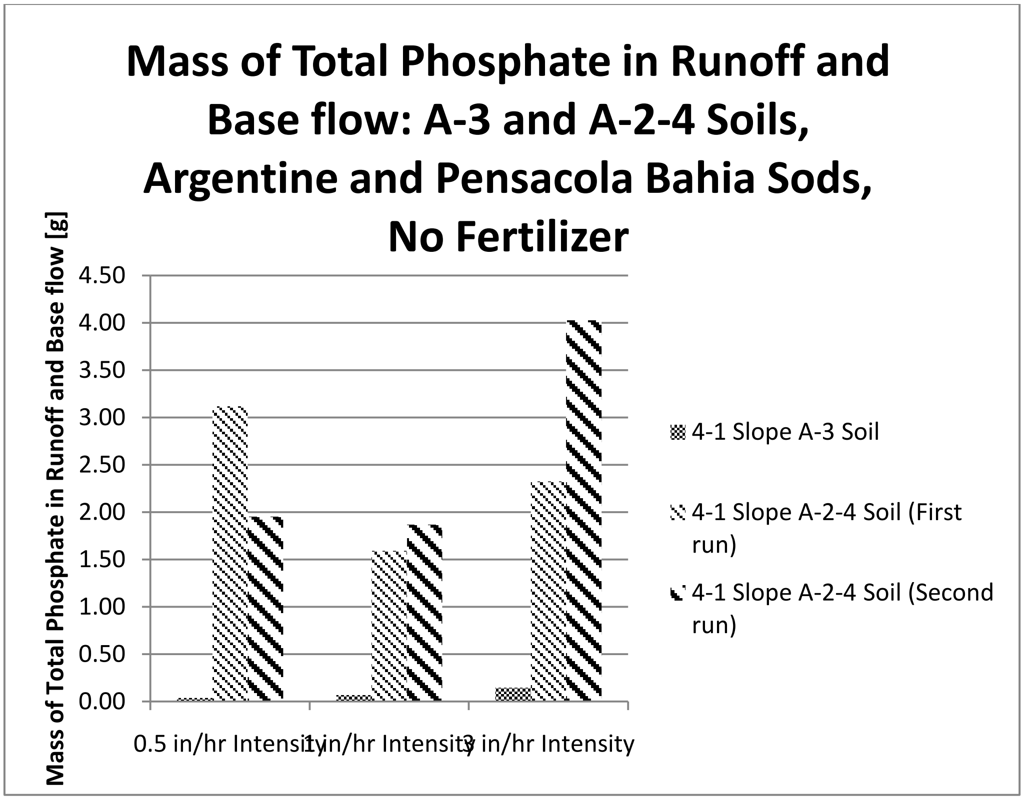


**Figure 7.5: Comparison of Total Phosphate Mass Lost in Runoff and Base Flow for A-3 and A-2-4 Soils and No Fertilizer Application**

## 7.2 10-10-10 Fertilizer @ 1 lb of N per 1000 ft$^2$ Comparison

Tests with 10-10-10 fertilizer applied at 1lb of N per 1000 ft$^2$ were run on both soil types. Figure 7.6 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 due to the fact that 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.

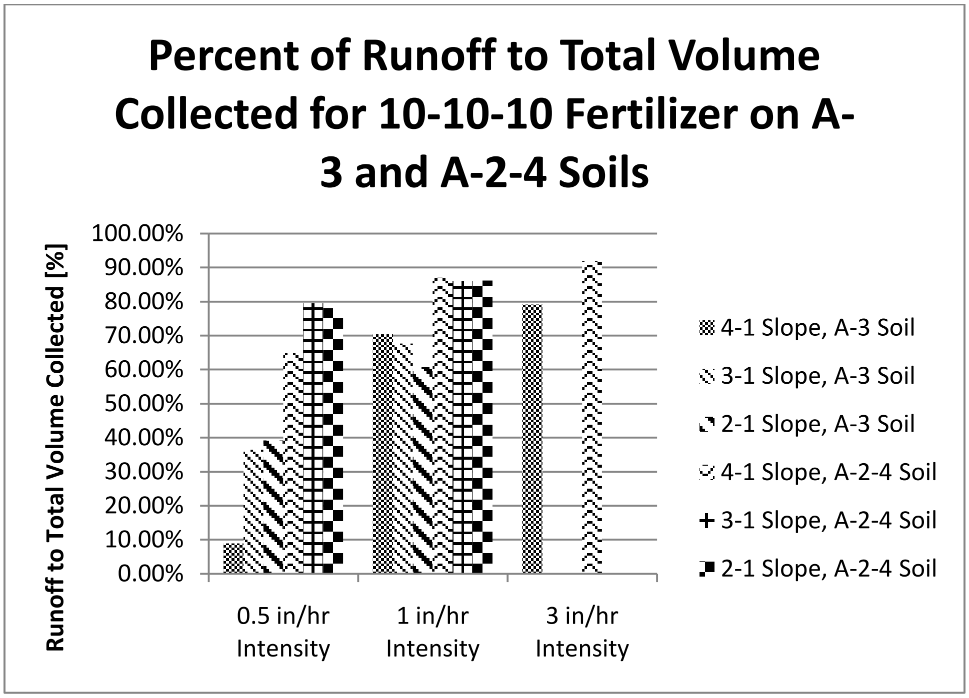


**Figure 7.6: Comparison of Percent Runoff to Total Volume Collected for 10-10-10 Fertilizer on A-3 and A-2-4 Soils**

The comparison of TN and TP mass lost from the 10-10-10 fertilizer applied at 1lb of N per 1000 ft$^2$ for both soil types is shown in Figures 7.7 and 7.8, respectively. It can be seen from this figure that the TN and TP loss generally increases with the A-2-4 soil. This is likely due to the fact that 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 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.

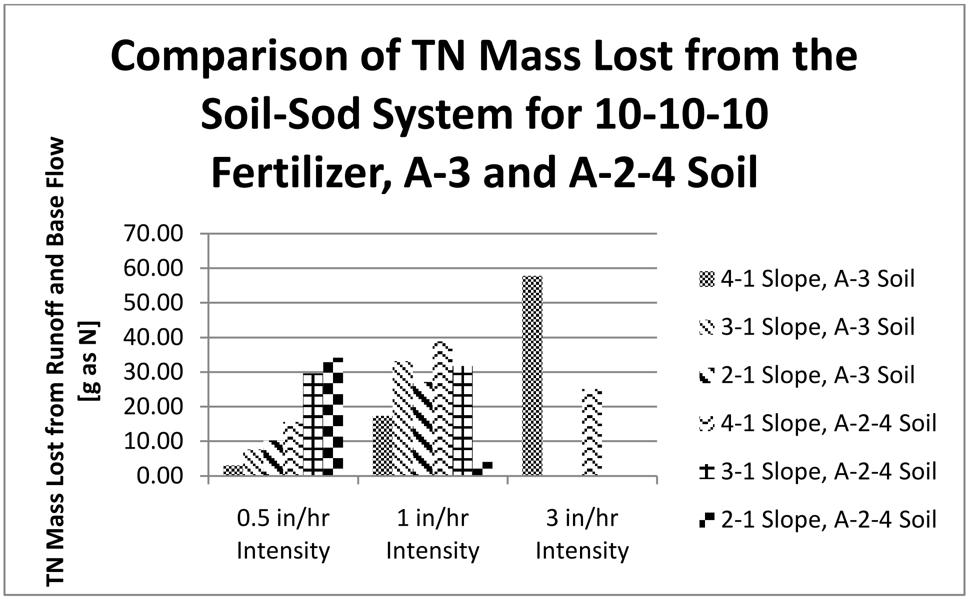


**Figure 7.7: Comparison of the TN Mass Lost from the Soil-Sod System, 10-10-10 Fertilizer, A-3 and A-2-4 Soils**

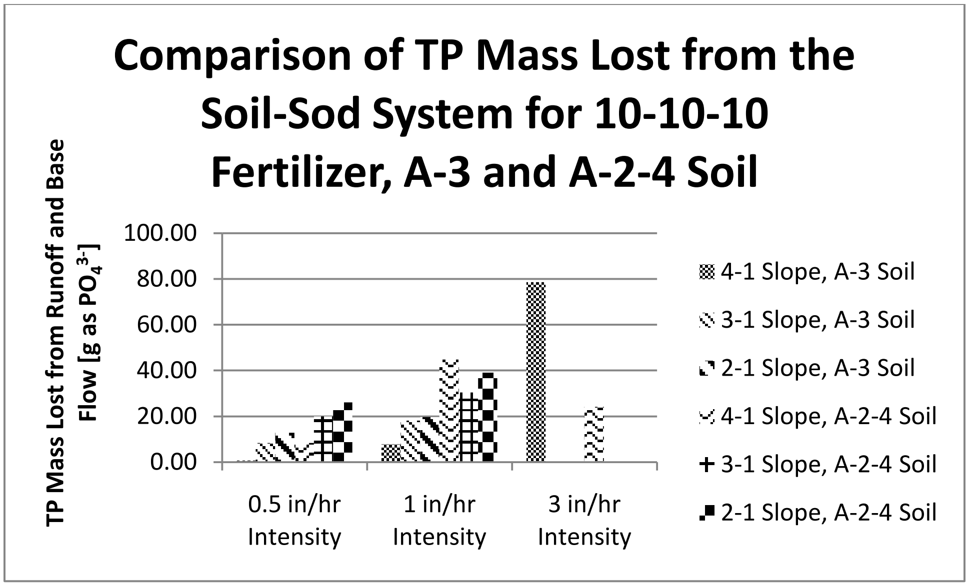


**Figure 7.8: Comparison of TP Mass Lost from the Soil-Sod System, 10-10-10 Fertilizer, A-3 and A-2-4 Soils**

## 7.3 10-10-10 Fertilizer @ 1 lb of N per 1000 ft$^2$ Seven-Day Test Comparison

The seven day tests for the 10-10-10 fertilizer applied at a rate of 1lb of N per 1000 ft$^2$ on day one was also conducted on both soil types. Figure 7.9 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.

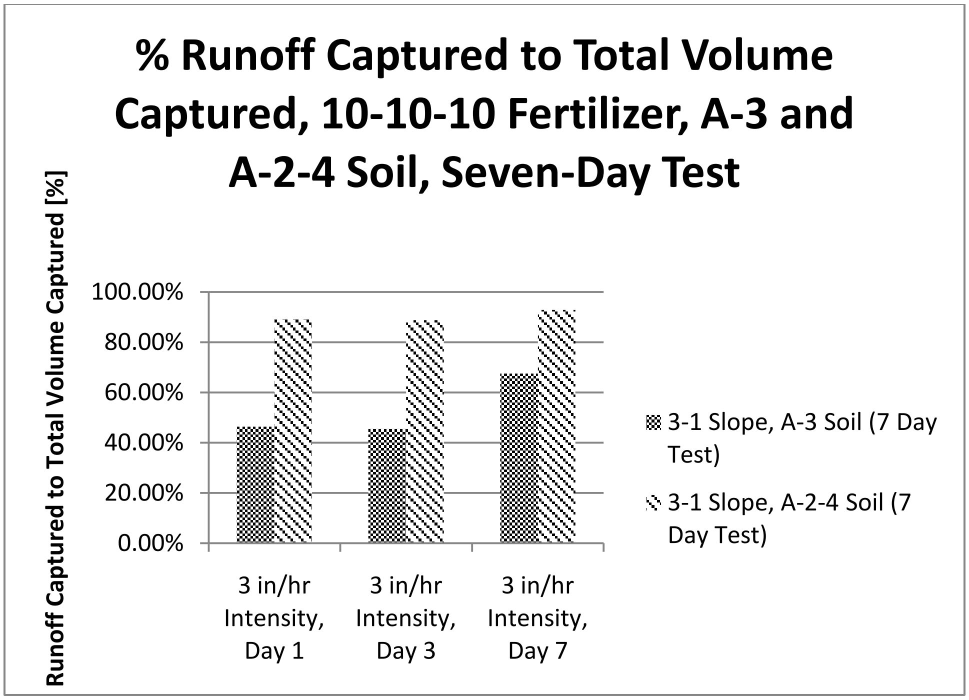


**Figure 7.9: Comparison of % Runoff Captured to Total Volume Captured, 10-10-10 Fertilizer, A-3 and A-2-4 Soils, Seven-Day Test**

The TN mass loss comparison for both soil types is shown in Figure 7.10. 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 inn Figure 7.11, depicts that the A-2-4 soil lost significantly more TP than the A-3 soil. This is due to the fact that 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.

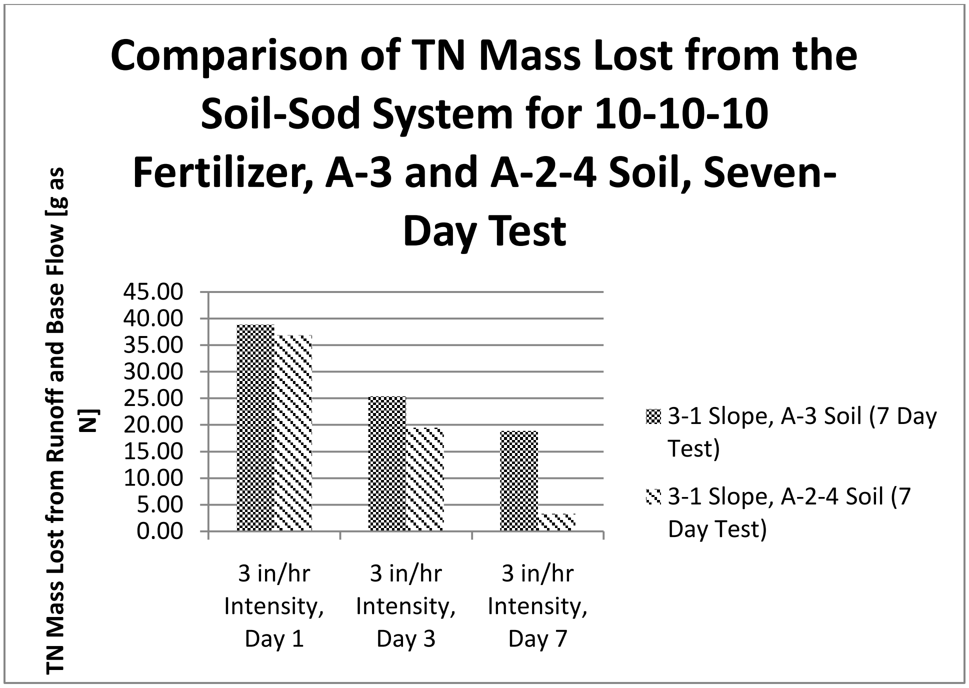


**Figure 7.10: Comparison of TN Mass Lost from the Soil-Sod System for 10-10-10 Fertilizer, A-3 and A-2-4 Soils, Seven-Day Test**

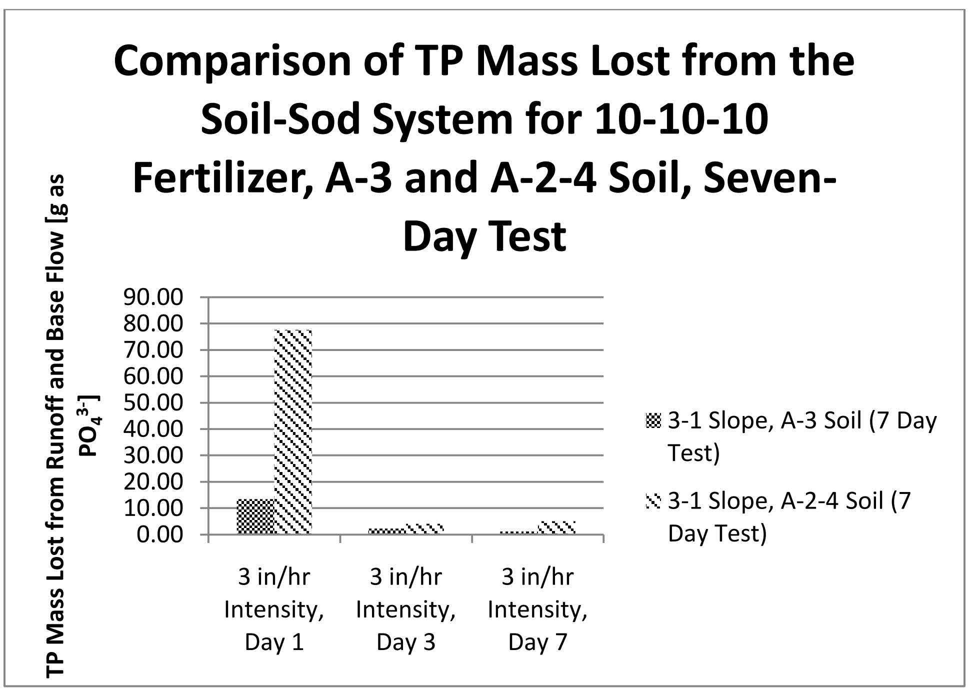


**Figure 7.11: Comparison of TP Mass Lost from the Soil-Sod System for 10-10-10 Fertilizer, A-3 and A-2-4 Soils, Seven-Day Test**

## 7.4 16-0-8 (SR) Fertilizer @ 0.5 lb of N per 1000 ft$^2$ Comparison

This subsection describes the results for 16-0-8 (SR) fertilizer applied at 0.5lb of N per 1000 ft$^2$ as a function of soil type. Figure 7.12 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.

The TN mass loss comparison between the two soil types is shown in Figure 7.13. 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 they were too low compared to the other values. These were the 1 in/hr rainfall intensity on both the 3 to 1 slope with A-2-4 soil and the 2 to 1 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.

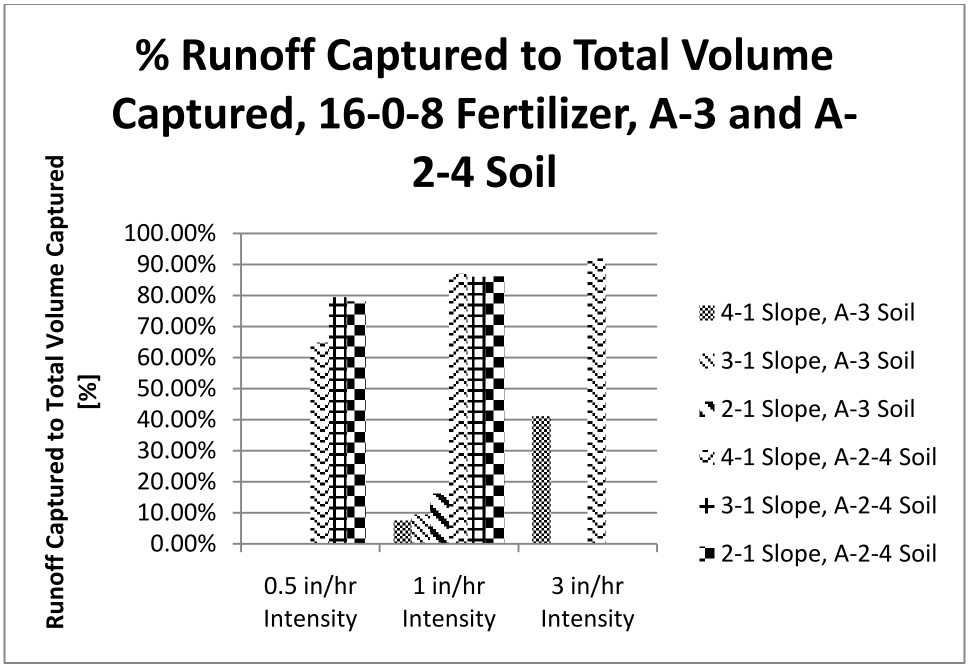


**Figure 7.12: Comparison of % Runoff Captured to Total Volume Captured, 16-0-8 Fertilizer, A-3 and A-2-4 Soils**

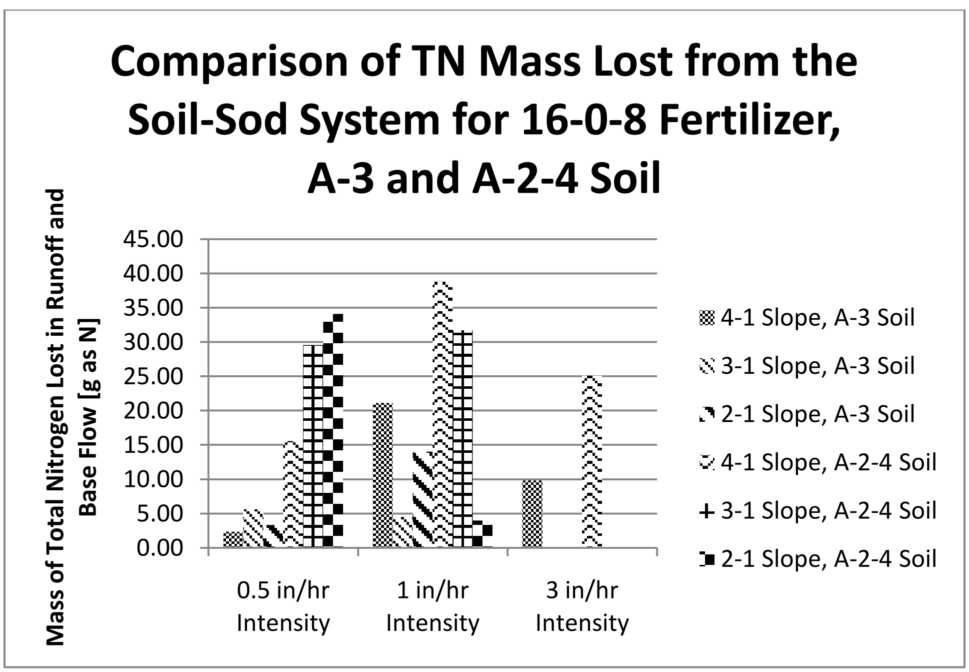


**Figure 7.13: Comparison of TN Mass Lost from the Soil-Sod System for 16-0-8 (SR) Fertilizer, A-3 and A-2-4 Soils**

# 8 CONCLUSIONS AND RECOMMENDATIONS

## 8.1 Summary of Conclusions

This research study was conducted with the primary objective of evaluating 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 4 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%.* Also, as 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, physico-chemical 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 successfully 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 single-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.

## 8.2 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 also 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.

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 understand 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.

## 8.3 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 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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# 9 APPENDIX A – WATER BALANCE, TN MASS BALANCE, TP MASS BALANCE, A-3 SOIL WITH ARGENTINE BAHIA SOD, 10-10-10 FERTILIZER

**Table 9.1: Analysis of Water Balance in the Soil-Sod Combination 1 (A-3 Soil with Argentine Bahia Sod and 10-10-10 Fertilizer)**

| | | | | | | |
|---|---|---|---|---|---|---|
| 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 | Evapo transpi ration (mm per day) | Bed Evapo transpi ration (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 | | | |
| 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 9.2: Mass Balance of Total Nitrogen in the Soil-Sod Combination 1 (A-3 Soil, Argentine Bahia, and 10-10-10 Fertilizer)

| | BEFORE Fert. Application | | | | AFTER Fert. Application | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of Test | Total N - mass (g) in test bed | Ammoniacal N in test bed (g) | Nitrate N in test bed (g) | Applied (Ammoniacal N) (g) | Ammoniacal N in test bed (g) | Nitrate N in test bed (g) | Temp °F | Avg pH | Volumetric Air Content | Total Day Light Hours | Ammonia Volatilization per day $k_{volati}$ | Nitrification per day $k_{nitri}$ | Denitrification per day $k_{denitri}$ | 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 |
| 5/27/2009 | 0.0 | 0.0 | 60.0 | 106.1 | 106.1 | 60.0 | 78.0 | 7.22 | 0.000 | 14.65 | 0.0042 | 0.00 | 0.002 | 2.03 | 7.0 | 3.09 | 0.00 | 0.84 | 14.18 |
| 6/3/2009 | 136.3 | 103.0 | 33.3 | 106.1 | 209.0 | 33.3 | 80.3 | 7.52 | 0.061 | 14.75 | 0.0070 | 0.07 | 0.002 | 2.08 | 7.0 | 10.24 | 108.61 | 1.75 | 14.57 |
| 6/10/2009 | 190.2 | 90.2 | 100.0 | 106.1 | 196.2 | 100.0 | 84.0 | 7.45 | 0.000 | 14.82 | 0.0071 | 0.00 | 0.002 | 2.12 | 12.0 | 16.79 | 0.00 | 2.40 | 25.42 |
| 6/22/2009 | 185.8 | 179.4 | 6.4 | 106.1 | 285.5 | 6.4 | 90.0 | 7.34 | 0.451 | 14.85 | 0.0072 | 0.20 | 0.001 | 2.14 | 7.0 | 14.35 | 271.14 | 1.17 | 14.96 |
| 6/29/2009 | 245.4 | 0.0 | 245.4 | 106.1 | 106.1 | 245.4 | 85.0 | 7.34 | 0.278 | 14.83 | 0.0063 | 0.16 | 0.001 | 2.13 | 3.0 | 2.00 | 50.32 | 0.93 | 6.383 |
| 7/2/2009 | 301.7 | 53.7 | 248.0 | 106.1 | 159.8 | 248.0 | 81.0 | 7.28 | 0.230 | 14.80 | 0.0051 | 0.14 | 0.001 | 2.11 | 4.0 | 3.25 | 91.91 | 1.61 | 8.436 |
| 7/6/2009 | 363.2 | 64.6 | 298.5 | 106.1 | 170.7 | 298.5 | 84.0 | 7.05 | 0.210 | 14.77 | 0.0037 | 0.14 | 0.001 | 2.09 | 0.0 | 0.00 | 0.00 | 0.00 | 0 |

| Date of 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 |
|---|---|---|---|---|---|---|
| 5/27/2009 | 0 | 0.00 | 0.00 | 11.64 | 3.10 | 1.9% |
| 6/3/2009 | 77.6 | 1.78 | 0.14 | 25.49 | 17.37 | 7.2% |
| 6/10/2009 | 2675.9 | 2.18 | 5.82 | 59.97 | 57.22 | 19.3% |
| 6/22/2009 | 1883.5 | 0.28 | 0.53 | 15.47 | 7.64 | 2.6% |
| 6/29/2009 | 63.5 | 2.31 | 0.15 | 40.28 | 33.15 | 9.4% |
| 7/2/2009 | 219.0 | 0.80 | 0.18 | 31.15 | 10.24 | 2.5% |
| 7/6/2009 | 101.8 | 2.16 | 0.22 | 46.74 | 27.13 | 5.8% |

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 9.3: Mass Balance of Total Phosphate in the Soil-Sod Combination 1 (A-3 Soil, Argentine Bahia, and 10-10-10 Fertilizer)**

| | BEFORE Fert. Application | | | | | | AFTER Fert. Application | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of Test | Total P - mass (g) in test bed | Extra-ctable P (g) **X** | Non-extra-ctable P (g) **Y** | $P_{Buffer}$ (g) | Applied P (g) | Partition co-efficient R | Extra-ctable P (g) **X** | Non-extra-ctable P (g) **Y** | **$P_{Buffer}$** (g) | Total Day Light Hrs | X to Y $K_1$ | Y to X $K_2$ | X to $P_{buffer}$ $K_3$ | $P_{buffer}$ to X $K_4$ | 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 co-efficient 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

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

**Table 10.1: Analysis of Water Balance in the Soil-Sod Combination 2 (A-3 Soil with Argentine Bahia Sod and No Fertilizer, 16-0-8 (SR) Fertilizer @ 1lb and 0.5lb of N per 1000 ft$^2$, and 10-10-10 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] | Volu-metric Air Content | Seepage Since Previous Test (L) | Rainfall, in | Natural Rainfall Volume (L) | Mean Temp. °F | Total Day Light Hours | Evapotranspiration (mm per day) | Bed Evapotranspiration (L) | Rainfall Applied [L] | Runoff and Base flow [L] | Final Storage [L] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8/17/2009 | 18.5% | 2110 | 0.11 | 0 | 0.05 | 28 | 84 | 13.92 | 4.10 | 91.01 | 3444 | 3017 | 2474 |
| 8/18/2009 | | | | | 0.55 | 310 | 84 | 13.90 | 4.08 | 90.62 | | | |
| 8/19/2009 | | | | | 0.12 | 68 | 82 | 13.87 | 3.87 | 85.86 | | | |
| 8/20/2009 | 21.6% | 2368 | 0.00 | 307 | 0.00 | 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 | | | | | 0.00 | 0 | 81 | 13.78 | 3.70 | 82.07 | | | |
| 8/23/2009 | | | | | 0.51 | 288 | 82 | 13.75 | 3.75 | 83.27 | | | |
| 8/24/2009 | 21.9% | 2368 | 0.00 | 1958 | 0.16 | 90 | 82 | 13.73 | 3.73 | 82.89 | 5159 | 4554 | 2981 |
| 8/25/2009 | | | | | 0.36 | 203 | 82 | 13.70 | 3.70 | 82.15 | | | |
| 8/26/2009 | | | | | 0.38 | 214 | 84 | 13.67 | 3.83 | 85.12 | | | |
| 8/27/2009 | 18.1% | 2064 | 0.13 | 1167 | 0.00 | 0 | 82 | 13.65 | 3.65 | 81.04 | 4907 | 4307 | 2583 |
| 8/28/2009 | | | | | 0.00 | 0 | 84 | 13.62 | 3.78 | 83.94 | | | |
| 8/29/2009 | | | | | 0.00 | 0 | 84 | 13.58 | 3.74 | 83.15 | | | |
| 8/30/2009 | | | | | 0.00 | 0 | 83 | 13.57 | 3.65 | 80.98 | | | |
| 8/31/2009 | 17.8% | 2030 | 0.14 | 305 | 2.02 | 1139 | 83 | 13.53 | 3.61 | 80.21 | 3689 | 3214 | 3564 |
| 9/1/2009 | | | | | 0.26 | 147 | 80 | 13.50 | 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 | 3.30 | 73.20 | 3978 | 3693 | 2132 |
| 9/4/2009 | | | | | 0.00 | 0 | 81 | 13.42 | 3.34 | 74.19 | | | |
| 9/5/2009 | | | | | 0.28 | 158 | 80 | 13.38 | 3.23 | 71.82 | | | |
| 9/6/2009 | | | | | 0.00 | 0 | 82 | 13.37 | 3.37 | 74.75 | | | |
| 9/7/2009 | | | | | 0.00 | 0 | 82 | 13.33 | 3.33 | 74.01 | | | |
| 9/8/2009 | | | | | 0.00 | 0 | 80 | 13.30 | 3.16 | 70.08 | | | |
| 9/9/2009 | | | | | 0.00 | 0 | 82 | 13.28 | 3.28 | 72.90 | | | |
| 9/10/2009 | 15.00% | 1711 | 0.28 | 141 | 0.00 | 0 | 82 | 13.25 | 3.25 | 72.16 | 4114 | 3488 | 2264 |
| 9/11/2009 | | | | | 0.00 | 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 | 3.10 | 68.81 | | | |
| 9/14/2009 | 16.90% | 1927 | 0.19 | 200 | 0.00 | 0 | 82 | 13.13 | 3.13 | 69.57 | 3965 | 3486 | 2337 |
| 9/15/2009 | | | | | 0.00 | 0 | 82 | 13.10 | 3.10 | 68.83 | | | |
| 9/16/2009 | | | | | 0.00 | 0 | 82 | 13.08 | 3.08 | 68.46 | | | |
| 9/17/2009 | 16.70% | 1905 | 0.20 | 295 | 0.00 | 0 | 82 | 13.05 | 3.05 | 67.72 | 3883 | 3524 | 2196 |
| 9/18/2009 | | | | | 0.00 | 0 | 82 | 13.02 | 3.02 | 66.98 | | | |
| 9/19/2009 | | | | | 0.00 | 0 | 83 | 12.98 | 3.05 | 67.62 | | | |
| 9/20/2009 | | | | | 0.00 | 0 | 83 | 12.97 | 3.03 | 67.24 | | | |
| 9/21/2009 | 16.10% | 1836 | 0.22 | 158 | 0.00 | 0 | 82 | 12.93 | 2.93 | 65.13 | 4020 | 3495 | 2296 |
| 9/22/2009 | | | | | 0.12 | 68 | 84 | 12.90 | 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 | | | | | 0.00 | 0 | 82 | 12.82 | 2.82 | 62.54 | | | |
| 9/26/2009 | | | | | 0.79 | 446 | 82 | 12.78 | 2.78 | 61.80 | | | |
| 9/27/2009 | | | | | 0.33 | 186 | 82 | 12.77 | 2.77 | 61.43 | | | |
| 9/28/2009 | | | | | 0.00 | 0 | 82 | 12.73 | 2.73 | 60.69 | | | |
| 9/29/2009 | | | | | 0.00 | 0 | 82 | 12.70 | 2.70 | 59.95 | | | |
| 9/30/2009 | | | | | 0.00 | 0 | 74 | 12.68 | 2.26 | 50.24 | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10/1/2009 | | | | | 0.00 | 0 | 74 | 12.65 | 2.24 | 49.68 | | | |
| 10/2/2009 | | | | | 0.00 | 0 | 79 | 12.62 | 2.47 | 54.74 | | | |
| 10/3/2009 | | | | | 0.00 | 0 | 79 | 12.60 | 2.45 | 54.40 | | | |
| 10/4/2009 | | | | | 0.00 | 0 | 81 | 12.57 | 2.52 | 55.90 | | | |
| 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 | | | | | 0.00 | 0 | 83 | 12.48 | 2.53 | 56.17 | | | |
| 10/8/2009 | | | | | 0.00 | 0 | 84 | 12.45 | 2.54 | 56.41 | | | |
| 10/9/2009 | | | | | 0.00 | 0 | 86 | 12.43 | 2.61 | 58.01 | | | |
| 10/10/2009 | | | | | 0.00 | 0 | 81 | 12.40 | 2.36 | 52.32 | | | |
| 10/11/2009 | | | | | 0.00 | 0 | 83 | 12.38 | 2.43 | 53.88 | | | |
| 10/12/2009 | | | | | 0.00 | 0 | 83 | 12.35 | 2.39 | 53.12 | | | |
| 10/13/2009 | 12.30% | 1403 | 0.41 | 464 | 0.00 | 0 | 83 | 12.32 | 2.36 | 52.35 | 1399 | 973 | 1777 |
| 10/14/2009 | | | | | 0.00 | 0 | 83 | 12.30 | 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 | | | | | 0.00 | 0 | 65 | 12.22 | 1.57 | 34.87 | | | |
| 10/18/2009 | | | | | 0.00 | 0 | 57 | 12.18 | 1.26 | 27.95 | | | |
| 10/19/2009 | 12.10% | 1380 | 0.42 | 304 | 0.00 | 0 | 63 | 12.17 | 1.47 | 32.73 | 1311 | 678 | 1980 |
| 10/20/2009 | | | | | 0.00 | 0 | 68 | 12.13 | 1.64 | 36.36 | | | |
| 10/21/2009 | | | | | 0.00 | 0 | 74 | 12.12 | 1.84 | 40.80 | | | |
| 10/22/2009 | | | | | 0.00 | 0 | 74 | 12.08 | 1.81 | 40.24 | | | |
| 10/23/2009 | | | | | 0.00 | 0 | 77 | 12.07 | 1.90 | 42.19 | | | |
| 10/24/2009 | | | | | 0.00 | 0 | 79 | 12.03 | 1.94 | 43.00 | | | |
| 10/25/2009 | | | | | 0.00 | 0 | 73 | 12.02 | 1.73 | 38.43 | | | |
| 10/26/2009 | 11.40% | 1300 | 0.45 | 439 | 0.00 | 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 | | | | | 0.00 | 0 | 80 | 11.93 | 1.88 | 41.63 | | | |
| 10/29/2009 | 17.00% | 1939 | 0.18 | 60 | 0.00 | 0 | 82 | 11.92 | 1.92 | 42.56 | 4639 | 4083 | 2452 |
| 10/30/2009 | | | | | 0.06 | 34 | 78 | 11.90 | 1.79 | 39.69 | | | |
| 10/31/2009 | | | | | 0.00 | 0 | 79 | 11.87 | 1.79 | 39.64 | | | |
| 11/1/2009 | | | | | 0.00 | 0 | 78 | 11.85 | 1.74 | 38.72 | | | |
| 11/2/2009 | | | | | 0.00 | 0 | 74 | 11.82 | 1.61 | 35.80 | | | |
| 11/3/2009 | | | | | 0.02 | 11 | 70 | 11.80 | 1.50 | 33.31 | | | |
| 11/4/2009 | | | | | 0.00 | 0 | 74 | 11.78 | 1.59 | 35.25 | | | |
| 11/5/2009 | 17.90% | 2041 | 0.14 | 234 | 0.00 | 0 | 72 | 11.75 | 1.52 | 33.65 | 3456 | 3009 | 2455 |
| 11/6/2009 | | | | | 0.00 | 0 | 68 | 11.73 | 1.41 | 31.36 | | | |
| 11/7/2009 | | | | | 0.00 | 0 | 71 | 11.72 | 1.47 | 32.65 | | | |
| 11/8/2009 | | | | | 0.00 | 0 | 73 | 11.68 | 1.49 | 33.11 | | | |
| 11/9/2009 | | | | | 0.00 | 0 | 77 | 11.67 | 1.56 | 34.69 | | | |
| 11/10/2009 | | | | | 0.33 | 186 | 76 | 11.65 | 1.53 | 33.93 | | | |
| 11/11/2009 | | | | | 0.00 | 0 | 74 | 11.63 | 1.48 | 32.75 | | | |
| 11/12/2009 | 17.30% | 1973 | 0.17 | 469 | 0.00 | 0 | 60 | 11.62 | 1.19 | 26.48 | 3578 | 3118 | 2407 |
| 11/13/2009 | | | | | 0.00 | 0 | 63 | 11.58 | 1.24 | 27.47 | | | |
| 11/14/2009 | | | | | 0.00 | 0 | 68 | 11.57 | 1.32 | 29.28 | | | |
| 11/15/2009 | | | | | 0.00 | 0 | 68 | 11.55 | 1.31 | 29.07 | | | |
| 11/16/2009 | | | | | 0.00 | 0 | 68 | 11.53 | 1.30 | 28.87 | | | |
| 11/17/2009 | 16.30% | 1859 | 0.22 | 433 | 0.00 | 0 | 72 | 11.52 | 1.36 | 30.09 | 3964 | 3485 | 2308 |
| 11/18/2009 | | | | | 0.00 | 0 | 72 | 11.50 | 1.34 | 29.84 | | | |
| 11/19/2009 | 18.00% | 2053 | 0.13 | 225 | 0.00 | 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 | | | | | 0.00 | 0 | 72 | 11.45 | 1.31 | 29.07 | | | |
| 11/22/2009 | | | | | 0.00 | 0 | 72 | 11.43 | 1.30 | 28.82 | | | |
| 11/23/2009 | 18.30% | 2087 | 0.12 | 567 | 0.00 | 0 | 74 | 11.42 | 1.31 | 29.14 | 4289 | 3713 | 2633 |

**Table 10.2: Mass Balance of Total Nitrogen in the Soil-Sod Combination 2 (A-3 Soil, Argentine Bahia Sod, and No-Fertilizer, 16-0-8 (SR) @ 1lb and 0.5lb, and 10-10-10 Seven-Day)**

| | **BEFORE Fert. Application** | | | | **AFTER Fert. Application** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of Test | Total N - mass (g) in test bed | Ammo niacal N in test bed (g) | Nitrate N in test bed (g) | Applied (Ammo niacal N) (g) | Ammo niacal N in test bed (g) | Nitrate N in test bed (g) | Temp°F | Avg pH | Volu metric Air Content | Total Day Light Hours | Ammonia Volati lization per day $k_{volati}$ | Nitrifi cation per day $k_{nitri}$ | Denitri fication per day $k_{denitri}$ |
| 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

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

# 11 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 11.1: Analysis of Water Balance in the Soil-Sod Combination 3 (A-2-4 Soil with Pensacola Bahia Sod and 10-10-10 Fertilizer 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 |
| 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 | | | |
| 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 11.2: Mass Balance of Total Nitrogen in the Soil-Sod Combination 3 (A-2-4 Soil, Pensacola Bahia, and 10-10-10 and No Fertilizer)

| | BEFORE Fert. Application | | | | AFTER Fert. Application | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of Test | Total N - mass (g) in test bed | Ammoniacal N in test bed (g) | Nitrate N in test bed (g) | Applied (Ammoniacal N) (g) | Ammoniacal N in test bed (g) | Nitrate N in test bed (g) | Temp° F | Avg pH | Volumetric Air Content | Total Day Light Hours | Ammonia Volatilization per day $k_{volati}$ | Nitrification per day $k_{nitri}$ | Denitrification per day $k_{denitri}$ | 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 |
| 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

| 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 |
|---|---|---|---|---|---|---|
| 1.3598 | 0 | 0.00 | 0.00 | 5.18 | 0.51 | 1.7% |
| 1.813 | 761.9 | 1.60 | 1.22 | 4.82 | 0.71 | 3.1% |
| 1.332 | 882.1 | 1.89 | 1.67 | 2.60 | 1.19 | 7.8% |
| 1.11 | 1124.6 | 1.71 | 1.93 | 40.34 | 20.61 | 17.8% |
| 1.628 | 1322.5 | 2.30 | 3.05 | 69.81 | 25.12 | 14.1% |
| 1.3875 | 1144.1 | 1.71 | 1.96 | 84.14 | 38.85 | 18.6% |
| 10.49 | 1337.1 | 2.66 | 3.56 | 69.23 | 29.58 | 13.0% |
| 3.219 | 1109.4 | 3.07 | 3.40 | 49.95 | 31.73 | 13.0% |
| 6.0865 | 742.8 | 11.03 | 8.19 | 53.26 | 34.11 | 11.6% |
| 7.77 | 2547.2 | 11.42 | 29.08 | 6.57 | 4.01 | 1.2% |
| 2.2015 | 1241.9 | 4.78 | 5.94 | 36.89 | 36.89 | 9.5% |
| 4.551 | 807.5 | 19.13 | 15.45 | 19.51 | 19.51 | 5.7% |
| 3.6075 | 1422.9 | 23.99 | 34.14 | 3.32 | 3.32 | 1.1% |
| 4.995 | 1103.8 | 18.81 | 20.76 | 8.59 | 3.08 | 1.2% |
| 3.9405 | 587.9 | 14.25 | 8.38 | 1.77 | 0.45 | 0.2% |
| 0 | 647.1 | 13.93 | 9.01 | 2.88 | 1.09 | 0.5% |

**Table 11.3: Mass Balance of Total Phosphate in the Soil-Sod Combination 3 (A-2-4 Soil, Pensacola Bahia Sod, and 10-10-10 and No Fertilizer)**

| | BEFORE Fert. Application | | | | | | AFTER Fert. Application | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of Test | Total P - mass (g) in test bed | Extra-ctable P (g) **X** | Non-extra-ctable P (g) **Y** | $P_{Buffer}$ (g) | Applied P (g) | Partition co-efficient R | Extra-ctable P (g) **X** | Non-extra-ctable P (g) **Y** | **$P_{Buffer}$** (g) | Total Day Light Hrs | X to Y $K_1$ | Y to X $K_2$ | X to $P_{buffer}$ $K_3$ | $P_{buffer}$ to X $K_4$ | 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 co-efficient 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

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

# 12 APPENDIX D – WATER BALANCE, TN MASS BALANCE, A-2-4 SOIL WITH PENSACOLA BAHIA SOD, 16-0-8 FERTILIZER

**Table 12.1: Analysis of Water Balance in the Soil-Sod Combination 4 (A-2-4 Soil with Pensacola Bahia Sod and 16-0-8 Fertilizer @ 0.5lb 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 transpi ration (mm per day) | Bed Evapo transpi ration (L) | Rainfall Applied [L] | Runoff and Base flow [L] | Seepage + Final Storage [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 12.2: Mass Balance of Total Nitrogen in the Soil-Sod Combination 4 (A-2-4 Soil, Pensacola Bahia Sod, 16-0-8 Fertilizer @ 0.5lb of N per 1000 ft$^2$)

| | BEFORE Fert. Application | | | | AFTER Fert. Application | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date of Test | Total N - mass (g) in test bed | Ammoniacal N in test bed (g) | Nitrate N in test bed (g) | Applied (Ammoniacal N) (g) | Ammoniacal N in test bed (g) | Nitrate N in test bed (g) | Temp° F | Avg pH | Volumetric Air Content | Total Day Light Hours | Ammonia Volatilization per day kvolati | Nitrification per day knitri | Denitrification per day kdenitri | 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 |
| 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 | 0.12 | 38.75 |
| 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 | 0.06 | 36.85 |
| 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 | 1.17 | 58.43 |
| 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 | 0.49 | 41.08 |
| 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 | 0.31 | 71.93 |
| 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 | 0.06 | 35.21 |
| 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 | 0.00 | 0.00 |

| Date of 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) | TN lost in test (RAIN only) | % loss in sim rain w.r.to TN after fert. Application |
|---|---|---|---|---|---|---|---|---|
| 5/13/2010 | 0.2184 | 7.51 | 0.00 | 0.00 | 0.00 | 27.7 | 17.6 | 21.2% |
| 5/17/2010 | 0.2 | 5.77 | 754.18 | 0.91 | 0.69 | 52.5 | 46.1 | 45.8% |
| 5/20/2010 | 0.2 | 7.81 | 941.18 | 0.83 | 0.78 | 30.2 | 17.4 | 18.4% |
| 5/24/2010 | 0.2 | 5.99 | 363.87 | 0.68 | 0.25 | 30.9 | 21.7 | 20.2% |
| 5/27/2010 | 0.5 | 10.13 | 283.71 | 1.18 | 0.34 | 34.2 | 18.9 | 15.4% |
| 6/1/2010 | 0.3 | 6.19 | 1506.67 | 1.42 | 2.15 | 11.9 | 1.5 | 1.2% |
| 6/4/2010 | 0.0 | 0.00 | 1084.57 | 0.02 | 0.03 | 11.2 | 2.3 | 1.4% |

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

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