Environmentally Sound Grazing

Draft Report on

Report on Nutrient Yield in Runoff from Rainfall simulation Runs

EPA 319 FY 1997, TASK 300

Environmentally Sound Grazing System

Tasks No. 304.15

January 8, 2002

M. D. Smolen, Project Director

Oklahoma State University

TABLE OF CONTENTS

Introduction

Background

Water is an essential resource to all life. Abundant supplies of water are needed for various domestic, agricultural and recreational activities. In the United States, surface and ground waters provide many uses. Recent concern has directed research towards the quality of our nation's waters.

Environmental concerns with non-point source (NPS) pollution has increased due to extensive and localized agricultural operations. In particular, a rapidly expanding poultry industry produced nearly 200 million birds from 600 contract growers in the 13 eastern Oklahoma counties in 1993. Total poultry litter produced is estimated to be approximately 36,000 tons annually; roughly containing 1400 tons total nitrogen (N), 790 tons phosphorus (P_2O_5), 700 tons potassium (K_2O), plus other plant and animal nutrients, and non-nutrient elements in lesser amounts (Smith et al., 1993).

Increasing poultry production in recent years created a greater awareness of the importance of proper management, utilization, and/or disposal of the poultry litter. Poultry litter includes the manure and bedding (straw, wood chips, rice hulls, etc.) and is a relatively dry material as compared to manure or manure slurry. Land application of poultry litter is considered an acceptable method of utilization. However, surface runoff from land where poultry litter has been applied may contain high levels of nutrients. These elevated nutrient levels may cause degradation of the receiving water.

Pastures with diverse forages and plants with varying growth habits more readily utilize the nutrients present in litter. A forage/grazing system utilizing combinations of warm-season grasses and legumes, and cool-season grasses and legumes customarily have component forage capable of utilizing nutrients from litter.

The movement of phosphorus (P) in runoff can accelerate the eutrophication of surface water. Agricultural soils and management practices that are vulnerable to P loss must be identified before economically viable management systems that minimize P movement can be developed (Sharpley et al. 1995a). Therefore, can poultry litter be used in intensively managed grazing systems to optimize forage production without accumulating P in the soil or increasing the concentration of Nitrogen (N) and P in surface runoff?

Objectives

There is evidence that nutrient runoff from agricultural areas receiving poultry litter as fertilizer pose a threat to surface water quality. However, the effect of alternative nutrient management scenarios is not well known. The goal of this research is to evaluate management practices that reduce P and N nutrient loading.

The objective of this study is to quantify the differences in nutrient accumulations in soils, and surface runoff when litter application is applied on a P-basis versus an N-basis for production of pasture forage in an intensively managed grazing system.

LITERATURE REVIEW

In Eastern Oklahoma poultry litter is typically applied as a fertilizer on pastures and forage crops for grazing and/or haying. Inclement weather may prevent timely spreading, forcing producers to stockpile the litter. Few producers, however, have sheds available for storage. Primary concerns with land application of PL include surface and ground water contamination with nutrients and microbes (Gerkin, 1977).

Robbins et al. (2000) and Wallingford et al. (1975) state that it is a common practice to apply animal waste as a fertilizer based on crop N requirements and the recommended rate of poultry litter is based on forage N requirement. However, environmental consequences are possible such as excessive P runoff into the receiving fresh water ecosystem. Edwards and Daniel (1993) reported that in surface applied litter 2.2% to 7.3% of total P in litter was lost in runoff during intensive rainfalls with more than 80% in the soluble reactive phosphorus (SRP) form. Soluble reactive P is immediately available for aquatic biota.

Nutrient loading, especially N and P, to rivers and streams often limits the aesthetic value of the affected bodies of water (Beaulac and Reckhow, 1982). Nutrient enrichment in streams can lead to significant disturbance of the stream ecosystem (Cairns et al., 1992; Novak et al., 2000). Non-point source pollution refers to nutrient sources, such as agricultural runoff, and is responsible for up to 65% of stream designated use impairment (EPA, 1992 and EPA 1997). In permanent pasture systems many factors affect runoff water quality including forage type, growth, cover, fertilizer applications and rainfall events (McLeod and Hegg, 1984; Nash et al. 2000; Sharpley et al., 1992).

Agricultural producers have attempted to optimize the economic return from nutrient management practices used to produce a crop. The main emphasis is on the expected crop response to added nutrients. In practice, poultry litter has not always been applied to optimize plant nutrient use. Under contemporary circumstances, application of poultry litter may be in excess of the plant needs. Therefore, nutrients may not be available for crop growth at the optimum time, so that they are often released into the air or water. These nutrient losses have prompted concerns about the impact of current nutrient management on environmental quality.

To develop environmentally sound management systems, an understanding of nutrient loss in agricultural systems is essential (Robbins et al., 2000). Nitrogen and phosphorus are the main nutrients of concern. Input from nitrogen and phosphorus in runoff can accelerate eutrophication and impair water quality.

Wilkerson and Stuedemann (1992) recommended that a more precise determination on the fate of N in grazed ecosystems is needed. An environmentally sensitive nutrient management system for grazing and haying would reduce surface nutrient loading and provide an economic incentive to producers by reducing the need to purchase additional nutrients.

Poultry litter has an average N:P ratio of 2:1, and major grain and hay crops use a N:P ratio of approximately 8:1 (Daniel et al., 1993). Therefore, excess phosphorus is supplied when manure is used to meet all N requirements for crop production. When it is applied on a P basis, there may be shortage of N. Continual use of PL on the N basis typically results in very high accumulation of P in soils. Because of concern for P in runoff to sensitive water resources, many waste utilization plans now are based on P. Because they have excess poultry litter, most producers do not practice the P-based application unless it is required of them. This research will provide information on different management strategies and how P-based vs. N-based application of poultry litter can change runoff quality.

When animal manure provides nutrients to meet the crop requirements on an N-based application the manure contains higher concentrations of P (Pote et al. 1996). When fertilizers are applied in heavy concentrations, leaching and surface runoff losses during heavy rainfalls can occur (Chen, et al., 1996 and Edwards et al., 1994). As P fertilizer is applied to the soil, it becomes sorbed onto soil particles. The sorption of P is a dynamic process that is limited by soil characteristics such as pH, soluble iron, and other minerals. Phosphorus poorly retained by the soil is potentially more mobile (Chapman et al., 1997).

Phosphorus build-up is a problem with animal manures, particularly in poultry litter. With the rapid growth of the poultry industry, information is needed to determine the impact of land application of poultry litter on the soil and surface waters (Sharpley et al., 1993 and Sharpley, 1995b). Poultry litter application methods need to be agronomically and environmentally sound (Robinison and Sharpley, 1996). To develop a sound soil test to determine the impact phosphorus has on water quality, testing methods using sensitive P test could provide information about the fate of P in the system (Edwards et al., 1993).

Bioavailable phosphorus (BAP) transported in agricultural runoff can accelerate surface water eutrophication (Sharpley, 1993 and Sharpley et al., 1995a). Bioavailable phosphorus is a measure of the species of P that have a direct impact on aquatic ecosystems; it represents potentially available phosphorus for algae uptake.

The management of phosphorus fertilizers and manure requires constant attention to minimize eutrophication in sensitive waters because P enriched soil increases chance of transport in runoff. Currently, several states have implemented plans to minimize the amount of P applied in an effort to protect the water supply. However, current data for these plans are insufficient (Sharpley, 1995b).

Daniel et al. (1993) studied the effect of extractable surface soil phosphorus on runoff water quality. The study focused on P additions to surface water from agricultural nonpoint sources. Numerous sources of P runoff exist: indigenous soil and plant material, land-applied manure, sludge, and commercial fertilizer. Long-term use of these products can lead to critical levels of P in the soil. Daniel et al. (1993) proposed methods of identifying these increased levels to evaluate P loss in runoff. For decades the P application in fertilizer has exceeded rates for crop removal, resulting in widespread build-up of P (Daniel et al., 1993). The build-up of P has led to increased assessment in current methods of soil testing. Both particulate and dissolved forms of P may be transported in agriculture runoff. Particulate P forms usually found in eroded sediments and dissolved P forms found in the solution phase of runoff need to be controlled. Minimizing erosion will control the amount of particulate P, but dissolved P forms are harder to control and test. Daniel et al. (1993) suggests there is a need to test surface soil

P and determine critical values that produce dissolved P in the runoff. The method should include provision for the high amount of variability in soil properties.

Currently, standardized tests are used to determine the amount of extractable phosphorus found in the soil. The tests are based upon the nutrients availability for crop uptake. Hooda et al. (2000) suggests the test is not sensitive enough to predict the release of phosphorus already present in the soil system. Most states test for plant availability of P with Bray I and Mehlich III (Gartley and Sims, 1994). Soil test P levels extracted by Bray I and Mehlich III solutions can identify high P levels in the soil. Due to a lack of field data relating Mehlich III to runoff P these levels have been based more on intuition than on fact (Sharpley, 1995a). Runoff P concentration is different from plant available P, although it is correlated (Pote et al., 1996).

Pote et al. (1996) developed a relationship between extractable soil phosphorus and phosphorus losses in runoff. The hypothesis of this test related the variability of runoff with soil test P (STP) to dissolved reactive P (DRP) and bioavailable P (BAP). Previous research indicates that P content on the soil surface directly influences the amount of DRP in runoff, for that soil.

To minimize and protect water quality, we need to establish an environmentally sound management system. The developing management plan should include ways to minimize phosphorus loading in runoff and the potential build up in soils. In order to create such protocols soil test phosphorus and runoff phosphorus need to be correlated.

MATERIALS AND METHODS

Location and Plot Layout

The project was located in LeFlore County at Briggs Ranch in the Poteau River watershed below Lake Wister (Figure 1). Lake Wister is cited in the Oklahoma Section 319 Assessment Report as having impaired recreational and drinking water uses. The Poteau River is also included on the Oklahoma 305(b) list (ODEQ 1998). Much of the watershed contains intensive poultry production. The purpose of the research project was to evaluate best management practices to protect water quality under intensive poultry litter-based forage production and grazing systems.

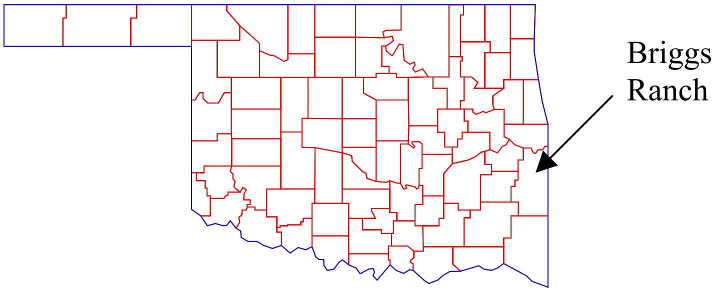

Figure 1. Location of Briggs Ranch project area

One field from the Briggs Ranch (approximately 51 hectares) was divided into four paddocks with permanent fencing. Treatments were labeled "N-based", "P- based", "control", and "negative control". A summary of treatments is found in Table 1. N-Based, P-Based and control paddocks were approximately 16 hectares each. The negative control treatment (no cattle, no fertilizer) was 3 hectares. Each paddock was maintained with a nutrient management plan and grazing protocol to achieve high, but sustainable production based on Oklahoma State University Cooperative Extension Fact Sheet 2584 Forage-Budgeting Guidelines.

The USDA Soil Survey of Leflore County, Oklahoma (1983) shows the soils in the study to be Sallisaw loam, Stigler silt loam, and predominately Pirum Clebit Complex. The characteristics of the Pirum series are very similar to what was observed in the field. The Pirum series consists of a moderately deep, well drained, moderately permeable soil. It is a loamy material derived from weathered sandstone. The slope of this soil ranged from 2 to 60 percent. Maximum slope in the study site is about 8 percent. The surface soil ranged up to 30 percent fragmented sandstone ranging from gravel to stone. The north and south field showed to have a small amount of gravel on the soil surface, whereas the middle fields showed to have very large stones across the soil surface.

Table 1. Summary of treatments.

	N-Based Treatment	P-Based Treatment	Control	Negative Control
Litter- P_2O_5 kg/ha (lb/ac)	175 (157)*	37 (33)*	None	None
Litter- N-N kg/ha (lb/ac)	230 (205)*	46 (41)*	None	None
Commercial Fertilizers NH_4NO_3-N* kg/ha (lb/ac)	None	174 (156)	None	None
Forage Yield Goal t/ha (ton/acre)	9 (4)	9 (4)	N/A	N/A
Winter Annuals Planted	Yes	Yes	No	No
Stocking Rate (cow/acre)	45	45	15	0
Soil Sampled Bi-annually	Yes	Yes	Yes	Yes
Forage Samples	35-day intervals	35-day intervals	None	None

*Average of 3 application values shown in Table 3.

Permanent rainfall simulator sites were installed in each paddock, for use with portable rainfall simulator to evaluate runoff quality and quantity from each paddock periodically. The rainfall simulator was built by Oklahoma State University, based on the Nebraska rotating boom design (Figure 2) (Huhnke et al., 1992; Storm et al., 1992).

Figure 2. Oklahoma State University rainfall simulator.

The use of the rainfall simulator allowed sampling of runoff without the problems of maintaining stream gages and water quality samplers. The field design and layout are shown in Figure 3. Each paddock received different nitrogen, phosphorus concentrations from applied poultry litter, and commercial fertilizer. All end products were managed within each treatment. Table 2 provides the sequence of events that took place during this study.

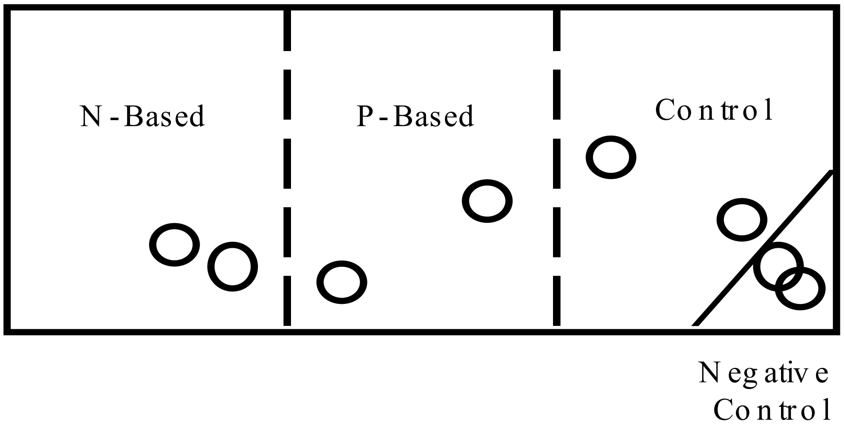

Figure 3. Field design and layout, circles show locations of rainfall simulator sites.

Runoff water samples were analyzed for nitrate-N (NO_3-N), ammonium-N (NH_4-N), total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), and total phosphorus (TP). The Soil, Water and Forage Analytical Laboratory (SWFAL) (Zhang and Kress, 1997) analyzed soil samples for nitrate-N, organic matter, and Mehlich III P. Soil sampling was conducted twice a year, two weeks prior to litter/fertilizer application. In addition, soil from the rainfall simulator sites was sampled immediately following each rainfall application. Excess forage was harvested as hay, weighed, and analyzed for total

N, P, and forage quality. The rate of forage production was measured directly by excluding cattle from selected areas, on exclosures, in each paddock.

Table 2. Experimental timetable.

Date	Activity on Simulator Plots (and fields)
May 9, 1977	1st Litter Application
February -- April 1998	Plot construction
April 29, 1998	Rainfall Simulator Run I
May 2, 1998	2nd Litter Application
May 21, 1998	Rainfall Simulator Run II
October 26, 1998	Rainfall Simulator Run III
May 17, 1999	Rainfall Simulator Run IV
May 19, 1999	3rd Litter Application
June 24, 1999	Rainfall Simulator Run V
October 25, 1999	Rainfall Simulator Run VI

Cattle were assigned to graze on all paddocks, except for the negative control, throughout the course of the demonstration. Stocking rates were determined using forage-budgeting guidelines from Oklahoma State University Cooperative Extension OSU Fact Sheet 2584. In determining stocking rate, dry matter (DM) requirements were estimated from annual forage DM production. Nitrogen and phosphorus based treatments had the same stocking rates throughout the growing season, generally about 45 cows per paddock. The control treatment received no fertilizers. Because its DM production was lower, stocking rates were decreased to about 15 cows per paddock to sustain productivity.

Nutrient analyses of litter are shown in Table 3. Each litter analysis was sampled and sent to University of Arkansas Analytical laboratory for nutrient analysis. Results were averaged to determine application rates. Once application rates were determined, each paddock received an amount of litter based on recommendation from fact sheet 2225 OSU Soil Test Interpretations (Table 4). The P-based application received an additional application of commercial fertilizer to meet crop N requirements, based on a yield goal of 9 t/ha.

Table 3. Nutrient analyses of poultry litter "as is" basis.

	Litter Analysis		
	N	P_2O_5	K_2O
	----------lb/ton--------		
May 10, 1997	59	34.1	44.7
May 2, 1998	59.7	44.3	48.8
May 19, 1999	49.6	48.4	43.4

Table 4. Litter and commercial fertilizer application Rate

	Manure and Commercial Fertilizer Applied				
	-------N- Based-------		-----------------P-Based------------		
	N	P_2O_5	N	C*-N	P_2O_5
	-------------------------kg/ha (lb/acre)--------------------				
May 10, 1997	229(204)	132(118)	63(57)	164(147)	37(33)
May 2, 1998	230(205)	170(152)	33(29)	179(159)	44(39)
May 19, 1999	230(205)	224(200)	43(38)	180(160)	30(27)

* Commercial fertilizer ammonium nitrate applied

Site and Plot Preparation

At each prospective plot location a 16-meter x 16-meter (54-ft x 54-ft) area was first surveyed using a 0.91-meter (3-ft) grid to define the general topography. Next suitable locations for the eight rainfall simulator setups were selected and plot corners were located. Plots were installed July through August 1997.

Permanent simulator sites were constructed by installing low earthen berms 15 cm (6-in.) high by 37 cm (24 in.) wide at the edge of the central alley and along the lower edge of the wetted circle. Berms were stabilized and protected by sod. Berms were wide and low enough to remain in place indefinitely without interfering with cattle or machinery (Figure 4).

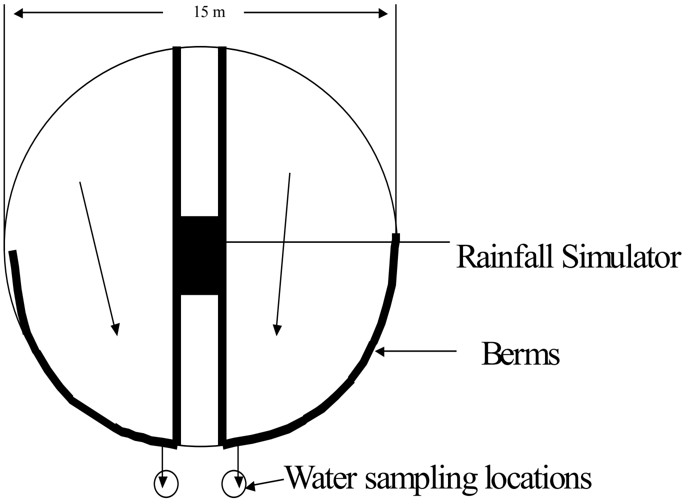

Figure 4. Rainfall simulator plot layout shows alleyways, berms, and sample collection points.

A mild steel funnel was used as an end plate funnel at the lowest corner of each semi-circular plot (Appendix 1). The funnel diverted all runoff water through a 7.6 cm (3 in.) PVC pipe into a collection pit 76 cm (30-in.) diameter by nominally 76-cm (30 in.) deep. Flow rate was measured at the outlet of the PVC pipe and samples collected (Figure 5). The end plate funnel was sealed to the soil surface with melted paraffin wax to insure runoff did not flow underneath. An expanded metal frame covered and protected the collection funnel from cattle and other large contaminants between rainfall simulation events.

A trencher/back hoe dug the collection pits and installed drainage pipes to empty the collection pits through four-inch PVC pipe. Figure 6 provides a drawing of the collection pit as it collects water and drains.

Water Supply

Each rainfall simulation setup requires approximately 13,000 liters (3,500 gal) of water. A ¼ acre pond on Briggs Ranch was treated with 2000 lb. alum the afternoon prior to its use as water supply for the simulator to precipitate the P and clay particles from the water. A gas powered water pump was used to apply alum as a slurry. Two gasoline-engine pumps, transferred water from the pond through a two-inch fire hose supplying water to the rainfall simulator. Distances from pond to simulator sites ranged from 91 meters (300 ft) to 426 meters (1400 ft). Elevation change from the pond to the simulator sites ranged from 4.6 meters (15 ft) to 11 meters (35 ft) above the pond. A 5-hp gasoline pump was placed at the edge of the pond to pump the water 3-9 meters (10–30 ft) up gradient. A second 7-hp pump provided a masthead pressure of 30 psi and maintained flow regulation at the rainfall simulator.

Figure 5. Rainfall simulator collection pit

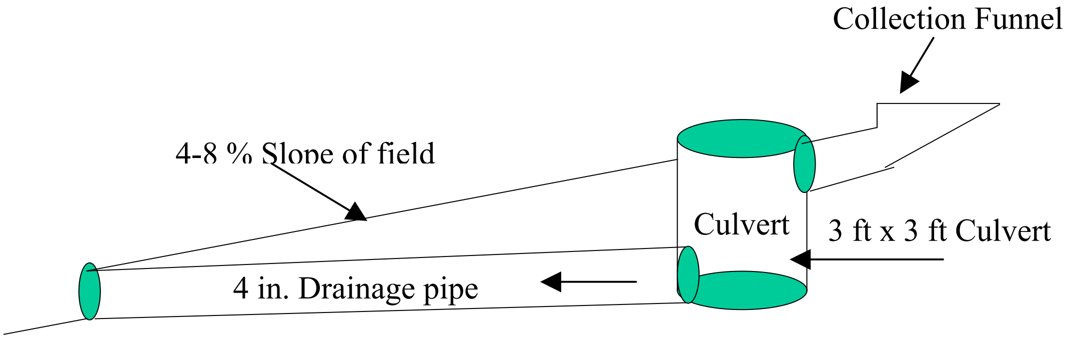

Figure 6. Collection funnel and pit discharge for runoff collection.

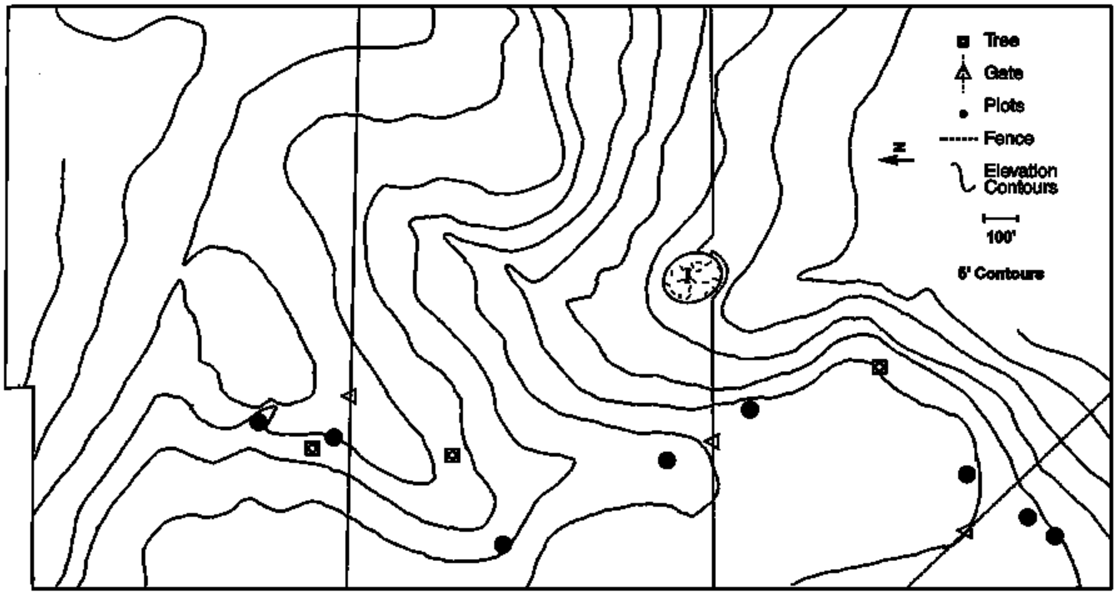

Figure 7. Topographic map shows the distance and hydraulic head.

Rainfall Simulator

Each rainfall simulator setup provided controlled precipitation for two plots simultaneously, A and B. The rainfall simulator was capable of wetting a 15-m (50-ft) diameter area (Huhnke et al. 1993). The simulator was leveled with its center at 2.7 m (9 ft) above the ground. The nozzles spray continuously, while the booms rotate. Closing selected nozzles, rainfall intensity may be set at two nominal rates, 12 and 6 cm/h (5.0 and 2.5 in./h). The boom rotates at approximately four revolutions per minute. A central alley, 3 m (10 ft) wide, between plots, allows room for simulator placement, between semi-circular plot pairs. The rainfall simulator was operated at an intensity of 6 cm/h (2.5 in./hr). Rainfall simulator setup required a complete flush of all lines and nozzles prior to each scheduled rainfall event. If problems appeared, repairs were made immediately.

Soil and Forage Sampling

Two soil probes were used to collect soil samples in the field. The first soil probe had an adjustable sleeve set at 5 cm (2 in.). This allowed the sampler to collect the first 5-cm (2 in.) of the soil sample. The second probe was marked at a depth of 15 cm (6-in.), and used in the same hole. SWFAL recommends a 15-cm (6-in.) depth of sample based on the agronomic calibration. A clean plastic bucket was used to mix soil cores before putting soil in to labeled sample bags. Each sample submitted for analyses was a composite sample of 15 cores taken randomly on each plot. The four paddocks were sampled bi-annually, once in the early April and once in October before litter was applied. Two sets of soil samples were taken from the plots after simulated rainfall at 0-5 cm (0-2 in.) and 5-15 cm (2-6 in.). Soils sample bags were labeled by location, depth, and date of sampling.

Forage samples were collected throughout the growing season on 35-day intervals. Three randomly placed grazing exclosures were maintained in each treatment except the negative control. Samples were clipped at approximately 2-cm (¾ in.) height to mimic that of forage removal by haying. Forage samples were collected from a randomly placed 9 cm x 18 cm (1ft x 2 ft) PVC grid. Subsequent to collection of the samples from a grazing exclosure, all remaining standing forage was cut with a weed eater, raked and removed from the exclosure. Collected samples were placed in paper bags labeled as to date and location of collections. Samples were air-dried, weighed and shipped to the laboratory in their sample bags. Samples were analyzed for moisture, crude protein, ADF, TDN, net energy maintenance, lactation and growth, calcium, P, K, sulfur, magnesium, sodium iron, manganese, copper, and zinc.

Runoff Sampling and Analysis

Seven 500-ml runoff samples and one rainwater sample were collected from each plot during rainfall simulator-runoff events. After each rainfall simulator-runoff event, samples were taken to a field laboratory where they were split into three sub-samples, two of which were filtered (0.45 μm pore diameter). One filtered 60-ml subsample was preserved for NO_3-N and NH_4-N with 0.2 ml of 4M sulfuric acid solution to reduce pH to 2. The other filtered 60-ml sample was used for Ortho-P analysis without preservation. All subsamples were cooled with ice immediately after filtration. The remaining 320 ml of sample was frozen for analysis of Total P and total Kjeldahl nitrogen (TKN). All the filtered samples were taken to OSU SWFAL for further analysis within 24 hours.

Quality Assurance and Quality Control

During scheduled rainfall events a coordinating supervisor (the pit-bull) was in charge of monitoring, and recording all sampling times. The pit-bull would notify the water pit crew when to take samples. All water samples were collected in polyethylene containers, labeled with indelible ink according to rainfall event, simulator setup, and sample sequence number.

During each rainfall simulation event seven runoff samples were collected from each plot and one rainwater sample. Simulator supervisor (water boy) collected rainwater samples (field blank) by placing a pre-labeled polyethylene container under the rotating boom. A spike, split and duplicate were also submitted with water samples from each rainfall simulation circle. The spikes and splits were created during field laboratory filtration by splitting a predetermined subsample into two 60 ml vials, spikes and splits were handled identically to runoff samples. Quality control checks were assigned to runoff-collected subsample #4. The spikes and splits were assigned to samples 1A, 3A, 5A, 7A, 2B, 4B, 6B, and 8B. While the numbers in front of the letter signify from which simulation site the sample originated. Spike samples originated from 1A4, 3A4, 5A4, and 7A4, splits were assigned to samples 2B4, 4B4, 6B4, and 8B4. The field laboratory finished separating all subsamples by placing them in the appropriate cooler for delivery to SWFAL. The results of the quality assurance and quality control are found in appendix 2.

SWFAL analyzed both preserved (Nitrate and Ammonia) and unperserved (Ortho-P) samples within 24-hours. All samples received the same quality control checks throughout the project. The analytical methods used by SWFAL are shown in Table 5.

Table 5. Nutrient analysis and chemical method used by SWFAL.

Analyte	Method*
Ammonia (Phenolate) in potable and surface waters.	QuickChem Method 10-107-06-1-B
Nitrate/Nitrite, Nitrite in surface water, wastewater.	QuickChem Method 10-107-04-1-A
Orthophosphate in waters	QuickChem Method 10-115-01-1-A

*Lachat Instruments, 6645 West Mill Road, Milwaukee, WI 53218

Statistical Analyses

The experimental design was a 4 x 6 factorial arrangement of treatment in a completely randomized design. The factors of interest were date (6 levels) and treatment (4 levels). Treatment levels were litter applications based on crop-N requirements with grazing (N-based), litter and commercial fertilizer application based on crop-P requirements with grazing (P-based), no fertilizer with grazing (control), and one without fertilizer or grazing (negative control). Treatment effects were examined on the the following parameters:

Runoff Volume

Soil Test Nitrate-N (NO_3-N

Soil Test Ammonium (NH_3-N)

Soil Test Phosphorus

Runoff Nitrate-N

Runoff Soluble Reactive Phosphorus

All statistical analyses were performed at an alpha level of 0.05 (α=0.05). The soil samples from 0-5 cm (0-2 in.) and 5-15 cm (2-6 in.) were analyzed separately. PROC MIX from SAS software performed the analyses of variance (ANOVA) (SAS Institution Inc,. 1999).

Simple effects (treatment and date) were evaluated first for each variable holding one factor constant with the slice option from the LSMEAN procedure statement. The DIFF option from the LSMEANS procedure compared mean by a least significant difference procedure when overall simple effects of a factor were significant.

Total Load and Flow Weighted Mean Concentration

The flow-weighted mean concentration was calculated for each plot, A and B. All information to complete the calculation was obtained from rainfall runoff and nutrient concentrations. Flow-weighted mean concentrations were calculated as the ratio of total load to total flow value from the following equations. Equation (1) was used to compute load, and equation (2) was used to compute flow. Equation (3) was used to compute the flow weighted mean concentration for each plot. In each equation $_{i-1}$ is where runoff begans.

$$L= \sum_{i=1}^{n} \Delta t_i \frac{(Q_{i-1} + Q_i)}{2} * C_i \qquad (1)$$

$$F= \sum_{i=1}^{n} \Delta t_i \frac{(Q_{i-1} + Q_i)}{2} \qquad (2)$$

$$FWM= \frac{L}{F} \qquad (3)$$

Q= bucket size (l)/ fill time (s)

C= nutrient concentration (mg l^{-1})

t= time after rainfall
L= flow weighted average (mg)

F= total flow (l)

FWM= flow weighted mean concentration

All informati the start of runoff to the last runoff san

RESULTS

Soil Nitrate-N

Soil nitrate-N concentrations varied throughout the course of the project. Figures 8 and 9 show nitrate-N from soil depths 0-5 cm (0-2 in.) and 5-15 cm (2-6 in.). Soil nitrate concentrations in both N-based and P-based treatments were similar in the top of the soil profile 0-5 cm (0-2 inches) depth. May 2, 1998 and May 19, 1999 litter and commercial fertilizers were applied to the appropriate fields. In both years, both application of commercial fertilizer and poultry litter produced higher soil nitrate-N mean concentration in the first soil sampling (May 1998 and June 1999). The control and negative control were similar to one another and always lower than either litter or commercial fertilizer treatments. There was a difference between the controls and both N-based and P-based treatment after fertilizer was applied. During late season soil sampling, the soil nitrate-N concentrations decreased. The soil samples collected from the P-based treatment showed a decrease in nitrate-N, whereas the N-based treatment decreased but not as mush as the P-based treatment. Following one year after the first soil sampling the P-based treatment was similar to the control and negative controls.

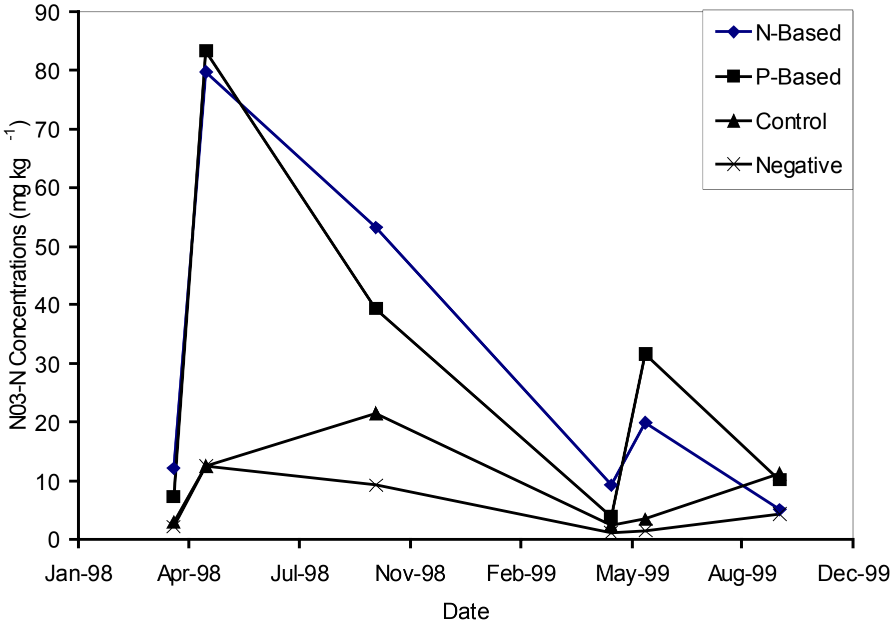

Figure 8. Soil test nitrate-N concentration at 0-5 cm (0-2 in.). Litter application dates: May 9, 1997, May 2, 1998, and May 19, 1999.

Soil nitrate-N concentrations, at depths of 5-15 cm (2-6 in.), followed the same trends as the 0-5-cm (0-2 in.) before and after litter and fertilizer applications. Soil nitrate-N on the P-based treatments were higher than N-based treatments immediately after litter and commercial fertilizer applications as indicated in Figure 9 (May 21, 1998 and June 26, 1999).

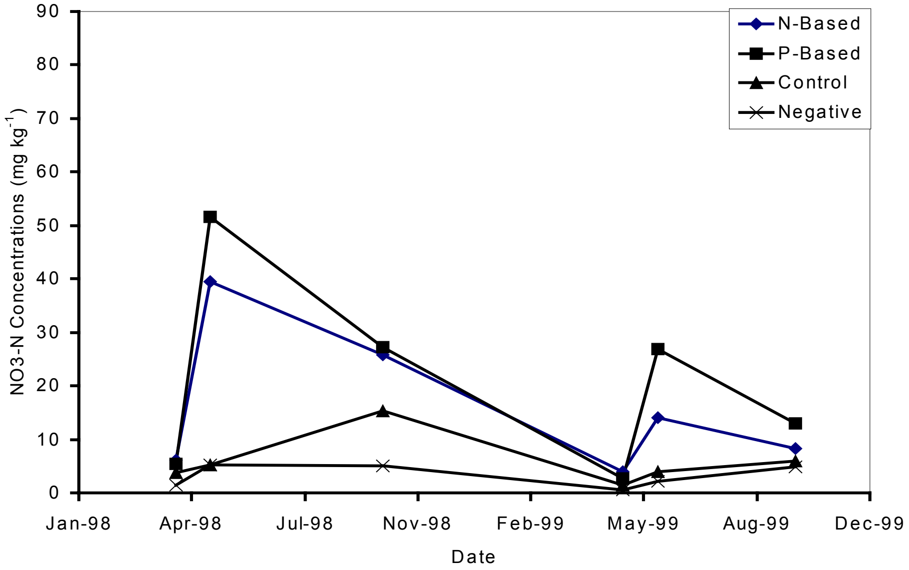

Figure 9. Soil test nitrate-N concentration at 5-15 cm (2-6 in.). Litter application dates: May 9, 1997; May 2, 1998 and May 19, 1999.

Analysis of treatment means of soil NO_3-N by least significant difference by date (Table 6) shows no significant difference between controls and treatments one year after litter and commercial fertilizer application (April 1998 and May 1999). There were not significant differences between treatments and controls four months following the second litter application (October 25, 1999). But there was a significant difference between treatments and controls for the third years, October 26, 1998.

Table 7, provides the results for 5-15 cm (2-6 in) depth. The analysis of least significant differences for soil NO_3-N by date showed a significant difference between treatments and controls for P-based and N-based application immediately following litter and commercial fertilizer application (May 21, 1998 and June 26, 1999). There was not a significant difference between controls and treatments one year after litter application (May 17, 1999). There was a significant difference between controls and treatments for October 26, 1998, four months after fertilizer applications.

Table 6. Soil nitrate-N treatment means at 0-5 cm (0-2 in.).

Date	Treatment			
	Negative	Control	N-Based	P-Based
	-------------------------mg kg^{1}--------------------			
April 29, 1998	2.13(a)	2.88(a)	12.0(a)	7.25(a)
May 21, 1998	12.5(a)	15.8(a)	79.8(b)	83.3(b)
October 26, 1998	9.25(a)	21.5(a)	53.3(c)	39.3(b)
May 17, 1999	1.00(a)	2.38(a)	9.25(a)	3.75(a)
June 26, 1999	1.38(a)	3.50(a)	24.9(b)	31.5(b)
October 25, 1999	4.35(a)	11.6(a)	5.10(a)	10.5(a)

Different letters within a row denote significant difference between treatment groups on that date (α=0.05).

Table 7. Soil nitrate-N treatment means at 5-15 cm (2-6 in.).

Date	Treatment			
	Negative	Control	N-Based	P-Based
	-------------------------mg kg^{1}--------------------			
April 29, 1998	1.50(a)	3.88(a)	6.13(a)	5.38(a)
May 21, 1998	5.25(a)	12.5(a)	39.5(b)	51.5(c)
October 26, 1998	5.00(a)	15.3(b)	25.8(c)	27.3(c)
May 17, 1999	0.63(a)	1.50(a)	4.00(a)	2.63(a)
June 26, 1999	2.25(a)	4.00(a)	17.8(b)	26.9(c)
October 25, 1999	4.95(a)	5.98(a)	8.25(a)	13.1(a)

Different letters within a row denote significant difference between treatment groups on that date (α=0.05).

Soil Ammonium Nitrate

Figures 10 and 11 show NH_4-N from soil depths at 0-5 cm (0-2 in.) and 5-15 cm (2-6 in.). Overall, soil NH_4-N concentrations at both depths were similar in control and treatments. There was a slight difference between the controls and both N-based and P-based treatments on October 26, 1998 and on June 26, 1999 in the 0-5 cm (0-2 in.). In the 5-15 cm (2-6 in.) soil NH_4-N on the P-based treatments and N-based treatments were lower than the controls immediately after litter and commercial fertilizer applications as indicated in Figure 11 dates May 21,1998 and June 26, 1999.

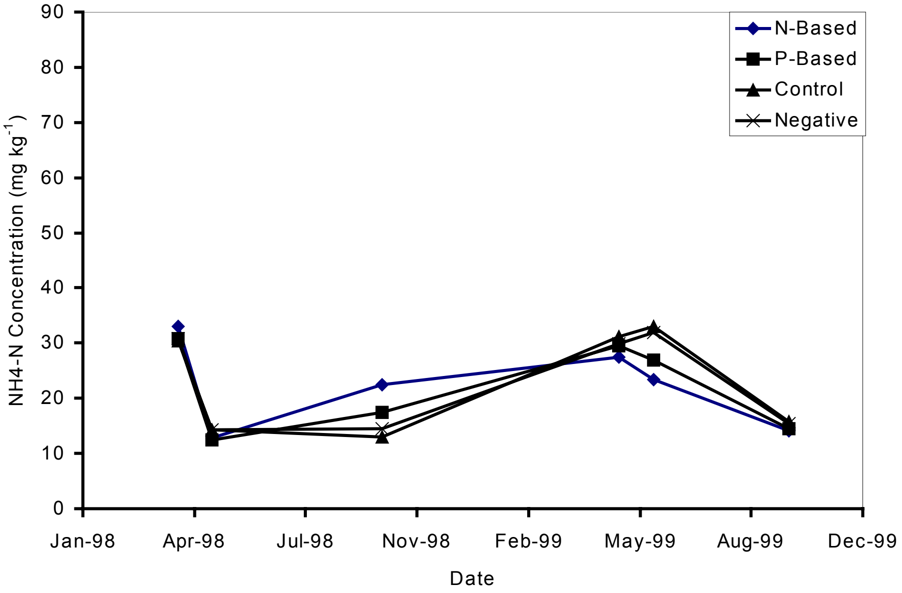

Figure 10. Soil test ammonium-N concentration at 0-5 cm (0-2 in.). Litter application dates: May 9, 1997; May 2, 1998, and May 19,1999.

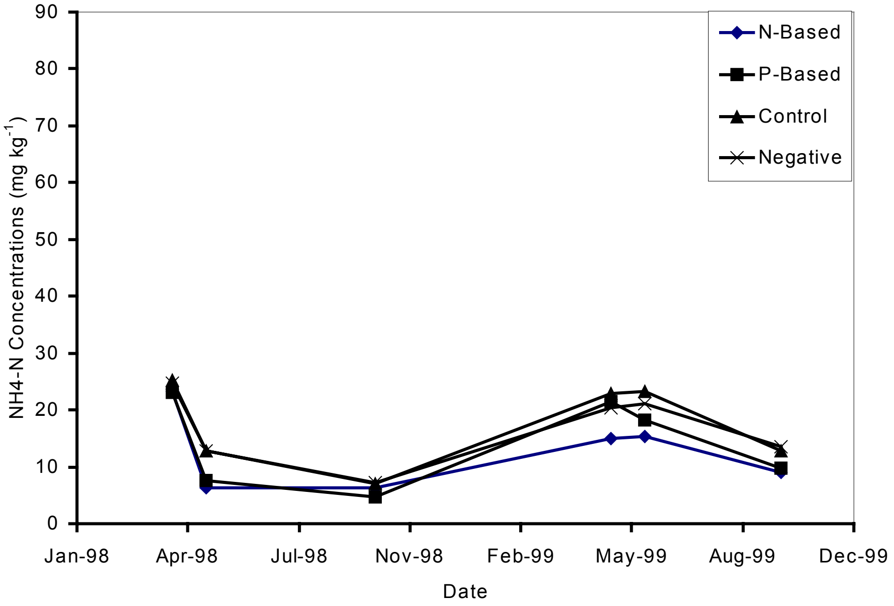

Figure 11. Soil test ammonium-N concentrations at 5-15 cm (2-6 in.). Litter application dates: May 9, 1997, May 2, 1998, and May 19, 1999.

Table 8 shows no difference in soil NH_4-N between controls and treatments means before litter application one year after litter and fertilizer application (April 1998 and May 1999) or following the first litter application (May 21, 1998). There was significant difference between N-based treatments and controls on the second litter application (June 26, 1999), however. The P-based treatment also showed no significant difference compared to control or N-based treatments on that date (June 26, 1999). However, the soil NH_4-N means for the controls were higher than N-based and P-based treatments on both fertilizer application dates (May 17, 1998 and June 26, 1999). There was no significant difference between treatments and controls for the third years, October 26, 1998.

Table 8. Soil ammonium-N treatment means at 0-5 cm (0-2 in.).

Date	Treatment			
	Negative	Control	N-Based	P-Based
	-------------------------mg kg^1--------------------			
April 29, 1998	30.8(a)	30.5(a)	33.0(a)	30.8(a)
May 21, 1998	14.3(a)	16.5(a)	12.8(a)	12.5(a)
October 26, 1998	14.5(a)	13.0(a)	22.5(b)	17.5(a,b)
May 17, 1999	29.8(a)	31.2(a)	27.5(a)	29.6(a)
June 26, 1999	32.0(a)	33.0(a)	26.2(b)	26.9(a,b)
October 25, 1999	15.4(a)	13.0(a)	22.5(a)	17.5(a)

Different letters within a row denote significant difference between treatment groups on that date (α=0.05).

Table 9, provides the results for 5-15 cm (2-6 in) depth. The analysis of least significant differences for soil NH_4-N by date showed a significant difference between treatments and controls for P-based and N-based application immediately following litter and commercial fertilizer application (May 21, 1998 and June 26, 1999). There was a significant difference between controls and N-based treatments one year after litter application (May 17, 1999). There was no significant difference between controls and treatments for October 26, 1998, four months after fertilizer applications. Following the second fertilizer application there was a significant difference between controls and treatments (June 26, 1999 and October 25, 1999).

Table 9. Soil ammonium-N treatment means at 5-15 cm (2-6 in.).

Date	Treatment			
	Negative	Control	N-Based	P-Based
	-------------------------mg kg^1--------------------			
April 29, 1998	24.8(a)	25.3(a)	23.3(a)	23.0(a)
May 21, 1998	12.8(a)	12.0(a)	6.25(b)	7.5(b)
October 26, 1998	7.25(a)	7.00(a)	3.25(a)	4.75(a)
May 17, 1999	20.3(a)	22.9(a)	14.9(b)	21.5(a)
June 26, 1999	21.1(a)	23.3(a)	17.7(b)	18.2(a,b)
October 25, 1999	13.6(a)	12.8(a)	9.00(b)	9.08(b)

Different letters within a row denote significant difference between treatment groups on that date (α=0.05).

Soil Test Phosphorus

Figures 12 and 13 show STP from soil depths at 0-5 cm (0-2 in.) and 5-15 cm (2-6 in.). Concentrations of STP at 0-5 cm depth (0-2 inches) were consistently higher in N-based treatments compared to P-based treatments and control. On May 2, 1998 and May 19, 1999 litter and commercial fertilizers were applied to the appropriate plots. This application of commercial fertilizer produced a higher STP mean concentration at the next sampling on May 1998 and June 1999. The control and negative control were similar to one another. There was a difference between the controls and both N-based and P-based treatments after fertilizer was applied. The P-based treatment followed a variable trend compared to the unpredictable N-based treatment.

Soil test phosphorus (STP) concentrations, at depths of 5-15 cm (2-6 in.), followed different trends from the 0-5 cm (0-2 in.) before and after litter and fertilizer applications (Figure 13). Soil test phosphorus (STP) on the P-based treatments were always lower than on N-based treatments immediately after litter and commercial fertilizer applications as indicated in Figure 13 dates May 21, 1998 and June 26, 1999. The P-based treatment STP means were very similar to the control treatments at 5-15 cm (2-6 in.). Only the N-based treatment stands out.

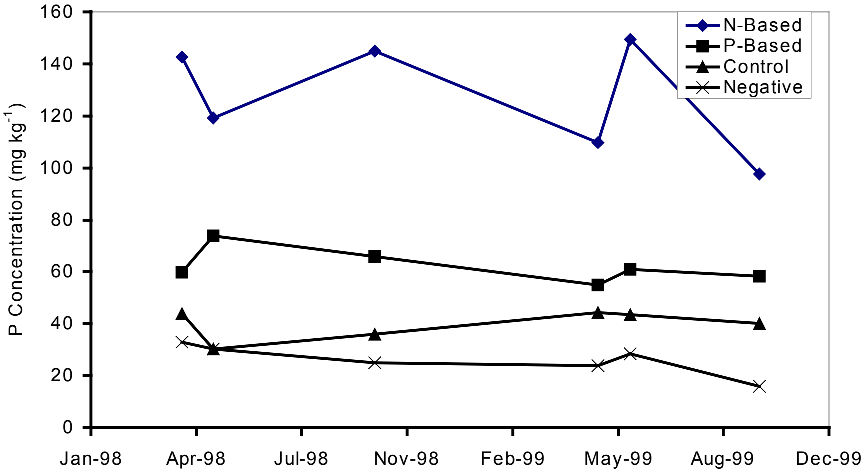

Figure 12. Soil test phosphorus concentration at 0-5 cm (0-2 in.). Litter application dates: May 9, 1997, May 2, 1998, and May 19, 1999.

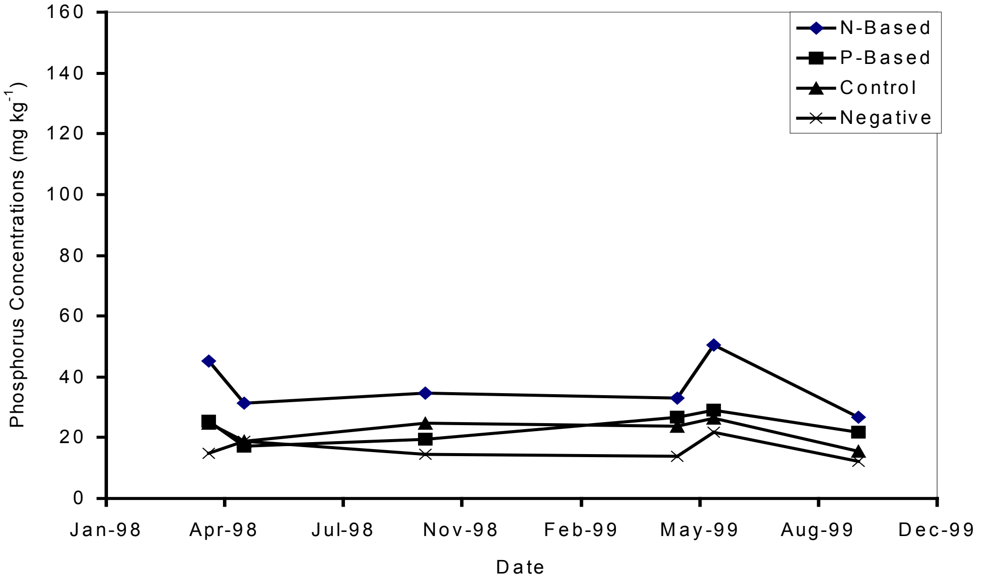

Figure 13. Soil test phosphorus concentrations at 5-15 cm (2-6 in.). Litter application dates: May 9, 1997, May 2, 1998, and May 19,1999.

Analysis of treatment means for STP by least significant difference by date for 0-5 cm (0-2 in) depth are shown in Table 10. All treatments were significantly different from controls. Control and negative control treatment were not significantly different on any date. N-based and P-based treatments were significantly different from one another on any date. The P based treatment was significantly different from the control and negative control on all sample dates.

Table 11, for 5-15 cm depth (2-6 in) shows no significant difference between controls. N-based treatment, however, was significantly different from control, negative control, and P-based treatment on April 29, 1998, May 21, 1998, October 26, 1998 and June 26, 1999. N-based and P-based treatments were not significantly different from one another on sample dates May 17, 1999 and October 25, 1999. There were significant differences between P-based treatments and controls on May 17, 1999.

Table 10. Soil test phosphorus means at 0-5 cm (0-2 in.).

Date	Treatment			
	Negative	Control	N-Based	P-Based
	-------------------------mg kg^{1}--------------------			
April 29, 1998	33.0(a)	43.9(a)	142(c)	59.6(b)
May 21, 1998	30.3(a)	38.5(a)	119(c)	73.8(b)
October 26, 1998	25.2(a)	36.0(a)	145(c)	66.0(b)
May 17, 1999	24.0(a)	44.4(a)	143(c)	59.6(b)
June 26, 1999	28.4(a)	43.5(a)	136(c)	60.8(b)
October 25, 1999	15.8(a)	40.1(a)	97.8(c)	58.2(b)

Different letters within a row denote significant difference between treatment groups on that date (α=0.05).

Table 11. Soil test phosphorus means at 5-15 cm (2-6 in.).

Date	Treatment			
	Negative	Control	N-Based	P-Based
	-------------------------mg kg^{1}--------------------			
April 29, 1998	14.8(a)	24.8(a)	45.3(b)	25.5(a)
May 21, 1998	18.8(a)	19.6(a)	31.5(b)	17.3(a)
October 26, 1998	14.5(a)	24.6(a)	34.8(b)	19.5(a)
May 17, 1999	13.8(a)	23.8(a)	33.1(b)	26.9(b)
June 26, 1999	21.8(a)	26.4(a)	47.6(b)	29.0(a)
October 25, 1999	12.3(a)	15.5(a)	26.8(b)	21.8(a,b)

Different letters within a row denote significant difference between treatment groups on that date (α=0.05).

Rainfall

Naturally occurring rainfall can affect the flow-weighted mean concentrations of nutrients in runoff over time. There was drought during the period from April 1998 and October 1998. After October 1998 rainfall patterns increased to normal during the final course of the project. Appendix 3 shows monthly rainfall totals from three different sites located near the project area. Figure 14 provides an averaged monthly total of rainfall from the three sites. The observations below discussed in reference to simulated rainfall.

Water Quality Data

The flow-weighted mean concentrations from simulated rainfall events were used to describe nutrient loss, through runoff. Figures 15 through 20 provide an overview of flow-weighted means concentrations over time from simulated rainfall events. Figure 15 through 17 show all flow-weighted mean concentrations for all simulation sites. Figures 18 through 20 show flow-weighted mean concentrations for the same simulations excluding plot 3. Results in plot 3 were somewhat inconsistent. Therefore, results are presented with and without plot 3.

During early rainfall events, forage density was extremely low and nutrient uptake was low due to lack of moisture. After the May 2, 1998 litter application rainfall decreased below normal conditions. Rainfall in June, July and August rainfalls totaled less than two inches, less than the one-month total for May 19, 1999 (8 – 22 cm).

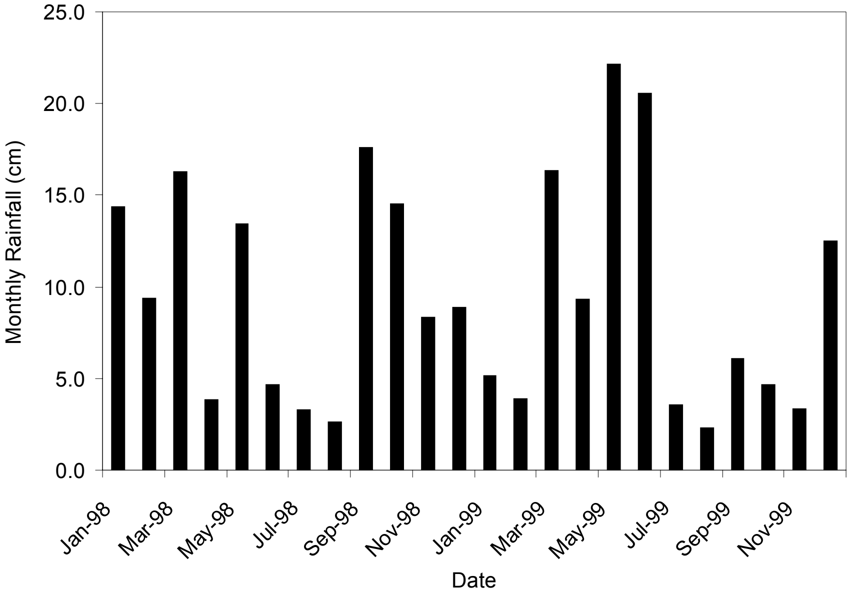

Figure 14. Monthly rainfall totals, average from three nearby stations (Mesonet, Heavner, Poteau).

Nitrate

Nitrate-N flow weighted means concentrations are shown graphically in Figure 15. Before litter and fertilizer application all treatments were very similar during April 29, 1998 rainfall event. After the first litter application, the P-based treatment was higher than the N-based treatment (May 21, 1998, June 26, 1999, and October 25, 1999 rainfall events). Typically the early flush of nitrate-N on the P-based application would be expected to be graphically closer to the N-based applications concentration. However, naturally occurring rainfall was minimal from April 98 through October 98. The decrease in natural rainfall initially left more nitrate-N at the surface and consequently higher concentrations of nitrate-N in runoff. During the second year of sampling, a normal rainfall patterns was present. The N-based and P-based treatments were very similar. The peak nitrate-N concentration observed October 26 ,1998 was due to high nitrate in the source water used for the rainfall simulator.

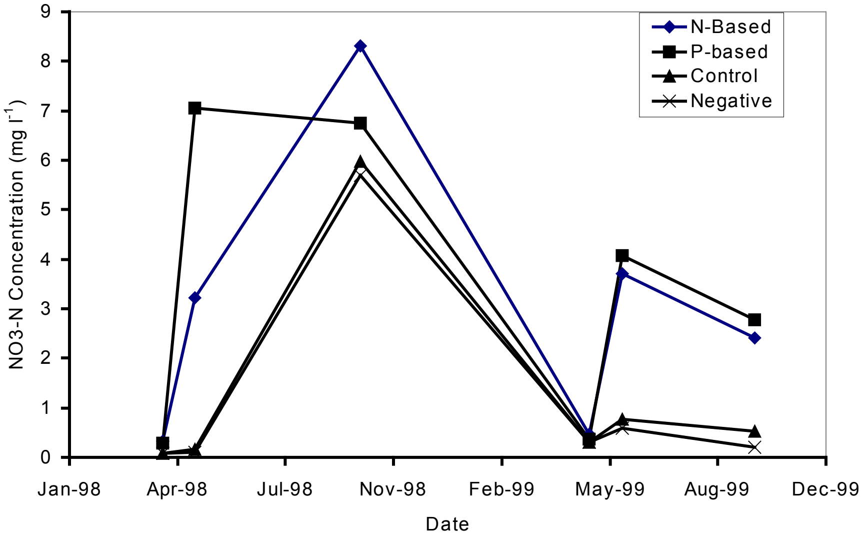

Figure 15. Nitrate-N flow-weighted mean concentrations. Litter application dates: May 9, 1997, May 2, 1998, and May 19,1999.

An analysis of Nitrate-N flow-weighted treatment mean concentrations by least significant means is shown in Table 12. Mean concentrations of control, negative control, N-based and P-based treatments for April 29, 1998 and May 17, 1999 were not significantly different. Control and negative control treatments showed no significant differences on any date. N-based and P-based treatments were not significantly different (α=0.05) from one another on sample dates October 26, 1998, May 17,1999, June 26, 1999 and October 25, 1999. The P-based treatment was significantly different from the N-based on May 21,1998, however, corresponding to poultry litter and commercial fertilizer being applied just weeks before sampling.

Table 12. Runoff nitrate-N flow weighted mean concentrations.

Date	Treatment			
	Negative	Control	N-Based	P-Based
	--------------------------mg l^{-1}--------------------			
April 29, 1998	0.07(a)	0.09(a)	0.32(a)	0.28(a)
May 21, 1998	0.10(a)	0.16(a)	3.23(b)	7.06(c)
October 26, 1998	5.69(a)	5.97(a)	8.31(b)	6.76(b)
May 17, 1999	0.30(a)	0.30(a)	0.46(a)	0.36(a)
June 26, 1999	0.59(a)	0.77(a)	3.71(b)	4.07(b)
October 25, 1999	0.21(a)	0.53(a)	2.42(b)	2.77(b)

Different letters within a row denote significant difference between treatment groups on that date (α=0.05)

Ammonium

Ammonium (NH_4-N) flow weighted means concentrations are shown graphical shown in Figure 16. Initially, April 29, 1998, P-based, control, and negative control treatments were very similar (less than 1 mg l^{-1}) whereas the N-based treatment was about 2 mg l^{-1}. P-based treatments were higher during the May 21, 1998 and June 26, 1999 rainfall events immediately following litter and commercial fertilizer application.

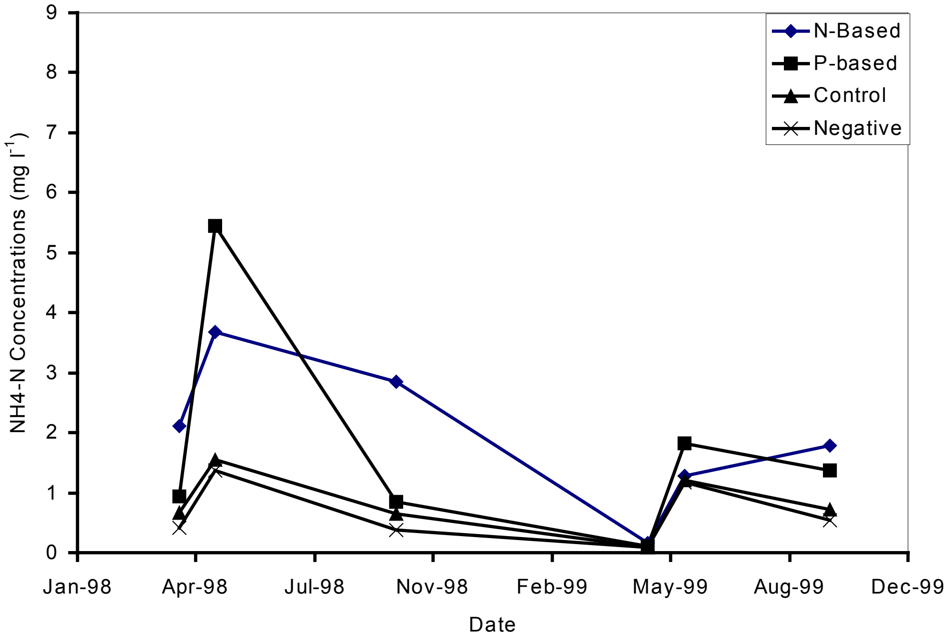

Figure 16. Ammonium-N flow rated mean concentration. Litter application dates: May 9, 1997, May 2, 1998, and May 19 1999.

An analysis of ammonium flow-weighted mean concentrations was completed by least significant difference by date showed no significant difference among all treatments on May 17, 1999, June 26, 1999 and October 25, 1999 (Table 13). Control and negative control treatments showed no significant differences on any date. N-based and P-based treatments were significantly different (α=0.05) from one another on sample dates April 29, 1998, October 26, 1998 and May 21, 1998. The P-based treatment mean concentration was higher than the N-based treatment on May 21,1998. However, naturally occurring rainfall was minimal from April 98 through October 98. The decrease in natural rainfall initially provided higher concentrations of ammonium in runoff. During the second year of sampling, normal rainfall patterns were present.

Table 13. Runoff ammonium-N flow weighted mean concentrations.

Date	Treatment			
	Negative	Control	N-Based	P-Based
	--------------------------mg l^{-1}--------------------			
April 29, 1998	0.42(a)	0.67(a)	2.12(b)	0.94(a)
May 21, 1998	1.37(a)	1.55(a)	3.67(b)	5.44(c)
October 26, 1998	0.38(a)	0.65(a)	2.85(b)	0.84(a)
May 17, 1999	0.08(a)	0.09(a)	0.16(a)	0.10(a)
June 26, 1999	1.17(a)	1.20(a)	1.28(a)	1.83(a)
October 25, 1999	0.54(a)	0.73(a)	1.79(a)	1.37(a)

Different letters within a row denote significant difference between treatment groups on that date (α=0.05).

Soluble Reactive Phosphorus

Soluble reactive phosphorus (SRP) flow-weighted mean concentrations are shown graphically in Figure 17. Before litter and fertilizer application P-based, control and negative control treatments were very similar during April 29, 1998 rainfall event. The N-based treatment had a higher SRP concentration from May 9, 1997 litter application. N-based treatments and P-based were always higher than control treatments during all rainfall events. Graphically the N-based and P-based treatments followed the same trend. The control and negative control treatment were almost identical throughout the course of the project.

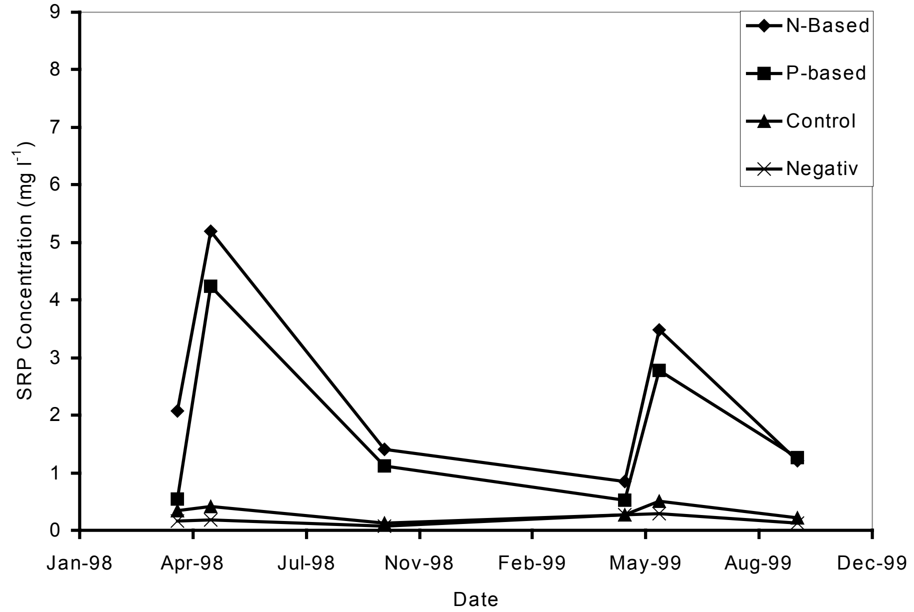

Figure 17. Soluble reactive phosphorus flow weighted mean concentrations. . Litter application dates: May 9, 1997, May 2,1998 and May 19 1999.

An analysis of SRP flow weighted treatment means concentrations by least significant difference by date showed a significant difference between treatment and controls following litter and commercial fertilizer applications (May 21, 1998 and June 26, 1999) (Table 14). Control and negative control treatment showed no significant differences on any date. N-based and P-based treatments were not significantly different from one another on all sample dates except April 29, 1998. There was no significant difference between control and treatment during the end of season rainfall events (May 17, 1999, October 26, 1998 and October 25, 1999).

Table 14. Runoff Soluble reactive phosphorus flow weighted mean concentrations.

Date	Treatment			
	Negative	Control	N-Based	P-Based
	--------------------------mg l^{-1}--------------------			
April 29, 1998	0.16(a)	0.34(a)	2.07(b)	0.54(a)
May 21, 1998	0.18(a)	0.42(a)	5.20(b)	4.24(b)
October 26, 1998	0.07(a)	0.13(a)	1.40(a)	1.12(a)
May 17, 1999	0.12(a)	0.26(a)	0.85(a)	0.52(a)
June 26, 1999	0.28(a)	0.51(a)	3.48(b)	2.78(b)
October 25, 1999	0.13(a)	0.21(a)	1.20(a)	1.26(a)

Different letters within a row denote significant difference between treatment groups on that date (α=0.05).

DISCUSSION

The lack of significant differences in runoff SRP between N-based and P-based treatments was surprising in light of the large differences in litter application rates. The difference between N-based and P-based management is amplified by removing plot 3, which seems to be a large source of variance. The removal of plot 3 changed SRP but didn't change nitrate or ammonium flow-weighted mean runoff concentrations. Even with plot 3 removed; there was a large increase in the SRP flow-weighted mean concentration in the first rainfall after litter application.

Figure 18 displays flow-weighted mean runoff concentrations for P-based treatment with and without plot 3. On April 29, 1998 both P-based treatment showed the same mean SRP concentration. After litter and commercial fertilizer application both N-based and P-based treatments were within 1 mg l^{-1} form each other following litter and commercial fertilizer application. By removing plot 3, P-based concentrations were 3.2 mg l^{-1} lower than N-based treatment following litter and commercial fertilizer applications. The decrease in SRP concentrations after plot 3 removal is consistent with expectation, suggesting that the P-based management system, SRP runoff concentration could be maintained below 2 mg l^{-1}, even in the period following litter application.

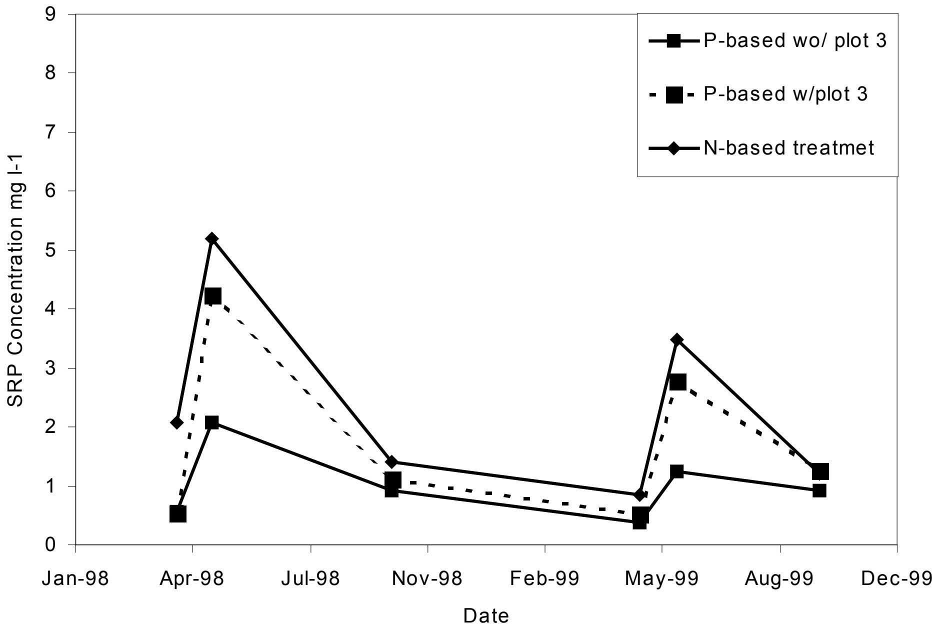

Figure 18. Soluble reactive phosphorus flow weighted mean concentrations. . Litter application dates: May 9, 1997, May 2, 1998 and May 19, 1999. Plot 3 removed.

An analysis of SRP flow-weighted treatment mean concentrations was completed with plot 3 removed. With plot 3 removed, the SRP for treatments were significantly different from the control and negative control. However, comparison of treatment for SRP values least significant difference by date showed mean concentrations for May 21, 1998 and June 26, 1999 still not significantly different from the controls at $\alpha= 0.05$ (Table14 and 15). The actual probability that N-based and P-based treatments were not equal was just outside the confidence interval (p=0.052). There was no significant difference in controls on any date. On June 26, 1999, there was a significant difference between the N-based and P-based treatment in Table 15.

Table 15. Runoff Soluble reactive phosphorus flow weighted mean concentrations. Plot 3 removed.

Date	Treatment			
	Negative	Control	N-Based	P-Based
	--------------------------mg l^{-1}--------------------			
April 29, 1998	0.16(a)	0.34(a)	2.07(b)	0.64(a)
May 21, 1998	0.18(a)	0.42(a)	5.2(b)	2.07(b)
October 26, 1998	0.07(a)	0.13(a)	1.4(a)	0.92(a)
May 17, 1999	0.12(a)	0.26(a)	0.85(a)	0.38(a)
June 26, 1999	0.28(a)	0.51(a)	3.48(b)	1.24(a)
October 25, 1999	0.13(a)	0.21(a)	1.2(a)	0.92(a)

Different letters within a row denote significant difference between treatment groups on that date (α=0.05).

The overall results from the project have provided significant information about how different treatments affect nutrient concentration in runoff. Furthermore, seasonal rainfall may have affected nutrient runoff concentrations. Through April 1998 and October 1998 rainfall events, nutrient runoff concentrations were higher than later rainfall events. The increase in concentrations appears to be related to the amount of natural rainfall. As natural rainfall increased, nutrient concentration decreased.

By comparing soil nutrients and flow-weighted mean concentration, I can create an overall analysis of what is taking place in the field. The analysis only looks at N-based and P-based treatment at the 0-5 cm (0-2 in.) of the soil, the depth most likely to influence runoff.

Correlation Coefficient of Determination

Figure 19 shows the correlation of SRP in runoff with STP in soils. The coefficient of determination (R^2) indicates that STP explains 33 percent of the variance in runoff SRP.

Analyzing the correlation for rainfall events April 1998 and May 1999, one year after litter application shows a higher coefficient of determination (R^2=0.60)(Figure 20). This suggests that increasing STP cause an increase in runoff SRP. The R^2 indicates 60 percent of the variance is explained by the regression.

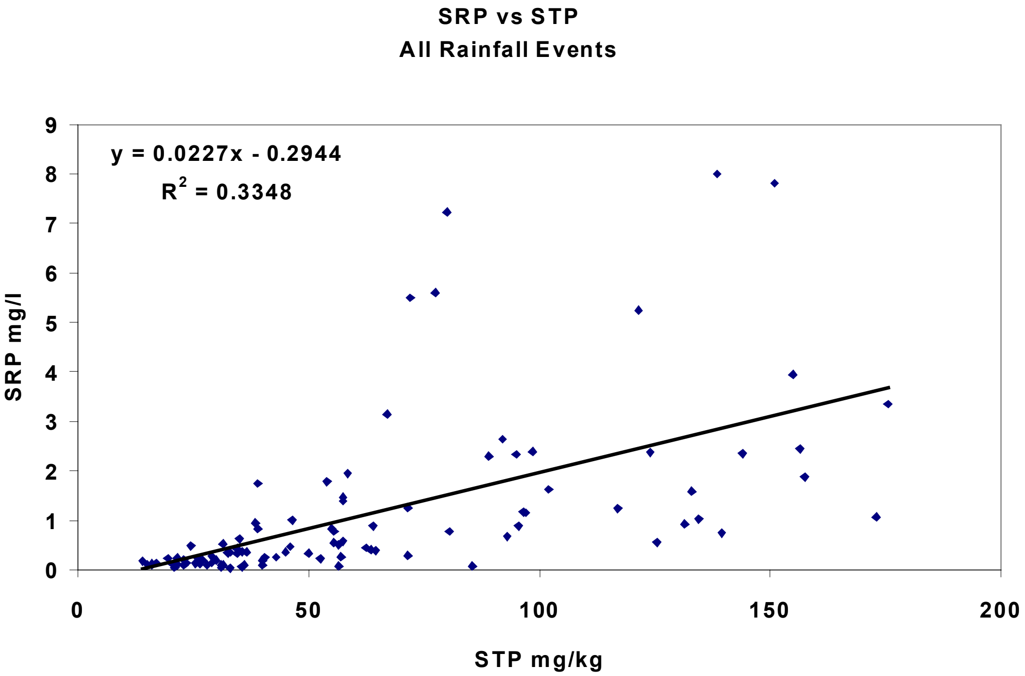

Figure 19. STP vs SRP correlation on all rainfall event.

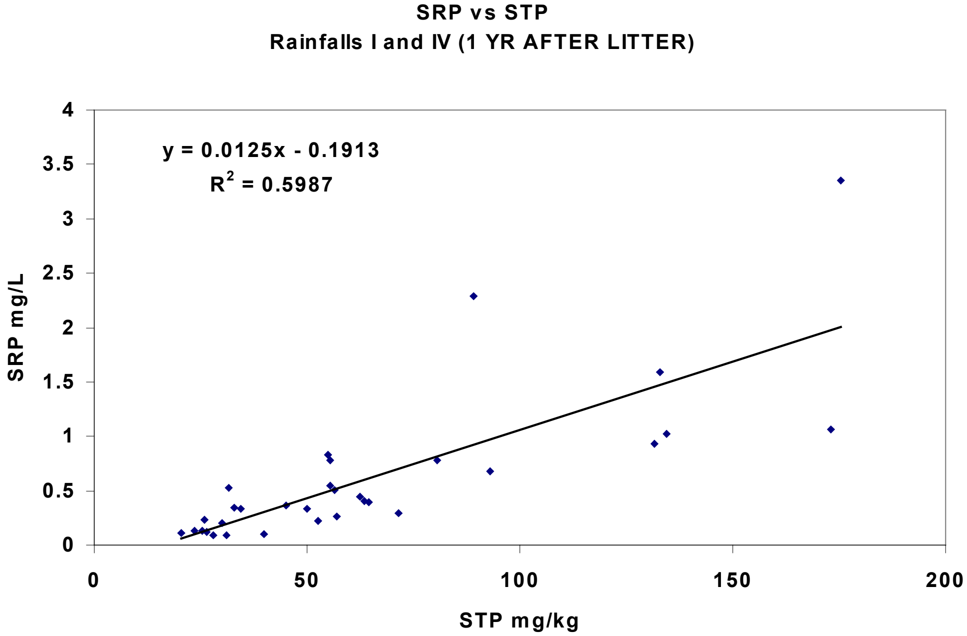

Figure 20. STP vs. SRP correlation after litter applications one year apart.

Grazing Management

Under traditional management plans, poultry litter provides all nutrients for the grazing system. P-Based management limits the amount of litter applied according to recommendations based on STP (OSU Fact Sheet 2225). Commercial fertilizer is substituted for the remaining nitrogen needed to establish a forage yield goal.

By substituting commercial nitrogen fertilizer for poultry litter, the STP concentrations do not continue to increase beyond agronomic recommend levels for crop production. This is not the case for N-based management where STP increased indefinitely.

SRP for P-based management was lower than N-based management (P=0.052) (plot 3 removed). Under P-based management a lower mean SRP concentration was identifiable throughout all sampling dates. By following the P-based management plan runoff concentrations during rainfall event can be maintained below 2 mg l^{-1}.

There was no significant difference between control and negative control treatments with respect to N, P, or runoff on all sampling dates. However, the grazed control showed higher mean concentrations of nutrients throughout the project. In order to determine the effect of cattle on a sensitive grazing system further research must be done.

CONCLUSIONS

The rainfall simulator allowed us to collect runoff samples from small plots under 4 management scenarios. This method was very time consuming and labor intensive, but much less than monitoring natural rainfall. The design was based on subsampling from treatments repeatable throughout this experimental design.

Comparison of a P-based to N-based strategies showed the average forage yields to be similar over the three-year study. Forage production at Briggs ranch was also used to maintain high stocking rates. The fertility level was able to maintain a relatively high amount of protein content, which sustained a high stocking.

Under N-based and P-based treatments, soil test nitrate-N was applied at identical rates. However, soil test nitrate-N was higher in the P-Based treatment immediately after commercial fertilizer application. The increased soil nitrate-N levels within this treatment are from the commercial fertilizer high fraction of soluble nitrate-N. As soil depth increased the nitrate-N concentrations increased with treatment following fertilizer application. The increase of nitrate-N at deeper depths is likely to be from leaching. The poultry litter applied to N-based treatments wasn't as soluble as commercial fertilizer, therefore, poultry litter-N didn't leach in the soil profile. The N-based treatment didn't significantly increase soil test nitrate after litter applications compared to P-based treatments. Therefore, P-based treatment receiving a commercial (inorganic) fertilizer should be applied twice a year. A late spring and late summer application could reduce nitrogen loss in runoff.

Applying poultry litter to meet crop nitrogen requirements increased soil test phosphorus. STP increased in the N-based applications. The application of poultry litter provided a minimum of a 3-fold difference. Therefore, STP increased due to the plant inability to remove excess phosphorus from the management scenario.

Analysis shows a strong relationship between soil test phosphorus and runoff soluble reactive phosphorus. This suggests that control of soil test phosphorus may be important in reducing runoff soluble reactive phosphorus. In order to control soil test phosphorus, the described P-based management strategies should be used. This study shows the P-based management strategies do not cause any loss of production, but can reduce runoff SRP. The P-based management plan provided a lower SRP flow-weighted mean concentration throughout.

BIBLOGRAPHY

Abrams, M. M. and W. M. Jarrell. 1995. Soil processes and chemical transport: Soil phosphorus as a potential nonpoint source for elevated stream phosphorus level. *Environmental Quality* 24: 132-138.

Beaulac, M. N. and K. H. Reckhow. 1982. An examination of land use and nutrient export relationship. Water Resources Bulletin, American Water Resources Association, 18(6): 1013-1024.

Chapman, P. J., C.A. Shand, A. C. Edwards, and S. Smith. 1997. Effect of storage and sieving on the phosphorus composition of soil solution. *Soil Science Society of America* 60: 315-321.

Chen, J. S., R. S. Mansell, P. Nkedi-Kizza, and B. A. Burgoa. 1996. Phosphorus transport during transient, unsaturated water flow in an acid soil. *Soil Science Society of America* 60: 42-48.

Cairns, J., B. R. Niederlehner, D. R. Orvos. 1992 *Predicting Ecosystem Risk*. New Jersey: Princeton Scientific Pub. Co..

Daniel, T. C., A. N. Sharpley, D. R. Edwards, R. Wedepohl, and J. L. Lemunyon, 1994. Minimizing surface water eutrophication from agriculture by phosphorus management. *Journal of Soil and Water Conservation* (49): 30-38.

Daniel, T. C., D. R. Edwards and A. N. Sharpley. 1993. Effect of extractable soil surface phosphorus on runoff water quality. *Transactions of the ASAE* 36(4): 1079-1085.

Edwards, D. R. and T. C. Daniel. 1993. Effects of poultry litter application rate and rainfall intensity on quality of runoff from fescue grass plots. *Journal of Environmental Quality* 22: 361-365.

Edwards, D. R., T. C. Daniel, P. A. Moore, Jr., P. F. Vendrell. 1994. Drying interval effects on quality of runoff from fescue plots treated with poultry litter. *American Society of Agricultural Engineers* 37(3): 837-843.

Environmental Protection Agency. 1992. EPA Journal 18(4). 175-N-92-010. USEPA, Wanshington, D. C.

Gartley, K. L. and J. T. Sims. 1994. Phosphorus soil testing: Environmental uses and implications. Commun. Soil Science. Plant Analysis 25:1565-1582.

Gerkin, H. J. 1977. Feeding broiler litter to beef cattle and sheep, Cooperative Extension Service Publication 754. Virginia Poly Tech., Institution and State University., Blackburg, VA.

Heathman, G. C., A. N. Sharpley, S. J. Smith, and J. S. Robinson. 1995. Land application of poultry litter and water quality in Oklahoma, U.S.A. *Fertilizer Research* 40: 165-173.

Hooda, P. S., A. R. Rendell, A. C. Edwards, P. J. A. Withers, M. N. Aitken and V. W. Truesdale. 2000. Relating soil phosphorus indices to potential phosphorus release to water. *Journal of Environmental Quality.* 29: 1161-1171.

Huhnke, R. L., D. E. Storm, G. O. Brown, and M. D. Smolen, 1992. Effect of poultry litter on surface water quality—Part 1. A field experiment. ASAE Paper No. 922135. St. Joseph, MI: ASAE.

Huhnke, R. L., D. E. Storm, G. O. Brown, and M. D. Smolen, 1993. Examination of potential risks to water quality from animal waste applied to soils of eastern Oklahoma.

McLeod, R. V., and R. O. Hegg. 1984. Pasture runoff water quality from application of inorganic and organic nitrogen sources. American Society of Agronomy 13(1): 122-126.

Oklahoma Department of Environmental Quality. 1998. The State of Oklahoma Water Quality Assessment Report. Oklahoma City: State of Oklahoma.

Pote, D. H., T. C. Daniel, A. N. Sharpley, P. A. Moore, Jr., D. R. Edwards, and D. J. Nichols. 1996. Relating extractable soil phosphorus to phosphorus losses in runoff. *Soil Science Society of America* 60(3): 855-859

Nash, D., M. Hannah, D. Hallewell, and C. Murdock. 2000. Factors affecting phosphorus export from a pasture-based grazing system. *Journal of Environmental Quality.* 29): 1160-1166.

Novak, J. M., D. W. Watts, P. G. Hunt, and K. C. Stone. 2000. Phosphorus movement through a coastal plain soil after a decade of intensive swine manure application. *Journal* of *Environmental Quality.* 29: 1310-1315

Robbins, C. W., L. L. Freeborn, and D. T. Westermann. 2000. Organic phosphorus source effects on calcareous soils phosphorus organic carbon. J*ournal* of *Environmental Quality.* 29: 973-978

Robinson, J. S. and A. N. Sharpley, 1995. Reaction in soil of phosphorus released from poultry litter. *Soil Science Society of America* 60(5): 1583-1588.

Sharpley, A. N. 1993. Assessing phosphorus bioavailability in agricultural soils and runoff. *Fertilizer Research.* 36: 259-272.

Sharpley, A. N. 1995a. Dependence of runoff phosphorus on extractable soil phosphorus. J*ournal of Environmental Quality.* 24(5): 920-926

Sharpley, A. N. 1995b. Identifying sites vulnerable to phosphorus loss in agricultural runoff. J*ournal of Environmental Quality.* 24(5): 947-951.

Sharpley, A. N., T. C. Daniel, J. T. Sims, and D. H. Pote. 1995a. Determining environmentally sound soil phosphorus level. *Soil and Water Conservation* 51(2): 160-166.

Sharpley, A. N., J. S. Robinson and S. J. Smith. 1995b. Assessing environmental sustainability of agricultural systems by simulation of nitrogen and phosphorus loss in runoff. *Journal of Agronomy* 4(4): 453-464.

Sharpley, A. N., S. J. Smith and W. R. Bain. 1993. Nitrogen and phosphorus fate from long-term poultry litter applications to Oklahoma soils. *Soil Science Society of America* 57: 1131-1137.

Smith, S.C., J. G. Britton, J. D. Ernis, K. C. Barnes, and K. S. Lusby. 1993. Mineral level of broiler house litter and forages and soils fertilized with litter. *Journal of Poultry Science* (70): 116

Storm, D. E., G. O. Brown, R. L. Huhnke, and M. D. Smolen, 1992. Effect of poultry litter on surface water quality—Part 2. Runoff results and analysis. ASAE Paper No. 922136. St. Joseph, MI: ASAE.

Wallingford, G. W., W. L. Powers, and L. S. Murphy. 1975. Present knowledge on the effect of land application of animal waste. P. 580-582, 586. In Proc. 3rd. Int. Symp. on managing livestock wastes., Urbana Champaign, IL. 21-24 April 1975. Am. Soc.Agric. Eng., St. Joseph, MI.

Wilkinson, S. R., and J. A. Steudemann. 1992 Macronutrient cycling and utilization on sustainable pasture systems. So. Piedmont Cons. Res. Center. USDA-ARS. Watkinsville, GA.

Zhang, H. A. and Michael Kress. 1997. Laboratory Procedures Manual. Soil Water Forage Analytical Laboratory. Oklahoma State University.