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Nutrient Runoff Following Swine Manure Application

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Nutrient Runoff Following Swine Manure Application

By

Seth J. Lamb

A THESIS

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NUTRIENT RUNOFF FOLLOWING SWINE MANURE APPLICATION

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A field study was completed to compare the effects of land application methods, swine growth stage, and varying flow rates following the application of varying amounts of swine manure to 0.75-m by 2.00-m long plots. Three different manure sources were used to represent key different growth stages including growers, finishers, and sows and gilts. The different swine manures were applied in May and Jun 2011 to meet a 1 year nitrogen (N) requirement for corn. Three different land application methods were used to apply the swine manure, broadcast, incorporation, and injection. Runoff water quality was measured during three 30 minute simulated rainfall events. Following the third and final simulated rainfall even, inflow was added at the top of the plots to simulate increased slope length. Application method significantly affected dissolved phosphorus (DP) transport but did not affect the transport of particulate phosphorus (PP), total phosphorus (TP), NO_3-N, NH_4-N, or total nitrogen (TN). The disking and injection application methods resulted in significantly lower DP transport than that of the broadcast method. The growth stage significantly affected DP transport but was not found to significantly affect PP or TP transport. Growth stage also significantly affected NH_4-N and TN transport but did not affect the transport of NO_3-Nnutrient transport rate was found to increase in a linear fashion with increasing runoff rate.

Another paper evaluated the effectiveness of a narrow grass hedge in reducing nutrient runoff loads following land application of swine manure. Swine manure was applied to 0.75-m wide by 4.00 m long plots established on an Arksarben silty clay loam located in southeast Nebraska. Manure treatments consisted of no manure application and manure application to meet the 1, 2, or 3 year nitrogen (N) requirements for corn. Runoff water quality was measured during three 30 minute simulated rainfall events. Following the third and final simulated rainfall event, inflow was added at the top of the plot to simulate increased slope length. The narrow grass hedge did not significantly affect runoff nutrient transport. Varying nitrogen application rate also did not significantly affect runoff nutrient transport. The grass hedge significantly reduced electrical conductivity (EC) measurements from 0.78 to 0.73 dS m^{-1} and pH values from 8.16 to 7.85. Overland flow rate did significantly affect nutrient transport rates which increased in a linear fashion with increasing runoff rate. A narrow grass hedge did not significantly reduce runoff loads of N and P following swine slurry application.

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INTRODUCTION

The swine industry is a strong and historic staple in America grossing over 22 Billion dollars in 2012 (USDA, 2013). As of December 1, 2012 there were 66,348,000 hogs in the United States (NHF, 2013). This large population of hogs can produce between 8.5 and 25 pounds of manure per day per hog which results in a large volume of manure. A 1997 study found that there were 137,038 tons of nitrogen and 138,400 tons of phosphorus that was present in swine manure produced in farms in the US (USDA, 1997). The land application of animal waste has been a valuable and cost effective tool used as a nutrient supplement for crop production. The high phosphorus and nitrogen content in manure are key nutrients that boost agricultural growth and replenish weathered soils.

Historically, manure and nutrients were applied to crops to meet the nitrogen needs of plants. Unfortunately, the plant required ratio of nitrogen to phosphorus is not the same as the nitrogen to phosphorus ratio found in manure. The ratio of nitrogen (N) to phosphorus (P) is referred to as the N:P ration. The average N:P ratio of nutrients available at land application is 4.7:1 while grain corn requires an average of 5.9:1 for optimum yield (Eghball et al., 1997; Gilbertson et al., 1979). The lower N:P ratio indicates that to meet the nitrogen requirement of corn that excess phosphorus will be applied which will not be utilized by the plant. This excess phosphorus is collected in the soil and either leaches into the groundwater or erodes into surface waters. A more efficient approach to manure application is being used. Manure is applied to meet the plants phosphorus requirement and supplemental inorganic nitrogen is applied to make up for the difference in then nitrogen required. Sims et al. 1998 identified the heavy application of manure over time as having a negative impact on the environment. Heavy application would be defined as applying manure at rates that exceed the crop nutrient requirements and thus creating an accumulation. The accumulation of nutrients in soil leads to the transportation of nutrients offsite and into rivers, lakes, and streams. Applying to a phosphorus requirement and supplementing the required nitrogen results in both nutrients being exhausted and less likely to runoff into local surface waters or leach into groundwater causing adverse effects to the environment.

Nutrient runoff is an issue because of the principles of “A little can go a long way”. A natural ecosystem functions because of a balance of nutrients and conditions that prevent one species from choking out the others and allows for an overall balanced existence. Nutrients in these systems are often found in small concentrations and are readily consumed by almost everything. In the ecosystem phosphorus and nitrogen are considered limiting nutrients. This means that they have the lowest concentrations in the environment and thus drive how much biological growth is allowed to occur. It is very case specific which nutrient is the actual limiting factor for growth. In general, natural river lakes and streams around Nebraska are phosphorus limited. Because almost all of the other macro and micro-nutrients needed for biological growth are readily available and in high concentrations, any added phosphorus or Nitrogen is going to be used for biological growth. Another interesting feature about phosphorus and nitrogen is that because they are generally limited in the natural environment, most plant species have adapted to only need a small amount to grow and multiply. Added nutrients into a balanced system can have serious and irreversible consequences. This process is known as eutrophication.

In an effort to reduce nutrient runoff different practices have been researched and developed. The practices that have been found as a practical method to reduce nutrient runoff are called best management practices. These practices can vary in effectiveness and may be used in combination to prevent nutrient runoff. With the increase in focus of nutrient runoff from agricultural lands, state environmental quality agencies are seriously considering regulating nutrient runoff. This will result in mandatory best management practices.

Tillage is an often used practice that helps reduce nutrient runoff. Tilling in manure distribute the nutrients throughout a soil profile and lowers the nutrient concentration sitting on the soil that can be eroded or washed away all while keeping the nutrients available for plant growth. Tillage also reduces odors often found in manure application and has been shown to reduce the amount of dissolve phosphorus found in field runoff (Eghball and Gilley, 1999).

The type of manure used and the characteristics of the animal it came from is often considered when land applying manure. Each animal has different internal efficiencies and nutrient requirements which results in a variation in nutrient content. The amount of nutrients excreted is also affected by age and diet, Klopfenstein et al. 2002. While no land applier would seek manure from a certain animal growth stage and most facilities combine the different manures it is an important factor consider when it comes to land application. The nutrients in the manure can be present in many different forms which affect how and when a plant can utilize it.

Another important best management practices for both reducing nutrient runoff and also reducing crop erosion is vegetative filter strips and buffers. Vegetative filter strip are areas of grass or vegetation that are permanent and are intended to act as buffers to runoff. These strips can be placed between crops, along crop borders, in grazing land, and tilled land (Helmers et al., 2008). An important characteristic of the vegetative filter strips is the type of vegetation used. The vegetation needs to have stiff stems and a high stem density at the ground surface to be able to slow the flow and allow for filtration (NRCS, 2011). The filter strips physically block and slow the water flowing through the field. This blockage slows the velocity of the runoff and allows for pooling and the sediment to settle. As the sediment settles, nutrients can adsorb to the soil surface where it is consumed by the plant. The filter strips also filter the eroded solids. As water passes through the vegetation it is trapped and removed from the flow. The types of vegetation can influent the thickness of the filter strip. A denser grass can be used in a narrow strip to effectively reduce the transport of sediment and nutrients (Dabney et al., 2006). Narrow grass hedges acting as vegetative filter strips have been shown in a study conducted by Gilley et al. (2008) to decreased runoff by 41 percent and decreased soil erosion rates by an average of 92 percent.

An important factor that is contributes to nutrient loss and erosion is the rate of overland flow through the field. As the contributing slope length of a field increases, the runoff flow increases. The higher rates of overland flow scour and agitate the soil and cause greater erosion. In a 2008 study by Gilley et al. overland flow was found to significantly affect nutrient runoff and soil loss. As runoff rate increased soil loss and nutrient runoff occurred more rapidly. In the study longer slope lengths were simulated using overland flow rates.

The National Phosphorus Research Projects (NPRP) has established methods for measuring nutrient transport which allows for research in nutrient runoff to be compared and progressed. The NRPR method uses 2-m long plots and simulated rainfall events. Through the set testing methods the effects of best management practices can be evaluated and compared (Sharpley and Kleinman, 2003).

OBJECTIVES

The literature relating to swine manure land application revealed the need to continue investigation into additional areas. The objectives of this research were:

Manuscript I. Runoff Nutrient Transport as Affected by Land Application Method, Swine Growth Stage, and Runoff Rate.

1. Compare how selected tillage practices and swine growth stage affected runoff nutrient loads (mass per unit area) occurring soon after swine slurry application.
2. Compare the effects of tillage, swine growth stage, and different overland flow rates on runoff nutrient loads (mass per unit area per time).

Manuscript II. Narrow Grass Hedge Effects on Nutrient Transport Following Swine Slurry Application.

1. Determine the effects of a narrow grass hedge and varying manure application rates on runoff nutrient loads (mass per unit area) occurring soon after manure application.
2. Compare the effects of a narrow grass hedge, varying manure application rates, and different overland flow rates on runoff nutrient loads (mass per unit area per unit time).

THESIS PRESENTATION

This thesis is being written in manuscript form as drafts for publication. The manuscripts are formatted to be published in Transactions of the ASABE.

The thesis is comprised of two chapters. The first chapter is the manuscript titled, "Runoff Nutrient Transport as Affected by Land Application Method, Swine Growth Stage, and Runoff Rate". The manuscript evaluates the effectiveness of different swine slurry land application methods in reducing runoff nutrient transport. Manures from different swine growth stages were also evaluated to compare runoff nutrient transport rates. This information will help evaluate how nutrient transport is affected when swine manure is land applied. It will also help determine the difference swine growth stage and overland flow rates makes on nutrient transport rates

The second chapter is the manuscript titles, "Narrow Grass Hedge Effects on Nutrient Transport Following Swine Slurry Application". The manuscript looks at the effectiveness of a narrow grass hedge in reducing runoff nutrient transport on plots where swine slurry was land applied. The manuscript will also help understand the effects of variable application rate of swine slurry on nutrient transport rate. The manuscript also determines how nutrient transport is affected by varying overland flow rates through a narrow grass hedge as well.

RUNOFF NUTRIENT TRANSPORT AS AFFECTED BY LAND APPLICATION METHOD, SWINE GROWTH STAGE, AND RUNOFF RATE

S. J. Lamb, J. E. Gilley, D. B. Marx

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ABSTRACT. The effectiveness of slurry application method, swine growth stage, and runoff rate following land application of swine manure was examined in this study. Swine manure was applied to 0.75-m wide by 2.00 m long plots established on an Arksarben silty clay loam located in southeast Nebraska. Land application methods for applying swine manure included surface distribution, incorporation by disking, and injection. Three manure sources were used to represent different growth stages including growers, finishers, and sows and gilts. Manure treatments were applied to meet a one year nitrogen (N) requirement for corn. Runoff water quality was measured during three 30 minute simulated rainfall events. Following the third and final simulated rainfall event, inflow was added at the top of the plots to simulate increased slope length. Application method significantly affected dissolved phosphorus (DP) transport but it did not affect the transport of particulate phosphorus (PP), total phosphorus (TP), NO_3-N, NH_4-N, or total nitrogen (TN). The disking and injection application methods resulted in significantly lower DP transport than that of the broadcast method. The growth stage significantly affected DP transport but was not found to significantly affect PP or TP transport. Growth stage also significantly affected NH_4-N and TN transport but did not affect the transport of NO_3-Nnutrient transport rate was found to increase in a linear fashion with increasing runoff rate.

INTRODUCTION

Swine manure can be used effectively as a substitute for inorganic fertilizer and organic matter contained in manure can improve soil characterizes including infiltration, porosity, and water holding capacity. However, as a result of manure application, nutrient concentrations in runoff from agricultural areas my cause adverse environmental impacts (Sharpley et al., 1996; Wortmann and Walters, 2006). Key factors affecting the use of manure as a fertilizer include application method, loading rate and soil nutrient test level (Sims, 1993; Daniel et al., 1994; McDowell et al., 2001). Greater soil nutrient values have been shown to increase runoff nutrient concentrations (Pote et al., 1999; Andraski et al., 2003). However, nutrient transport may not be impacted by soil nutrient concentrations when runoff occurs soon after manure application (Eghball et al., 2002).

Land application is a key factor influencing the magnitude of nutrients present in runoff. Studies have shown that conservation tillage systems can increase nutrient runoff losses over time when there is a stratification of nutrients at the soil surface (Andraski et al., 2003). Surface soils that have excessive nutrient concentrations can be inverted by plowing by redistributing nutrients within the top 15 cm of soil (Pezzarossa et al., 1995; Rehm et al., 1995). Reducing the surface soil nutrient concentrations can reduce the total N and P transported by overland flow. Tillage also reduces odors often caused by manure application and has been shown to reduce the concentration of dissolved phosphorus in field runoff (Eghball and Gilley, 1999).

The objectives of this study were to a) compare how selected tillage practices and swine growth stage affected runoff nutrient loads (mass per unit area) occurring soon after swine slurry application; and b) compare the effects of tillage, swine growth stage, and different overland flow rates on runoff nutrient loads (mass per unit area per unit time).

MATERIALS AND METHODS

STUDY SITE CHARACTERISTICS

Field tests were conducted in May and June 2011 at the University of Nebraska Rogers Memorial Farm located 18 km east of Lincoln, NE in Lancaster County. The site has been cropped using a grain sorghum (Sorghum bicolor (L.) Moench), soybean (Glycine max (L.) Merr.), winter wheat (Triticum aestivum L. cv. Pastiche) rotation, under a no-till management system, and was planted to soybeans during the 2009-2010 growing season. Herbicide was applied as needed to control weed growth. The study site remained undisturbed prior to the field study.

The soil at the site is classified as the Aksarben silty clay loam soil (fine, smectitic, mesic Typic Argiudoll) contained 15% sand, 57% silt, and 28% clay. The organic matter and total carbon content of the soil was 4.7% and 22.62% respectively. The soil at the site developed in loess under prairie vegetation and had a mean slope of 5.8%. The site had an electrical conductivity of 0.38 dS m^{-1} and a pH of 6.8.

Soil samples for study site characterization were obtained from the surface down to 2 cm just prior to manure application, and the soil samples were air dried following collection. Mean measured concentrations of Bray and Kurtz No. 1 P, water soluble P, NO_3-N, and NH_4-N were 43, 5.2, 8, and 4 mg kg^{-1}, respectively.

PLOT PREPARATION

Thirty-six 0.75 m wide by 2 m long plots were established with the longer plot dimension parallel to the slope of the direction of overland flow. Experimental treatments included slurry application method, swine growth stage, and varying runoff rates. The different application methods were the main plot treatments and the swine growth stage was a subplot treatment (fig. 1).

Field tests were conducted on four plots for the first week and eight plots each additional week from 24 May to 24 June 2011. Just prior to field application the swine manure was collected from the U.S. Meat Animal Research Center (MARC) swine production facilities. Three different swine manure samples were used and were representative of different swine growth stages, grower, finisher, and sows and gilts (table 1). The swine slurry was applied to meet a one year nitrogen requirement for corn (151 kg N ha^{-1} $year^{-1}$ for an expected yield of 9.4 Mg ha^{-1}). When calculating manure application rates it was assumed that the N availability from swine manure was 70% of the total amount of nitrogen measured in the manure (Eghball et al. 2002).

Three different application methods, broadcast, incorporation by disking, and injection were tested. Each set of four plots received the same application method and each application method was tested in triplicate. Three of the plots received swine manure from swine at different growth stages, finisher, grower, and sows and gilts, and the fourth was a check plot that received no manure application.

Slurry was uniformly applied over the surface of the plot for the broadcast treatment. The diluted nature of the swine slurry resulted in a high volume of manure being applied to each plot. The manure was applied and allowed to infiltrate into the plot area. The plot borders helped keep the manure in the plot boundary.

The incorporated application method required disking the manure into the soil. Soil may be transported from its original location as part of the disking operation. To ensure adequate manure application, manure was applied to the surface of an area slightly larger than the final plot dimension. A 5 m tandem finishing disc was used to lightly incorporate the applied manure to a depth of approximately 8 cm Disking (single pass) occurred up and down the slope in the direction of overland flow. This provided a greater runoff and soil loss potential than would have occurred if disking had occurred perpendicular to the plots.

The injection method required injecting the swine manure into slots established perpendicular to the overland flow. The plot border was then placed over the plot. The tillage depth was approximately 8 cm. The injection process involved pouring liquid manure via funnel and pitcher through a pvc pipe into the previously established slot. The manual method of injection allowed for control of the distribution of manure and also prevented cross contamination between manure sources. After the allotted mass of manure was injected the surface soil was redistributed to cover the furrows.

RAINFALL SIMULATION PROCEDURES

The water used in the rainfall simulation tests was obtained from an irrigation well located near the experimental site. Concentrations of DP, TP, NO_3-N, NH_4-N, and TN in the irrigation water were determined to be 0.15,0.15,16.7,0.02 and 16.7 mg L^{-1} respectively. Measurements of EC and pH were 0.74 dS m^{-1} and 7.6 respectively.

Field rainfall simulation tests were performed separately by block over a 5 week period from May 24, 2011 to June 23, 2011 with tests conducted on 4 plots the first week and 8 plots each additional week using a portable rainfall simulator based on the design by Humphry et al. (2002). Three rain gauges were placed along the outer edge of each plot and one rain gauge was located between the plots. The simulator applied rainfall at a design intensity of approximately 70 mm hr^{-1} to a pair of 0.75 m wide by 2 m long plots. Procedures established by the National Phosphorus Research Project (NPRP) (Sharpley and Kleinman, 2003) were used during the initial 30 minutes of the study. Three 30 minute rainfall events were simulated 24 hours apart.

The plot border channeled runoff into a sheet metal lip that emptied into a collection trough that extended across the bottom of each plot. The collection trough diverted runoff into plastic buckets. A sump pump was then used to transfer the runoff into larger plastic storage containers. The storage containers were weighed to determine the total runoff mass and the accumulated runoff was agitated to maintain suspension of solids. Samples were obtained for water quality and sediment analysis.

After 30 minutes of rainfall simulation during the third run had passed, the runoff from the experimental plots was diverted into an HS flume with a stage recorder to measure the discharge rate (fig. 2). Four successive increments of inflow were then added to the top of each plot. A narrow synthetic mat was placed on the soil surface beneath the inflow device to prevent soil scouring and to evenly distribute the flow across the plot. Each flow increment was allowed to reach a steady state condition before runoff samples were collected. Each simulated overland flow increment was maintained for approximately eight minutes.

Centrifuged and filtered runoff samples were placed in a cooler at 2°C and then later analyzed for DP (Murphy and Riley 1962), NO_3-N and NH_4-N using the Lachat system (Zellweger Analytics, Miliwaukee WI). Non-centrifuged samples were stored in a cooler at 2°C and then analyzed at a commercial laboratory for TP (Johnson and Ulrich, 1959) and TN (Tate, 1994). Particulate phosphorus (PP) values were reported as the difference between measurements of TP and DP.

Runoff samples for sediment analysis were collected in 1 L plastic bottles for which tare weights had been previously measured. The 1 L plastic bottles were transported to the laboratory and total mass was measured. The bottles were then dried in an over at 105°C and weighed to determine the mass of sediment (total solids) remaining in the sample bottles. Sediment content was calculated as the mass of remaining material in the bottles after drying divided by the mass of water in the bottle before drying. When calculating sediment content the mass of dissolved chemical constituents contained in the runoff was assumed to be negligible.

STATISTICAL ANALYSES

The effects of varying manure application, antimicrobial present in the manure, and the inflow rate on runoff nutrient loads were determined using ANOVA (SAS Institute, 2003). For a given plot, water quality measurements obtained from each of the three-rainfall simulation runs were included in the analyses and were treated as repeated measures. The ANOVA program tested for significant differences among the experimental variables and established significant relationships between experimental variables. If a significant difference was identified the least significant difference test (LSD) was used to identify differences among experimental treatments. A probability level ≤ 0.05 was considered significant.

RESULTS AND DISCUSSION

RUNOFF CHARACTERISTICS

Phosphorus Load

Runoff loads of DP were found to be significantly affected by slurry application method. The DP load resulting from the broadcast application method was found to be significantly higher than the DP load from the disked and injected application methods. Runoff loads of DP were also found to be significantly affected by swine growth stage. Manure from sows and gilts resulted in a significantly higher DP runoff load of 0.17 kg/ha than the 0.11 kg/ha measured from the finisher swine. Runoff concentrations of PP and TP were not significantly affected by application method or by swine growth stage.

Gilley et al. (2007b) reported DP load in runoff from land applied swine manure on a no-till field to be 0.27 kg ha^{-1}, which is similar to the 0.20 kg ha^{-1} found in the present study for the broadcast treatment. Gilley et al. (2007b) also reported the DP load in runoff from land applied swine manure to a tilled field to be 0.14 kg ha^{-1}, which is also similar to the results found in the present study for both disked and injected, 0.11 and 0.08 kg ha^{-1}, respectively. Gilley et al. (2007b) did not find tillage to significantly affect DP concentrations in runoff from land applied swine manure.

The broadcast application method promoted an accumulation of nutrients near the soil surface as the slurry infiltrated into the soil. The disked and injection method better distributed phosphorus through the soil profile while the broadcast application method created a high phosphorus concentration near the surface. As runoff flowed over the plot the concentration differential promoted the phosphorus present at the surface to dissolve into the runoff, increasing the DP runoff loads. Because disking and injection better distributed the nutrient load, their respective DP runoff loads were significantly lower.

The amount of phosphorus excreted by swine is affected by the volume of phosphorus consumed and the efficiency of the swine for utilizing the phosphorus (Klopfenstein et al. 2002). The DP runoff loads from the sows and gilts manure was significantly higher than that of the grower and the finisher manures. This resulted from sows and gilts are fed a slightly higher level of phosphorus to ensure the sows and gilts have adequate phosphorus for gestation and lactation (Merck & Co, 2011). Sows and gilts also more readily digest phosphorus resulting in a higher DP runoff load (Heugten et al., 2000). The sows and gilts slurry used in this study reflects an increased phosphorus load of 760 mg kg^{-1} P_2O_5 compared to finisher and grower slurries that contained 273 and 502 mg kg^{-1} P_2O_5 respectively (table 1).

Nitrogen Load

Runoff loads of NO_3-N, NH_4-N, and TN were not significantly affected by application method (table 2). However, runoff loads for NH_4-N were found to be significantly affected by growth stage. The runoff load of NH_4-N for the finisher treatment, 0.70 kg ha^{-1}, was significantly higher that the load of 0.32 kg ha^{-1} found for the growers and sows and gilts treatments.

The NH_4-N concentrations present in the slurries from the finisher, grower, and sow and gilts were 788, 404, and 441 mg kg^{-1} respectively. The finisher slurry had a much higher concentration of NH_4-N than the other manure sources. The high initial concentration of NH_4-N in the finisher slurry resulted in a significantly higher runoff loads, Heugten et al. (2000) suggested that finisher pigs only retain between 30 and 50% of the nitrogen which they consume which is lower than that of sows and gilts and smaller grower swine. The lower nitrogen retention results in an increased nitrogen excretion.

Measurements of EC, pH, Runoff, and Soil Loss

EC and pH were not significantly affected by application method. However, EC measurements were found to be significantly affected by growth stage. . The finisher slurry had a higher EC concentration, 7.82 dS m^{-1}, compared to grower and sows and gilts, 4.26 and 4.36 dS m^{-1} respectively. The higher EC value in the finisher slurry resulted in a higher EC runoff concentration.

The application method and growth stage did not significantly affect pH. Runoff and erosion measurements also were not significantly affected by application method or growth stage. Gilley et al. (2007a) compared plow and non-plow conditions and did not find any significant difference in runoff or erosion.

RUNOFF CHARACTERISTICS AS AFFECTED BY OVERLAND FLOW

Phosphorus Measurements

Application method and swine growth stage did not significantly affect DP, PP, and TP transport measured during the inflow tests (table 3). However, runoff rate significantly affected transport rates for DP, PP, and TP which increased in a linear fashion with runoff rate as shown in (figure 3). Transport rates for PP and TP were much larger than values obtained for DP.

In a similar study, Gilley et al. (2008) found that runoff rates significantly affected PP and TP transport rates. Gilley et al. (2008) followed similar runoff testing methods. However, the swine slurry Gilley et al. (2008) used contained much larger nutrient concentrations than the slurries used in this study. The TP concentration of the slurry used by Gilley et al. (2008) was 1,010 mg kg^{-1} while the TP of the finisher, grower, and sows and gilts slurry used in this study were 119, 219, and 332 mg kg^{-1}, respectively. At a runoff rate of 3.3 kg min^{-1} Gilley et al. (2008) found DP, PP, and TP to be 41.4, 50.3, and 91.7 g ha^{-1} min^{-1} whereas in the current study DP, PP, and TP transport rates at a similar runoff rate were 8.4, 92, and 101 g ha^{-1} min^{-}, respectively. Despite Gilley et al. (2008) having a higher initial nutrient concentration, the current study had larger PP and TP transport rates. This can be attributed to the disking and injection methods which disrupted the soil and increased soil loss.

Nitrogen Measurements

Transport rates for NO_3-N and TN were not significantly affected by application method (table 3). However, it was found that application method significantly affected ammonia transport rate. The broadcast application method resulted in a significantly greater ammonia transportation rate, 33.5 g ha^{-1} min^{-1}, than disking or injection methods which were 10.5 and 8.9 g ha^{-1} min^{-1}, respectively.

Growth stage did not significantly affect NO_3-N and TN transport rates. However, NH_4-N transport rate was significantly affected by growth stage. Manure from the finisher treatment resulted in a significantly higher NH_4-N runoff transport rate, 36.1 g ha^{-1} min^{-1}, than the grower and sows and gilts applications, 16.2 and 15.0 g ha^{-1} min^{-1}, respectively.

Transport rates of NO_3-N, TN, and NH_4-N were significantly affected by runoff rate and were found to increase linearly with runoff rate. The regression equations for these linear increases in transport rates can be found in (figure 4). Transport rates for NO_3-N and TN were much greater than the NH_4-N transport rate.

Gilley et al. (2008) also showed runoff rate significantly affecting NO_3-N, NH_4-N, and TN transport rates. Gilley et al. (2008) measured NO_3-N, NH_4-N, and TN runoff rates for no-till conditions at 3.3 kg min^{-1} to be 573.0, 35.7, and 609.0 g ha^{-1} min^{-1} respectively. This study found NO_3-N, NH_4-N, and TN under no-till conditions and 3.2 kg min^{-1} to be 420.0, 10.7, and 470 g ha^{-1} min^{-1}. The current study had lower NO_3-N, NH_4-N, and TN transport rates that what was found in Gilley et al. (2008) but they do show the same linear increase in transport rate with an increase in runoff rate.

EC, pH, and Soil Loss Measurements

EC, pH, and soil loss values were not significantly affected by application method or growth stage (table 3). EC measurements were significantly affected by runoff rate, with values varying from 0.75 to 0.74 dS m^{-1}pH was also significantly affected by runoff rate. As runoff rate increased a linear decrease in pH was observed (figure 5). Soil loss was also significantly affected by runoff rate. Soil loss was found to increase in a linear fashion with an increase in runoff rate (figure 6). Soil loss is expected to increase with an increase in runoff rate as greater flows cause greater soil loss.

CONCLUSIONS

The objectives of this study were to a) compare how selected tillage practices and swine growth stage affected runoff nutrient loads (mass per unit area) occurring soon after swine manure application; and b) compare the effects of varying tillage, swine growth stage, and overland flow rates on runoff nutrient loads (mass per unit area per unit time).

Broadcast, disking, and injection were all evaluated as application methods in this study. Application method did not significantly affect transport of PP, TP, NO_3-N, NH_4-N, or TN. However, application method significantly affected DP transport. For the broadcast treatment a DP transport was 0.20 kg ha^{-1}, compared to 0.11 and 0.08 kg ha^{-1} for the disked and injection treatments). Application method was also found to significantly affect NH_4-N runoff transport rates during inflow testing. The broadcast application method resulted in a significantly higher NH_4-N runoff rate, 0.64 kg ha^{-1}, than both the disking and injection treatments, 0.31 and 0.10 kg ha^{-1}.

Three manure slurries were taken from different groups of swine to represent different growth stages, namely grower, finisher, and sows and gilts. Growth stage was found to significantly affect DP transport. The DP transport from the sows and gilts treatments, 0.17 kg ha^{-1}, was significantly higher than that that from the grower and finisher treatments, 0.13 and 0.11 kg ha^{-1}. This was attributed to difference in the diets between the growth stages and also the animal efficiency at digesting and retaining phosphorus. Growth stage was also found to significantly affect NH_4-N transport. Plots receiving finisher swine manure had significantly higher NH_4-N transport, 0.70 kg ha^{-1}, than that of grower and sows and gilts treatments, 0.32 and 0.32 kg ha^{-1}. Growth stage also significantly affected EC measurements. Finisher swine manure was found to produce significantly high EC values, 0.81 dS m^{-1}, than manure from the grower and sows and gilts, 0.76 dS m^{-1}. Growth stage also significantly affected NH_4-N runoff transport rates during inflow testing. Runoff from the finisher treatments was found to have significantly higher NH_4-N transport rates, 36.1 g ha^{-1} min^{-1}, than that from the grower and sows and gilts treatments, 16.2 and 15.0 g ha^{-1} min $^{-1}$.

Inflow introduced into the experimental plots was shown to significantly affect each of the measured water quality parameters. DP, PP, and TP transport rates were found to increase in a linear fashion with runoff rate. Increasing the runoff rate from 3.2 to 21.2 L min^{-1} significantly increased DP transport rates from 8.4 to 40.1 g ha^{-1} min^{-1}, PP transport rates from 92.0 to 619.0 g ha^{-1} min^{-1}, and TP transport rates from 101.0 to 659.0 g ha^{-1} min^{-1}. Runoff rate also significantly affected NO_3-N, NH_4-N, and TN transport rates. Increasing the runoff rate from 3.2 to 21.2 L min^{-1} significantly increased NO_3-N transport rates from 420.0 to 2,470 g ha^{-1} min^{-1}, NH_4-N transport rates from 10.7 to 24.4 g ha^{-1} min^{-1}, and TN transport rates from 470.0 to 2,850 g ha^{-1} min^{-1}. Runoff rate significantly affected EC measurements which decreased from 0.75 to 0.74 dS m^{-1}. pH significantly decreased from 7.73 to 7.56 as runoff rate increased. Soil loss from the experimental plots increased from 27.3 to 240 kg ha^{-1} min^{-1}as runoff rate increased

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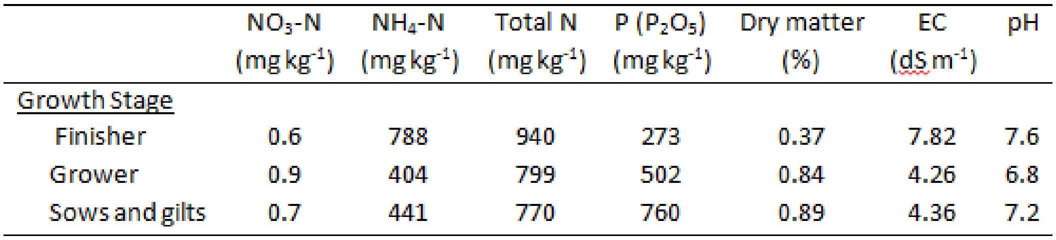
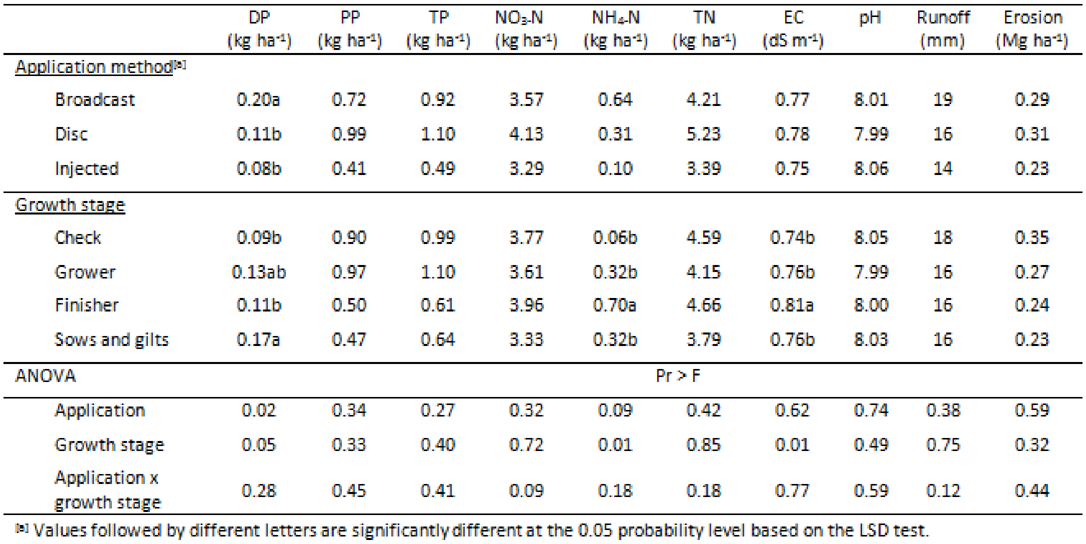
APPENDIX

Table 1. Characteristics of slurry obtained from swine at selected growth stages.



	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	Total N (mg kg^{-1})	P (P_2O_5) (mg kg^{-1})	Dry matter (%)	EC (dS m^{-1})	pH
Growth Stage							
Finisher	0.6	788	940	273	0.37	7.82	7.6
Grower	0.9	404	799	502	0.84	4.26	6.8
Sows and gilts	0.7	441	770	760	0.89	4.36	7.2

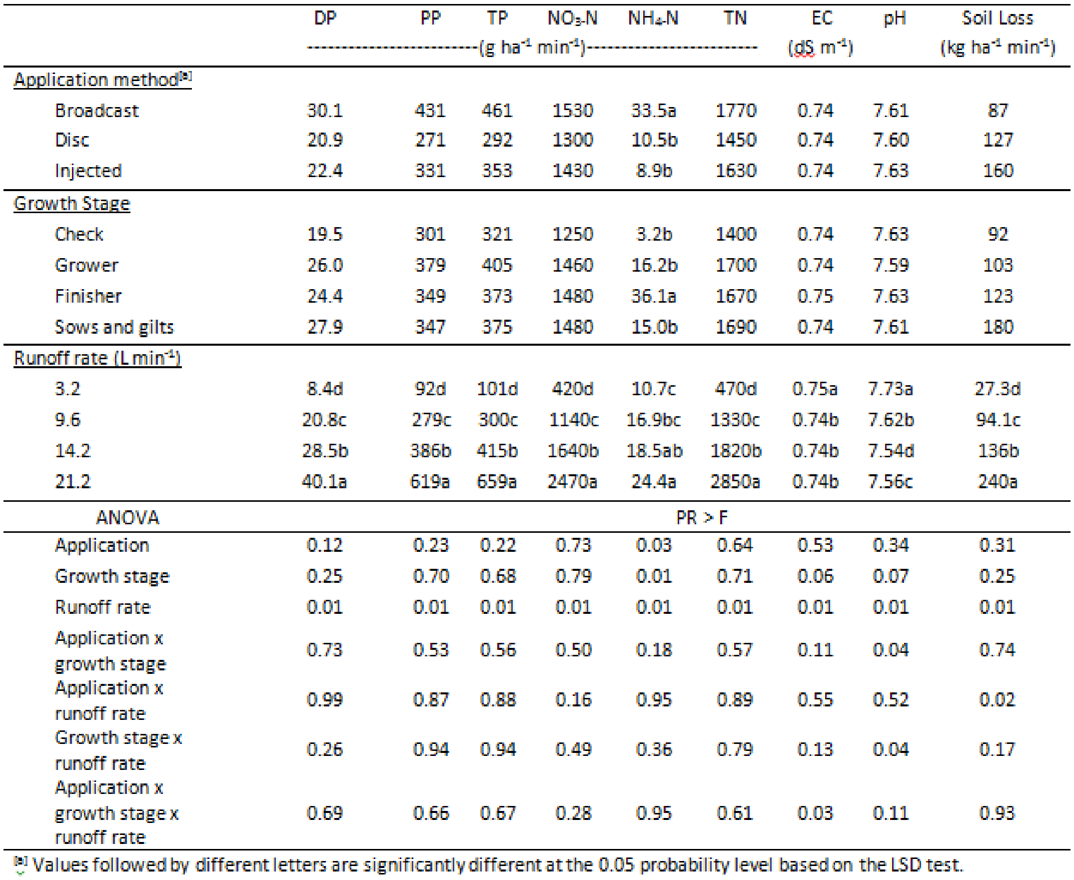
Table 2. Effects of slurry application method and swine growth stage on selected water quality parameters averaged over three rainfall simulation runs.



	DP (kg ha^{-1})	PP (kg ha^{-1})	TP (kg ha^{-1})	NO_3-N (kg ha^{-1})	NH_4-N (kg ha^{-1})	TN (kg ha^{-1})	EC (dS m^{-1})	pH	Runoff (mm)	Erosion (Mg ha^{-1})
Application method[a]										
Broadcast	0.20a	0.72	0.92	3.57	0.64	4.21	0.77	8.01	19	0.29
Disc	0.11b	0.99	1.10	4.13	0.31	5.23	0.78	7.99	16	0.31
Injected	0.08b	0.41	0.49	3.29	0.10	3.39	0.75	8.06	14	0.23
Growth stage										
Check	0.09b	0.90	0.99	3.77	0.06b	4.59	0.74b	8.05	18	0.35
Grower	0.13ab	0.97	1.10	3.61	0.32b	4.15	0.76b	7.99	16	0.27
Finisher	0.11b	0.50	0.61	3.96	0.70a	4.66	0.81a	8.00	16	0.24
Sows and gilts	0.17a	0.47	0.64	3.33	0.32b	3.79	0.76b	8.03	16	0.23
ANOVA						Pr > F				
Application	0.02	0.34	0.27	0.32	0.09	0.42	0.62	0.74	0.38	0.59
Growth stage	0.05	0.33	0.40	0.72	0.01	0.85	0.01	0.49	0.75	0.32
Application x growth stage	0.28	0.45	0.41	0.09	0.18	0.18	0.77	0.59	0.12	0.44

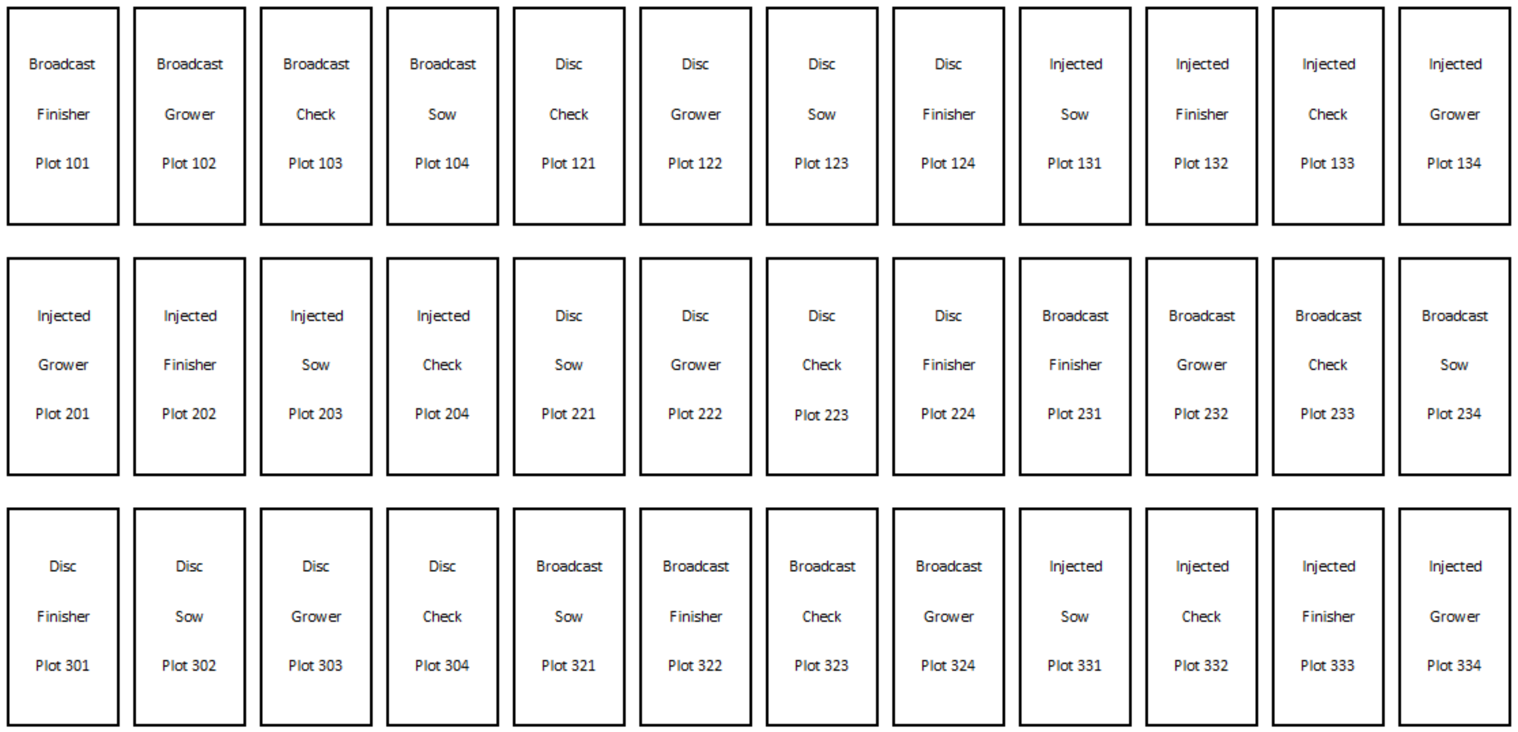
[a] Values followed by different letters are significantly different at the 0.05 probability level based on the LSD test.

Table 3. Selected runoff water quality parameters as affected by slurry application method, swine growth stage, and runoff rate.



	DP	PP	TP	NO_3-N	NH_4-N	TN	EC	pH	Soil Loss
	------------------------	-------	(g ha^{-1} min^{-1})	-------	-------	------------------------	(dS m^{-1})		(kg ha^{-1} min^{-1})
Application method[a]									
Broadcast	30.1	431	461	1530	33.5a	1770	0.74	7.61	87
Disc	20.9	271	292	1300	10.5b	1450	0.74	7.60	127
Injected	22.4	331	353	1430	8.9b	1630	0.74	7.63	160
Growth Stage									
Check	19.5	301	321	1250	3.2b	1400	0.74	7.63	92
Grower	26.0	379	405	1460	16.2b	1700	0.74	7.59	103
Finisher	24.4	349	373	1480	36.1a	1670	0.75	7.63	123
Sows and gilts	27.9	347	375	1480	15.0b	1690	0.74	7.61	180
Runoff rate (L min^{-1})									
3.2	8.4d	92d	101d	420d	10.7c	470d	0.75a	7.73a	27.3d
9.6	20.8c	279c	300c	1140c	16.9bc	1330c	0.74b	7.62b	94.1c
14.2	28.5b	386b	415b	1640b	18.5ab	1820b	0.74b	7.54d	136b
21.2	40.1a	619a	659a	2470a	24.4a	2850a	0.74b	7.56c	240a
ANOVA					PR > F				
Application	0.12	0.23	0.22	0.73	0.03	0.64	0.53	0.34	0.31
Growth stage	0.25	0.70	0.68	0.79	0.01	0.71	0.06	0.07	0.25
Runoff rate	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Application x growth stage	0.73	0.53	0.56	0.50	0.18	0.57	0.11	0.04	0.74
Application x runoff rate	0.99	0.87	0.88	0.16	0.95	0.89	0.55	0.52	0.02
Growth stage x runoff rate	0.26	0.94	0.94	0.49	0.36	0.79	0.13	0.04	0.17
Application x growth stage x runoff rate	0.69	0.66	0.67	0.28	0.95	0.61	0.03	0.11	0.93

[a] Values followed by different letters are significantly different at the 0.05 probability level based on the LSD test.



Broadcast Finisher Plot 101	Broadcast Grower Plot 102	Broadcast Check Plot 103	Broadcast Sow Plot 104	Disc Check Plot 121	Disc Grower Plot 122	Disc Sow Plot 123	Disc Finisher Plot 124	Injected Sow Plot 131	Injected Finisher Plot 132	Injected Check Plot 133	Injected Grower Plot 134
Injected Grower Plot 201	Injected Finisher Plot 202	Injected Sow Plot 203	Injected Check Plot 204	Disc Sow Plot 221	Disc Grower Plot 222	Disc Check Plot 223	Disc Finisher Plot 224	Broadcast Finisher Plot 231	Broadcast Grower Plot 232	Broadcast Check Plot 233	Broadcast Sow Plot 234
Disc Finisher Plot 301	Disc Sow Plot 302	Disc Grower Plot 303	Disc Check Plot 304	Broadcast Sow Plot 321	Broadcast Finisher Plot 322	Broadcast Check Plot 323	Broadcast Grower Plot 324	Injected Sow Plot 331	Injected Check Plot 332	Injected Finisher Plot 333	Injected Grower Plot 334

Figure 1. Schematic showing plot layout, slurry application method, and swine growth stage.

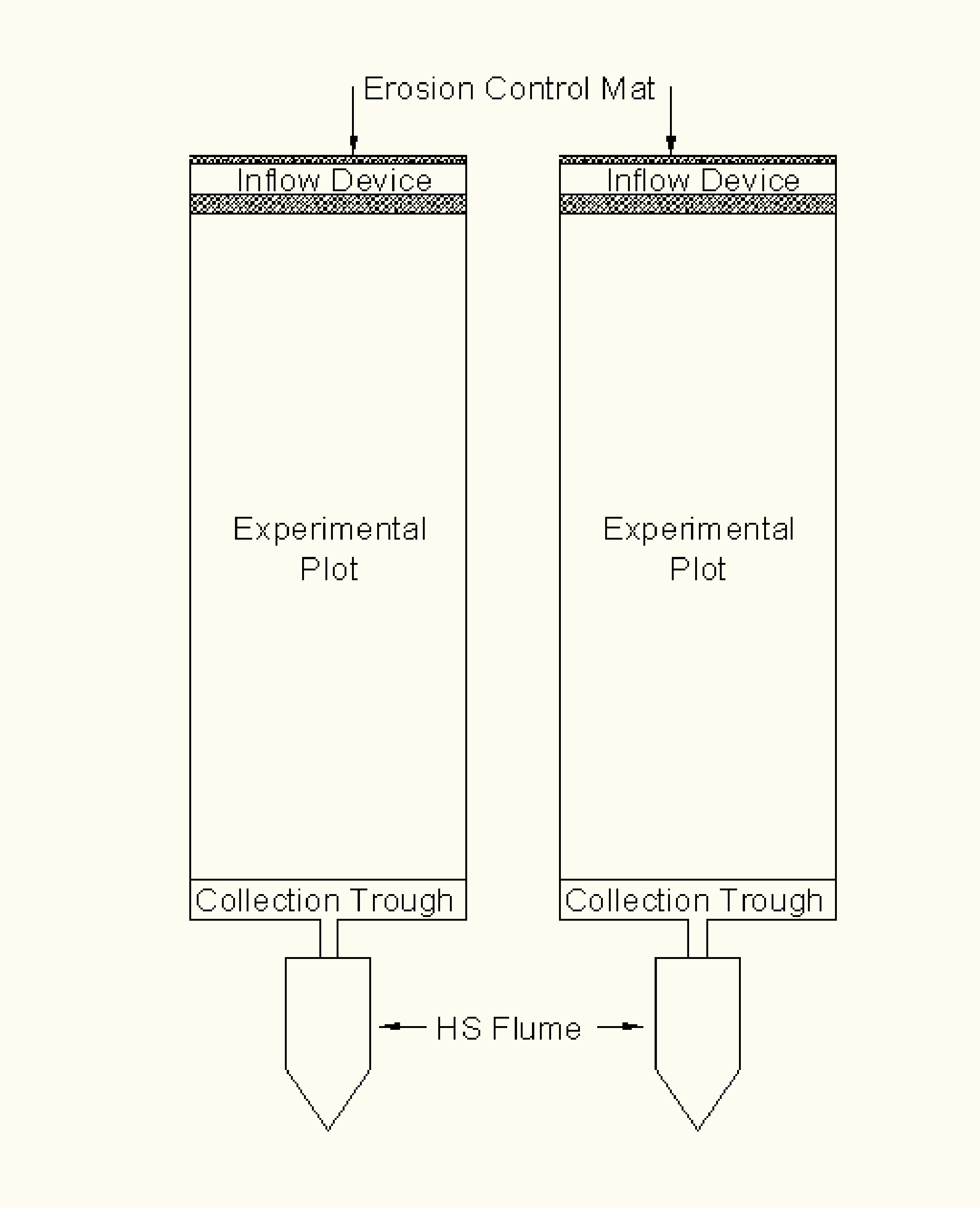


Figure 1. Schematic showing a pair of experimental plots, inflow devices, collection troughs, and HS flumes.

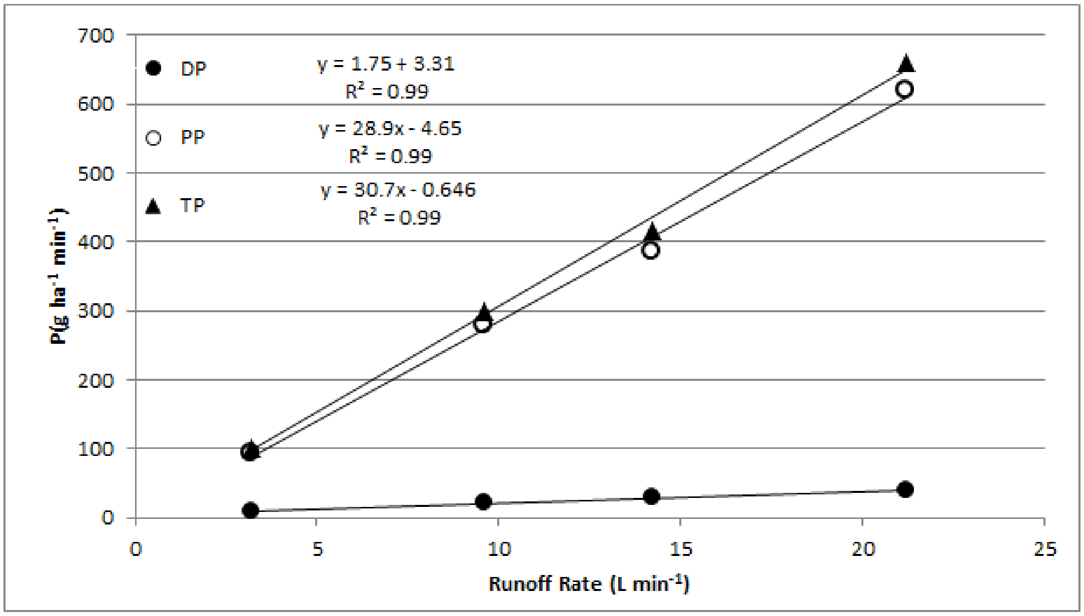


Figure 3. Dissolved phosphorus (DP), particulate phosphorus (PP), and total phosphorus (TP) transport rate as affected by runoff rate.

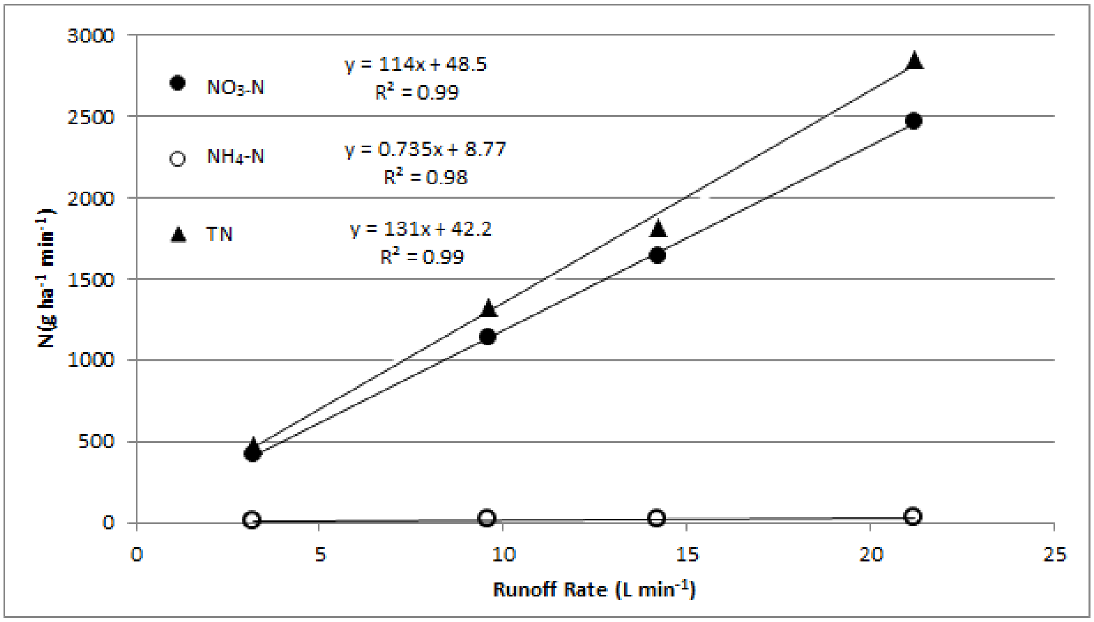


Figure 4. NO_3-N, NH_4-N, and total nitrogen (TN) transport rate as affected by runoff rate.

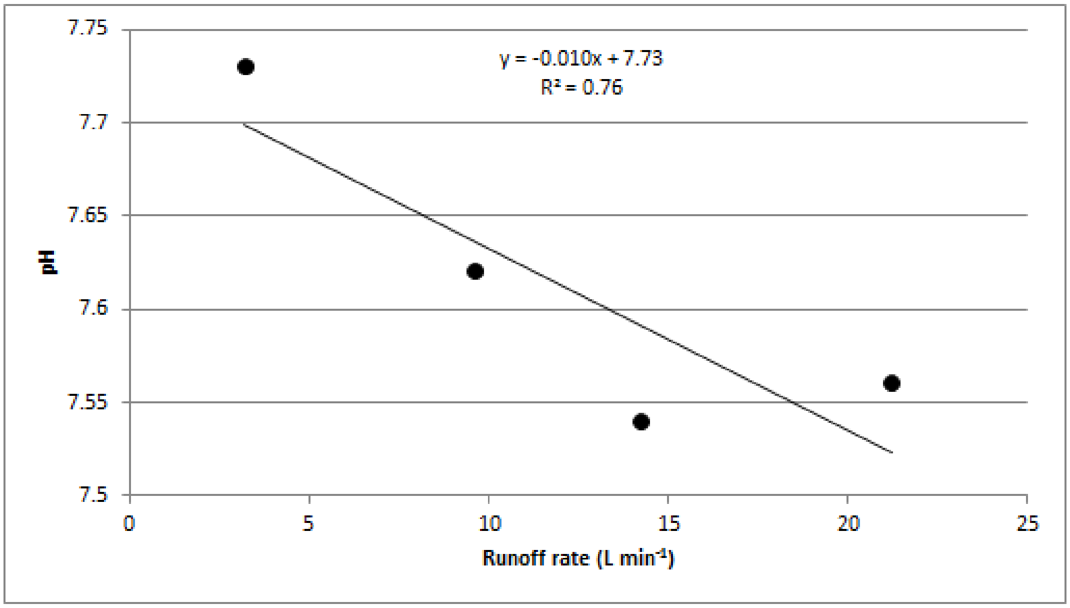


Figure 5. pH values as affected by runoff rate.

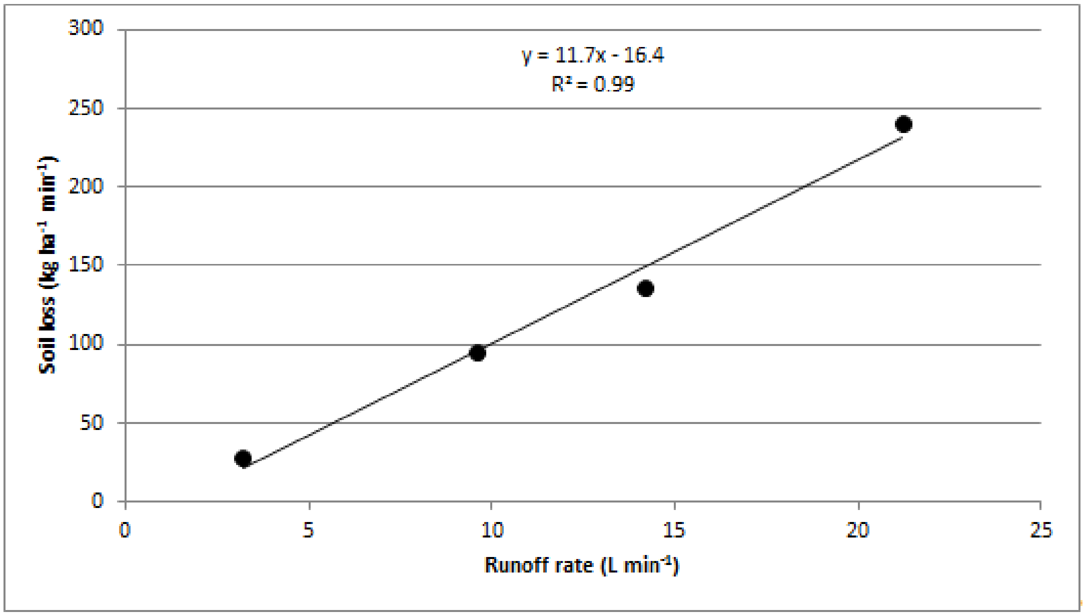


Figure 6. Soil loss rate as affected by runoff rate.

NARROW GRASS HEDGE EFFECTS ON NUTRIENT TRANSPORT FOLLOWING SWINE SLURRY APPLICATION

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ABSTRACT. The effectiveness of a narrow grass hedge in reducing nutrient runoff loads following land application of swine manure was examined in this study. Swine manure was applied to 0.75-m wide by 4.00 m long plots established on an Arksarben silty clay loam located in southeast Nebraska. Manure treatments consisted of no manure application and manure application to meet the 1,2, or 3 year nitrogen (N) requirements for corn. Runoff water quality was measured during three 30 minute simulated rainfall events. Following the third and final simulated rainfall event, inflow was added at the top of the plot to simulate increased slope length . The narrow grass hedge did not significantly affect runoff nutrient transport. Varying nitrogen application rate also did not significantly affect runoff nutrient transport. The grass hedge significantly reduced electrical conductivity (EC) measurements from 0.78 to 0.73 dS m^{-1} and pH values from 8.16 to 7.85. Overland flow rate did significantly affect nutrient transport rates which increased in a linear fashion with increasing runoff rate. A narrow grass hedge did not significantly reduce runoff loads of N and P following swine slurry application.

INTRODUCTION

Runoff from agricultural areas where manure is applied can contribute to increased nutrient concentrations in local streams in lakes, often resulting in a reduction in water quality. The concentration of nutrients in runoff may be influenced by the nutrient content of soil surfaces (Sharpley et al. 1996; Wortmann and Walters, 2006). When rainfall occurs soon after manure application, soil nutrient values may not significantly impact runoff nutrient concentrations (Eghball et al. 2002). The risk of nutrient contamination from land application areas has furthered research in management practices that reduce nutrient runoff.

Narrow grass hedges are used as a vegetative buffer to intercept field runoff and reduce field erosion and nutrient runoff. These buffer strips are areas of permanent vegetation positioned to intercept field runoff before it can cause serious erosion or allow nutrients to enter the local waterway (Helmers et al. 2008). Narrow grass hedges have been shown to be effective in reducing nutrient runoff. Narrow grass hedges placed along a slope contour have been shown to provide benefits similar to those of vegetative filter strips (Dewald et al. 1996; Jin and Romkens, 2000; Kemper et al. 1992). Narrow grass hedges provide improved soil hydraulic properties as water passes through the hedge and enhance infiltration and reduce runoff (Rachman et al., 2004a and 2004b). Narrow grass hedges also provide a physical interaction with runoff which promotes sediment deposition and berm formation and diffuse and spreads overland flow (Dabney et al., 1995 and 1999).

Runoff nutrient losses have been shown to be significantly reduced by narrow grass hedges (Eghball et al., 2000; Owino et al., 2006). Gilley et al (2008) found that narrow grass hedges reduced runoff loads of DP, TP, NO3-N, NH4-N, and TN following land application of beef cattle manure. Much of the sediment trapping that occurs in narrow grass hedges can be attributed to upslope ponding rather that filtration (Meyer et al., 1995).

The National Phosphorus Research Project (SPRP) established procedures for measuring nutrient transport from 2 m long plots (Sharpley and Kleinman, 2003). Gilley et al. (2000) showed that under no-till conditions, plots with corn residue and narrow grass hedges averaged 52% less runoff and 57% less soil loss than comparable plots without grass hedges Little information is currently available concerning the effects of narrow grass hedges on nutrient transport following the application of swine manure.

IMPACTS OF MANURE APPLICATION

The land application of animal manure has been a valuable and cost effective tool for supplying nutrients needed for crop production. Manure is effective in increasing crop production and improving soil properties because it contains nutrients and organic matter (Eghball and Power, 1994). Long term manure application has been found to substantially reduce both runoff and soil loss (Gilley and Risse, 2000). As the manure application rates increased, runoff and soil loss values were found to decrease. An increase in soil nutrient content may result in greater runoff nutrient concentration (Gilley et al. 2007a).

The objectives of this study were to a) determine the effects of a narrow grass hedge and varying manure application rates on runoff nutrient loads (mass per unit area) occurring soon after manure application; and b) compare the effects of a narrow grass hedge, varying manure application rates, and different overland flow rates on runoff nutrient loads (mass per unit area per unit time).

MATERIALS AND METHODS

STUDY SITE CHARACTERISTICS

Field tests were conducted in July and August 2011 at the University of Nebraska Rogers Memorial Farm located 18 km east of Lincoln, NE in Lancaster County. The site has been cropped using a corn, soybean, and winter wheat rotation, under a no-till management system, and was planted to soybeans during the 2009-2010 growing season. Herbicide was applied as needed to control weed growth. The study site remained undisturbed prior to the field study.

The soil at the site is classified as the Arksarben silty clay loam soil (fine, smectitic, mesic Typic Argiudoll) contained 14% sand, 54% silt, and 30% clay. The organic matter and total carbon content of the soil was 4% and 2.14%, respectively. The soil at the site developed in loess under prairie vegetation and had a mean slope of 3.6%. The soil had an electrical conductivity (EC) of 0.40 dS m^{-1} and a pH of 7.2.

Soil samples for study site characterization were obtained from the surface down to 2 cm just prior to manure application, and the soil samples were air dried following collection. Mean measured concentrations of Bray and Kurtz No. 1 P, water-soluble P, NO_3-N, and NH_4-N were 15, 1.6, 11, and 2 mg kg^{-1}, respectively.

PLOT PREPARATION

Twenty-four 0.75 m wide by 4 m long plots were established with the longer edge of the plot parallel to the slope of the direction of overland flow. Experimental treatments included the presence or absence within the plot of a 1.4 m wide switch grass (Panicum virgatum) hedge, varying manure application rates, and different runoff rates. The presence/absence of a narrow grass hedge was the main plot treatment and the manure application rate was a subplot treatment (fig.1). The twelve plots containing the grass hedge (established by randomized design) were positioned such that the 1.4 m wide switch grass hedge was at the lowest most part of the 4 m long plot according to the slope. The other twelve plots werealso established using a randomized design. The manure application rate was set to meet the 0, 1, 2, or 3 year nitrogen requirements for corn. The calculations for the manure application loads per unit area included the section that was covered by the grass hedge.

The narrow grass hedges were established during 1998 in parallel rows following the contour of the land. A specialized grass drill was used for the seeding operation. The grass hedges were spaced along the field hillslope to allow multiple passes of tillage equipment. The narrow grass hedges were part of a strip-cropping system where row crops were planted between hedges.

Field tests were conducted on six plots each week from 6 July to 28 July 2011. Just prior to field application, swine manure was collected from a swine production unit located at the U.S. Meat Animal Research Center near Clay Center, Nebraska. Swine manure was land applied to six experimental plots each week at rates of 0, 16, 31, or 47.5 Mg ha^{-1}, the amount of manure required to meet a zero, one two, or three year nitrogen requirement for corn (151 kg N ha^{-1} year^{-1} for an expected yield of 9.4 Mg ha^{-1}). When calculating manure application rates it was assumed that the N availability from swine manure was 70% of the total amount of nitrogen measured in the manure (Eghball et al. 2002).

RAINFALL SIMULATION PROCEDURES

The water used in the rainfall simulation tests was obtained from an irrigation well located near the experimental site. Concentrations of DP, TP, NO_3-N, NH_4-N, and TN in the irrigation water were 0.19, 0.19, 15.6, 0.00 and 15.6 mg L^{-1} respectively. Measurements of EC and pH were 0.77 dS m^{-1} and 7.2 respectively.

Rainfall simulation tests were performed over a 4 week period in July 2011. Tests were conducted on 6 plots each week using a portable rainfall simulator based on the design by Humphry et al. (2002).Three rain gauges were placed along the outer edge of each plot and two rain gauges were located between the plots. Water was first added to the plots with a hose until runoff began, providing more uniform antecedent soil water conditions. The simulator applied rainfall at a design intensity of approximately 70 mm hr^{-1} to a pair of 0.75 m wide by 2 m long plots. Procedures established by the National Phosphorus Research Project (NPRP) (Sharpley and Kleinman, 2003) will be used during the initial 30 minutes of the study. Three 30 minute rainfall events were simulated 24 hours apart.

The plot border channeled runoff into a sheet metal lip that emptied into a collection trough that extended across the bottom of each plot. The collection trough diverted runoff into plastic buckets. A sump pump was then used to transfer the runoff into larger plastic storage containers. The storage containers were weighed to determine the total runoff mass and the accumulated runoff was agitated to maintain suspension of solids.. Samples were obtained for water quality and sediment analysis.

After 30 minutes of rainfall simulation during the third run had passed, the runoff from the experimental plots was diverted into an HS flume with a stage recorder to measure the discharge rate. Four successive increments of inflow were then added to the top of each plot. A narrow synthetic mat was placed on the soil surface beneath the inflow device to prevent soil scouring and to evenly distribute the flow across the plot. Each flow increment was allowed to reach a steady state condition before a sediment sample taken. . Each simulated overland flow increment was maintained for approximately eight minutes.

Centrifuged and filtered runoff samples were placed in a cooler at 2°C and then later analyzed for DP (Murphy and Riley 1962), NO_3-N and NH_4-N using the Lachat system (Zellweger Analytics, Miliwaukee WI). Non-centrifuged samples were stored in a cooler at 2°C and then analyzed at a commercial laboratory for TP (Johnson and Ulrich, 1959) and TN (Tate, 1994). Particulate phosphorus (PP) values were reported as the difference between measurements of TP and DP.

Runoff samples for sediment analysis were collected in 1 L plastic bottles for which tare weights had been previously measured. The 1 L plastic bottles were transported to the laboratory and total mass was measured. The bottles were then dried in an over at 105°C and weighed to determine the mass of sediment (total solids) remaining in the sample bottles. Sediment content was calculated as the mass of remaining material in the bottles after drying divided by the mass of water in the bottle before drying. When calculating sediment content the mass of dissolved chemical constituents contained in the runoff was assumed to be negligible.

STATISTICAL ANALYSES

The effects of a narrow grass hedge, manure application rate, and inflow rate on runoff nutrient loads were determined using ANOVA (SAS Institute, 2011). For a given plot, water quality measurements obtained from each of the three-rainfall simulation runs were included in the analyses and were treated as repeated measures. The ANOVA program tested for significant differences among the experimental variables and established significant relationships among experimental variables. If a significant difference was identified, the least significant difference test (LDS) was used to identify differences among experimental treatments. A probability level ≤ 0.05 was considered significant.

RESULTS AND DISCUSSION

RUNOFF CHARACTERISTICS

Phosphorus Load

Runoff concentrations of DP and TP were not significantly affected by the presence of a grass hedge (table 1). The runoff concentrations of PP were found to be significantly higher with the presence of a grass hedge, 0.16 kg ha^{-1}, than without, 0.10 kg ha^{-1}. Runoff concentrations of DP increased in a linear fashion with nitrogen application rate, and was found to significantly higher in plots where slurry was applied than the check plots (fig 2). DP concentrations did not significantly vary with an increase in nitrogen application rates from 1 year to 3 years for corn. The runoff concentration of PP significantly decreased with the increase in nitrogen application rate. The check plot receiving no applied manure has a runoff concentration of 0.18 kg ha^{-}1 whereas the increase in nitrogen application rate of 1, 2, and 3 years resulted in PP runoff concentrations, 0.14, 0.11, and 0.08 kg ha^{-1} respectively. The increased amount of manure applied to meet each nitrogen requirement resulted in significantly higher DP runoff concentrations than the check plot but did not increase as the nitrogen application rate increased.

Gilley et al. (2007b) reported DP load in runoff from land applied swine manure to a no-till field to be 0.23 kg ha^{-1}. , which is larger than the 0.04 measured in the present study. Gilley et al. (2001) found that changing swine diet to control the amount of P in the manure did not significantly affect the total amount of DP transported in Runoff. This would help explain why increasing the amount of manure applied to meet the N requirement would not significantly affect the DP concentration in the runoff. The swine manure applied to the plots was highly diluted and also had a low TP load. The check plot in this study had a PP runoff concentration found to be significantly higher than the PP runoff concentrations from the plots receiving the increased nitrogen application rates. This can be attributed to the dilute nature of the slurry. As the large volumes of dilute manure were applied the slurry infiltrated into the soil and dispersed the nutrients into the soil profile. This infiltration of nutrients resulted in much lower PP concentrations at the soil at the highest nitrogen application rate. The swine slurry applied contained 153 mg kg^{-1} TP, which is an order of magnitude smaller than the TP concentration of 1010 mg kg^{-1} used by Gilley et al. (2007b) The low TP concentration in the slurry was responsible for the low P load found in the runoff.

The PP runoff concentrations were found to be significantly higher in the presence of a grass hedge than with no grass hedge. Due to the dilute nature of the slurry there were very sparse solids applied to the plots and the plots had a significant crop residue cover. The low solids and the crop residue cover resulted in the applied solids being contained on the plots and not interacting with the hedge as is present in a higher solids manure. The increased PP concentration can then be attributed to the capture of the first flush of the grass hedge. The first runoff through the grass hedge collected PP particles caught in the grass hedge from previous rainfall events and resulted in a higher PP concentration. PP runoff concentrations from the no-grass hedge plots experienced the same first flush but did not have the collected nutrients in the hedge.

Nitrogen Load

Runoff concentrations of NO_3-N, NH_4-N, and TN did not significantly decrease with the presence of a grass hedge (table 1). It was found that NH_4-N concentrations did increase with increasing nitrogen application rates. NO_3-N and TN showed no significant difference between the plots with no manure present and the plots with varying manure application rates. This is due to the nitrogen makeup of the manure where slurry NO_3-N concentrations were 0.5 mg kg^{-1} and NH_4-N concentrations were 776 mg kg^{-1}. The swine slurry that was used was obtained from a production facility containing a flush manure management system. . As the nitrogen application rate increased, the NH_4-N load increased in a linear fashion (fig. 3).

The TN concentration in the slurry that was used in the present study was 923 mg kg^{-1}. This is significantly lower than the TN concentration in the slurry used by Gilley et al. 2007b, of 5.82 g kg^{-1}. The lower concentration of TN in the slurry used in the present study resulted in a much larger volume of manure that was applied to meet the nitrogen requirements for corn. Gilley et al. (2007b) used a slurry containing more TN and thus produced more TN in the runoff.

Measurements of EC, pH, Runoff, and Soil Loss

The grass hedge was found to significantly decrease the EC concentration of runoff (table 1). Nitrogen application rate also significantly increased EC measurements in runoff. The EC concentration was found to increase linearly as the nitrogen application rate increased (fig. 4). The grass hedge also significantly reduced pH measurements in runoff. The nitrogen application rate did not affect pH. The pH value of 7.85 measured for runoff from the grass hedge was significantly less the value of 8.18 measured for the no grass hedge condition.

The grass hedge did not significantly affect the runoff amount. Nitrogen application rate also did not significantly affect the runoff amount. This is due to the fact that the plots were wetted down before hand to provide more uniform antecedent soil water conditions. No significant differences in soil loss were found between the grass hedge and no grass hedge treatments. Soil loss was minimal on the long term no-till field used in this study.

RUNOFF CHARACTERISTICS AS AFFECTED BY OVERLAND FLOW

Phosphorus Measurements

The grass hedge did not significantly affect DP, PP, and TP transport rates obtained during the inflow tests (table 2). Nitrogen application rate also did not significantly affect DP, PP, and TP transport rates. However, runoff rate ranging between 3.6 and 19.7 L min^{-1} did significantly affect rates of transport of DP, PP, and TP. DP, PP, and TP transport rates increased in a linear fashion with runoff rate was increased as shown in (fig. 5). Transport rates for PP and TP were found to be in the range of 65-357 and 72-382 g ha^{-1} min^{-1} respectively and were much larger than the range of values obtained for DP at 7-25 g ha^{-1} min^{-1}.

In a similar study Gilley et. al (2008) also found that runoff rate significantly affected PP, and TP transport rate with PP and TP runoff concentrations ranging between 26.8-169 and 81.1-220 g ha^{-1} min^{-1} respectively. Gilley et al. (2008) followed similar sampling methods but the swine slurry that was applied had significantly higher nutrient concentrations. The TP and PP transport rates found in the grass hedge study were higher than the PP and TP transport rates found Gilley et al.'s 2008 study. At a runoff rate of 8.5 L min^{-1} the PP and TP runoff concentrations were found to be 123 and 136 g ha^{-1} min^{-1}. The Gilley et al. 2008 study found PP and TP runoff concentrations to be 114 and 162 g ha^{-1} min^{-1} at a lower runoff rate of 7.4 L min^{-1}.The grass hedge study showed similar increased in nutrient runoff with increased runoff rate with the results found in Gilley et al. (2008). Its higher nutrient runoff can be attributed to a difference in applied manure where Gilley et al. 2008 compared tillage and residue rate at a nitrogen application rate of 1 year for corn, the grass hedge study compared nitrogen application rates ranging from 1-3 years for corn.

Gilley et al. (2008) also saw similar nutrient runoff in a no-till situation with a manure application for a 1 year nitrogen requirement as the grass hedge study saw in its no-grass hedge scenario. Gilley et al. (2008) found PP and TP nutrient concentrations in a no-till scenario to be 121 and 200 g ha^{-1} min^{-1} compared to the no-grass hedge scenario which found PP and TP runoff concentrations at 105 and 121 g ha^{-1} min^{-1}.

Nitrogen Measurements

Transport rates for NO_3-N, NH_4-N, and TN were not significantly affected by the presence of a grass hedge (table 2). It was also found that a variation in the nitrogen application rate had no significant effect on the NO_3-N, NH_4-N, or TN runoff transport rates. There were however, significant increases in NO_3-N, NH_4-N, and TN transport rates with an increase in runoff rate. NO_3-N, NH_4-N, and TN transport rates were found to increase linearly as runoff rate increased (figure 6). It was also found that transport rates for NO_3-N and TN were much larger than those measured for NH_4-N..

The results obtained in the present study were similar to the results found by Gilley et al. (2008) who showed that in no till condition NO_3-N, NH_4-N, and TN increased significantly with an increase in runoff rate. Gilley et al. (2008) also found that there was substantially less NH_4-N in runoff than NO_3-N and TN.

EC, pH, and Soil Loss Measurements

EC, pH, and soil Loss were not significantly affected by the presence of a grass hedge (table 2). EC measurements were significantly affected by runoff rate, with values varying from 0.74 to 0.75 dS m^{-1}. pH was also significantly affected by runoff rate with values decreasing in a linear fashion with increasing runoff rate (figure 7). Soil loss values also increased significantly with runoff rate. Soil loss was found to increase in a linear fashion with runoff rate (Figure 8).

CONCLUSIONS

The narrow grass hedge did not significantly reduce nutrient loads in runoff. However, the grass hedge was found to significantly decrease t EC values from 0.78 to 0.73 dS $m^{-1}$and pH measurements from 8.16 to 7.85. The grass hedge did not significantly affect runoff amounts soil loss measurements.

Increasing the nitrogen application rates did not significantly affect nutrient transport rates. However, EC measurements increased with increasing nitrogen application rate,

When inflow was introduced to the experimental plots, the increasing runoff rate significantly affected each of the water quality parameters. Increasing the runoff rate from 3.6 to 19.7 L min^{-1} significantly increase DP transport rates from 7 to 25 g ha^{-1} min^{-1}, PP transport rates from 65 to 357 g ha^{-1} min^{-1}, and TP transport rates from 72 to 382 g ha^{-1} min^{-1}. Runoff rate also significantly increased NO_3-N transport rates from 273 to 1204 g ha^{-1} min^{-1}, NH_4-N transport rates from 30 to 43 g ha^{-1} min^{-1}, and TN transport rates from 323 to 1490 g ha^{-1} min^{-1}. Increased runoff rate significantly increased EC runoff concentration from 0.74 to 0.75 dS m-1. pH was significantly decreased from 8.09 to 7.83, by an increase in runoff rate. An increase in runoff rate was also found to significantly increase the soil loss rates from the experimental plots from 15 to 51 kg ha^{-1} min^{-1}. Runoff rate is an important variable that should be considered when estimating nutrient transport from land application areas

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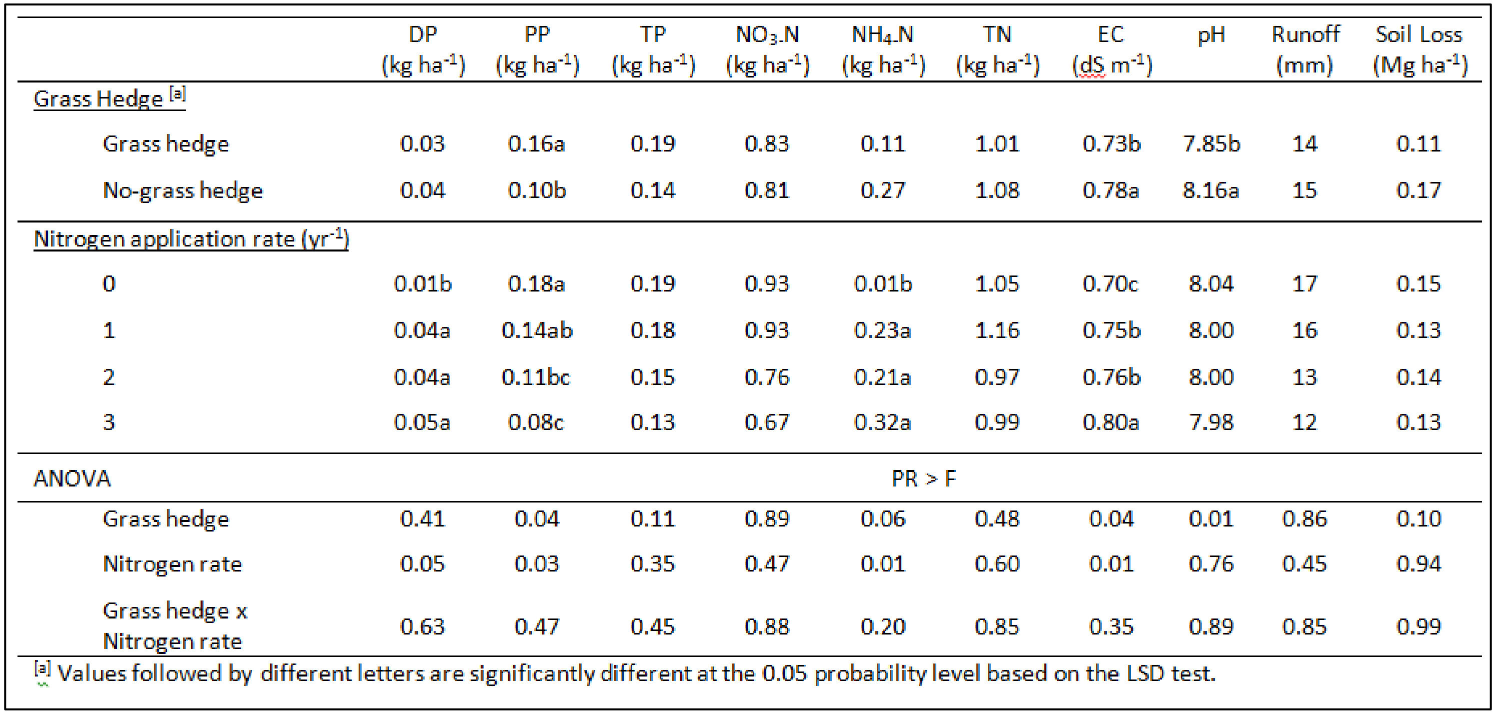
APPENDIX

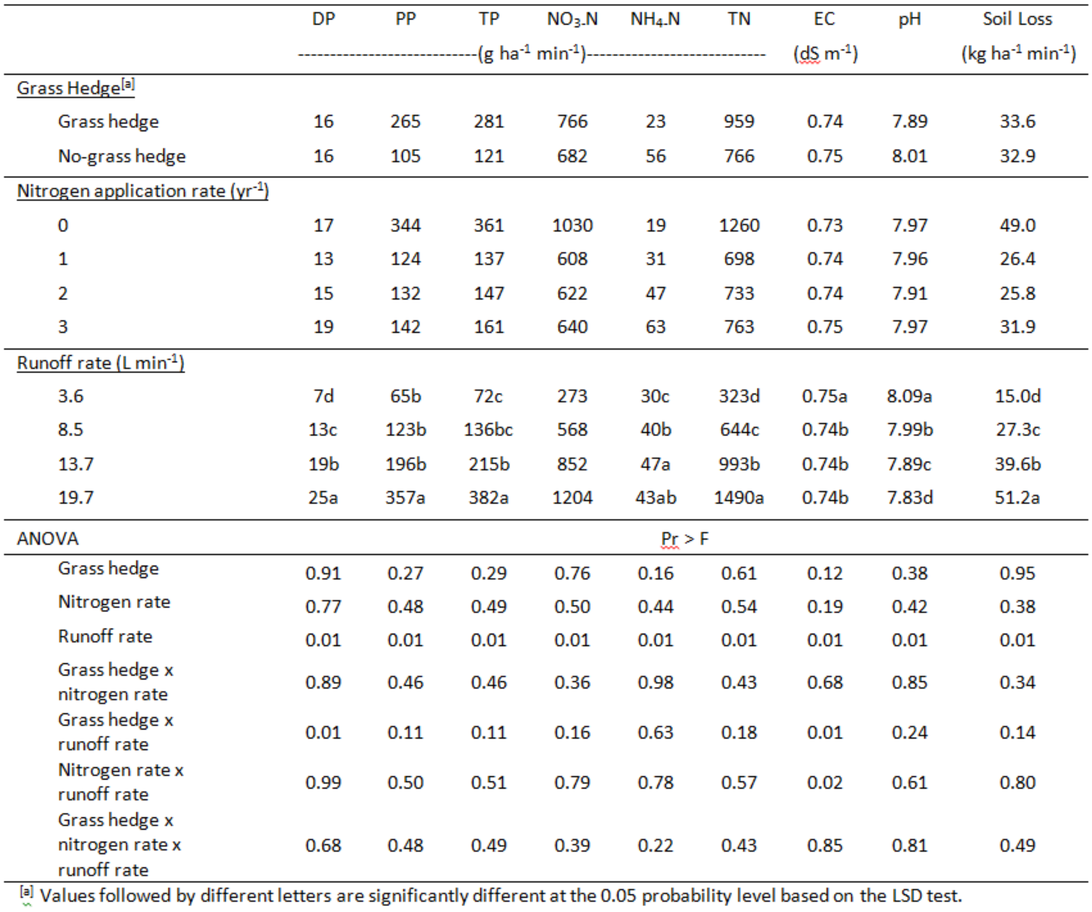
Table 1. Effects of a grass hedge and nitrogen application rate on selected runoff water quality parameters averaged over three rainfall simulation runs.



	DP (kg ha^{-1})	PP (kg ha^{-1})	TP (kg ha^{-1})	NO_3.N (kg ha^{-1})	NH_4.N (kg ha^{-1})	TN (kg ha^{-1})	EC (dS m^{-1})	pH	Runoff (mm)	Soil Loss (Mg ha^{-1})
Grass Hedge [a]										
Grass hedge	0.03	0.16a	0.19	0.83	0.11	1.01	0.73b	7.85b	14	0.11
No-grass hedge	0.04	0.10b	0.14	0.81	0.27	1.08	0.78a	8.16a	15	0.17
Nitrogen application rate (yr^{-1})										
0	0.01b	0.18a	0.19	0.93	0.01b	1.05	0.70c	8.04	17	0.15
1	0.04a	0.14ab	0.18	0.93	0.23a	1.16	0.75b	8.00	16	0.13
2	0.04a	0.11bc	0.15	0.76	0.21a	0.97	0.76b	8.00	13	0.14
3	0.05a	0.08c	0.13	0.67	0.32a	0.99	0.80a	7.98	12	0.13
ANOVA					PR > F					
Grass hedge	0.41	0.04	0.11	0.89	0.06	0.48	0.04	0.01	0.86	0.10
Nitrogen rate	0.05	0.03	0.35	0.47	0.01	0.60	0.01	0.76	0.45	0.94
Grass hedge x Nitrogen rate	0.63	0.47	0.45	0.88	0.20	0.85	0.35	0.89	0.85	0.99

[a] Values followed by different letters are significantly different at the 0.05 probability level based on the LSD test.

Table 2. Runoff water quality parameters as affected by a grass hedge, nitrogen application rate, and runoff rate.



	DP	PP	TP	NO_3.N	NH_4.N	TN	EC	pH	Soil Loss
	----------------------------(g ha^{-1} min^{-1})----------------------------						($dS\ m^{-1}$)		(kg ha^{-1} min^{-1})
Grass Hedge[a]									
Grass hedge	16	265	281	766	23	959	0.74	7.89	33.6
No-grass hedge	16	105	121	682	56	766	0.75	8.01	32.9
Nitrogen application rate (yr^{-1})									
0	17	344	361	1030	19	1260	0.73	7.97	49.0
1	13	124	137	608	31	698	0.74	7.96	26.4
2	15	132	147	622	47	733	0.74	7.91	25.8
3	19	142	161	640	63	763	0.75	7.97	31.9
Runoff rate (L min^{-1})									
3.6	7d	65b	72c	273	30c	323d	0.75a	8.09a	15.0d
8.5	13c	123b	136bc	568	40b	644c	0.74b	7.99b	27.3c
13.7	19b	196b	215b	852	47a	993b	0.74b	7.89c	39.6b
19.7	25a	357a	382a	1204	43ab	1490a	0.74b	7.83d	51.2a
ANOVA					Pr > F				
Grass hedge	0.91	0.27	0.29	0.76	0.16	0.61	0.12	0.38	0.95
Nitrogen rate	0.77	0.48	0.49	0.50	0.44	0.54	0.19	0.42	0.38
Runoff rate	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Grass hedge x nitrogen rate	0.89	0.46	0.46	0.36	0.98	0.43	0.68	0.85	0.34
Grass hedge x runoff rate	0.01	0.11	0.11	0.16	0.63	0.18	0.01	0.24	0.14
Nitrogen rate x runoff rate	0.99	0.50	0.51	0.79	0.78	0.57	0.02	0.61	0.80
Grass hedge x nitrogen rate x runoff rate	0.68	0.48	0.49	0.39	0.22	0.43	0.85	0.81	0.49

[a] Values followed by different letters are significantly different at the 0.05 probability level based on the LSD test.

No-Hedge Rate 2 Plot 401	No-Hedge Rate 1 Plot 402	No-Hedge Rate 0 Plot 403	No-Hedge Rate 3 Plot 404
No-Hedge Rate 2 Plot 501	No-Hedge Rate 0 Plot 502	No-Hedge Rate 1 Plot 503	No-Hedge Rate 3 Plot 504
No-Hedge Rate 1 Plot 601	No-Hedge Rate 2 Plot 602	No-Hedge Rate 0 Plot 603	No-Hedge Rate 3 Plot 604
With-Hedge Rate 2 Plot 701	With-Hedge Rate 1 Plot 702	With-Hedge Rate 0 Plot 703	With-Hedge Rate 3 Plot 704
With-Hedge Rate 2 Plot 801	With-Hedge Rate 1 Plot 802	With-Hedge Rate 3 Plot 803	With-Hedge Rate 0 Plot 804
With-Hedge Rate 2 Plot 901	With-Hedge Rate 0 Plot 902	With-Hedge Rate 1 Plot 903	With-Hedge Rate 3 Plot 904

Figure 1. Schematic showing the plot layout, hedge and no-hedge treatments, and nitrogen application rates based on 0-, 1-, 2-, or 3-year corn N requirements.

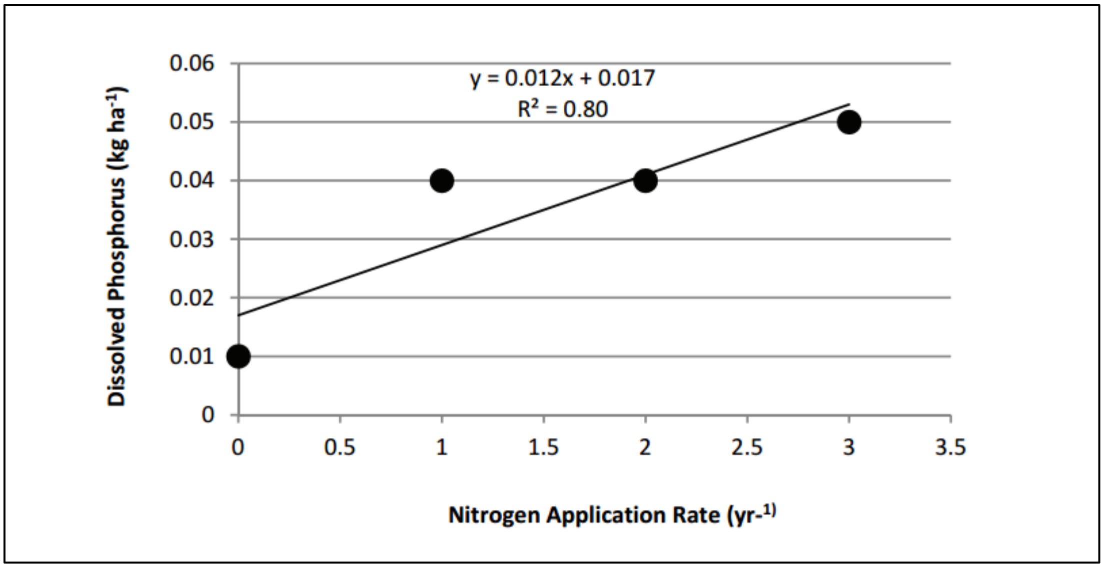


Figure 2. Dissolved phosphorus transport as affected by nitrogen application rate.

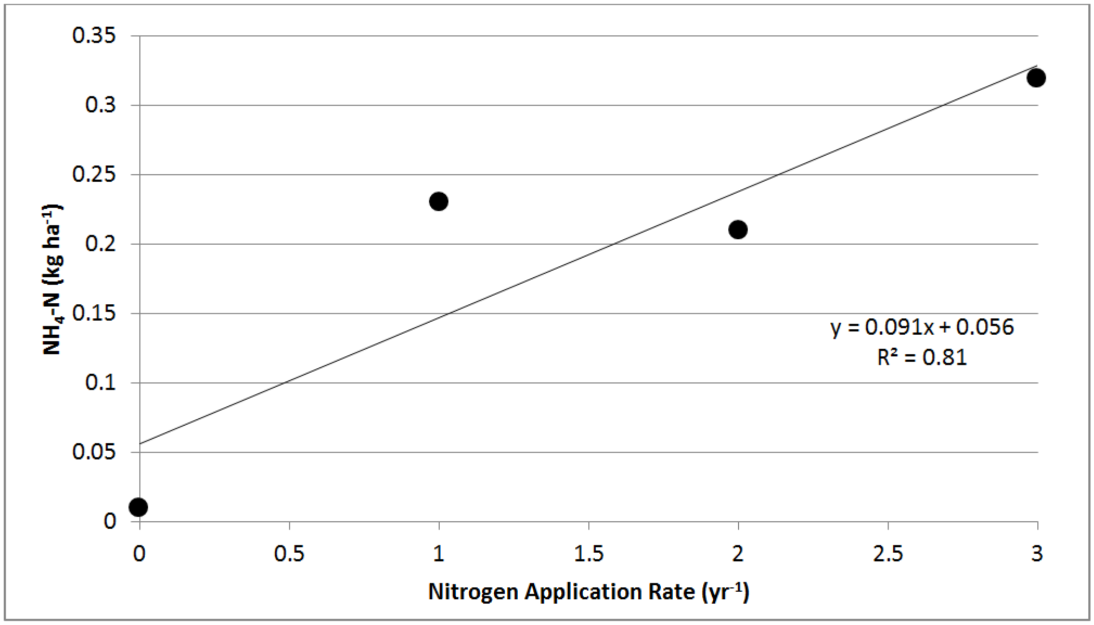


Figure 3. NH_4-N transport as affected by nitrogen application rate.

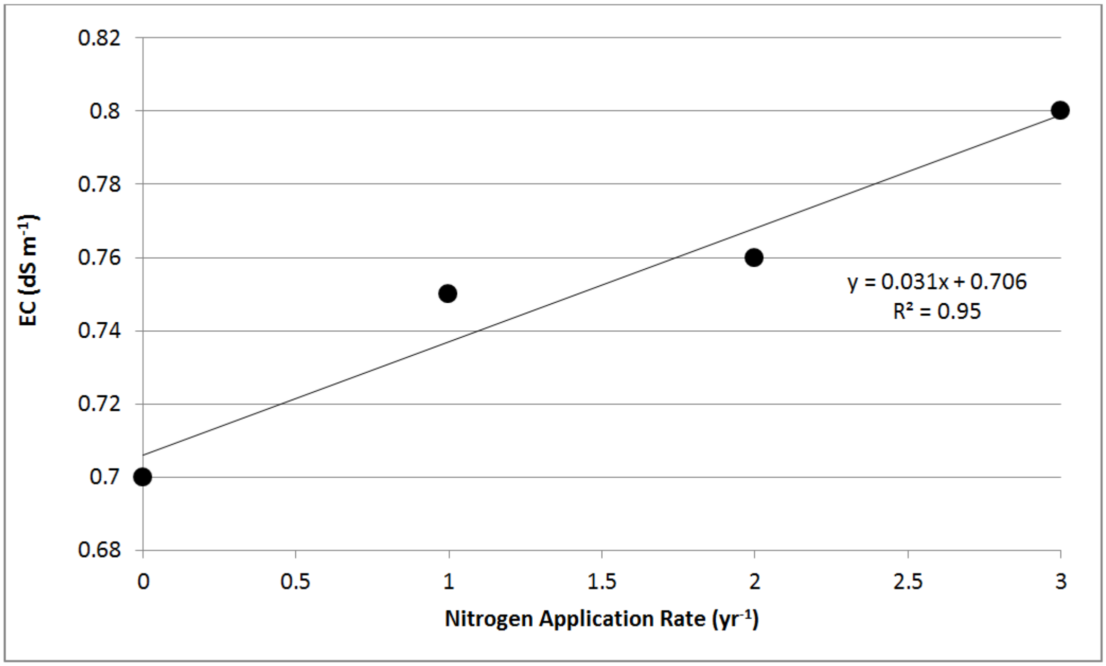


Figure 4. Electrical conductivity (EC) as affected by nitrogen application rate.

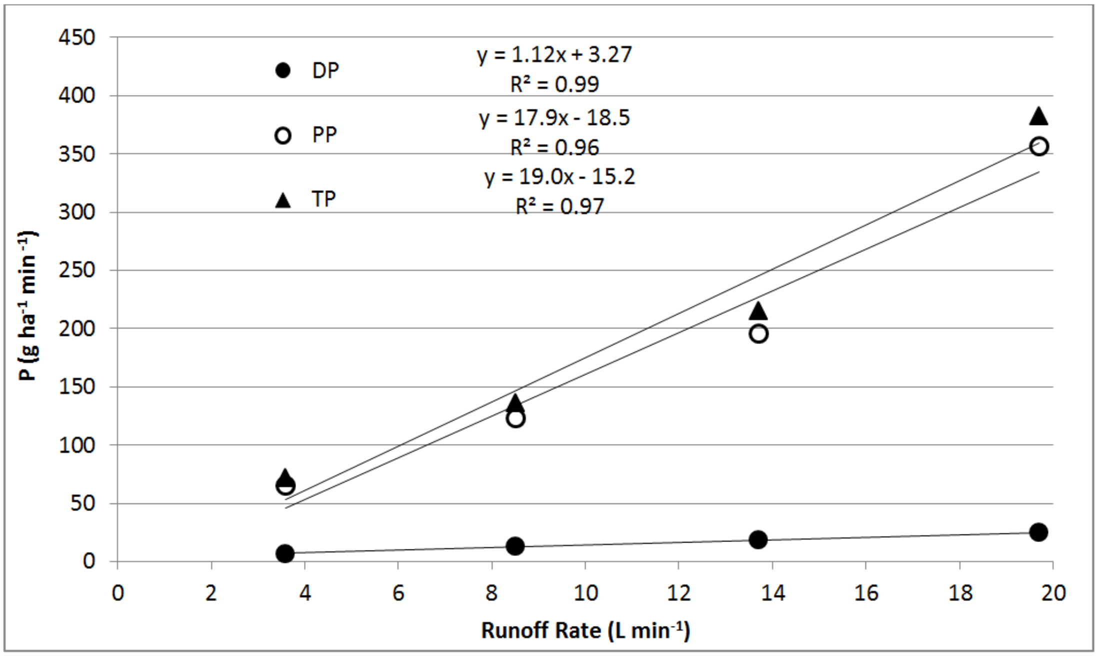


Figure 5. Dissolved phosphorus (DP), particulate phosphorus (PP), and total phosphorus (TP) transport rate as affected by runoff rate.

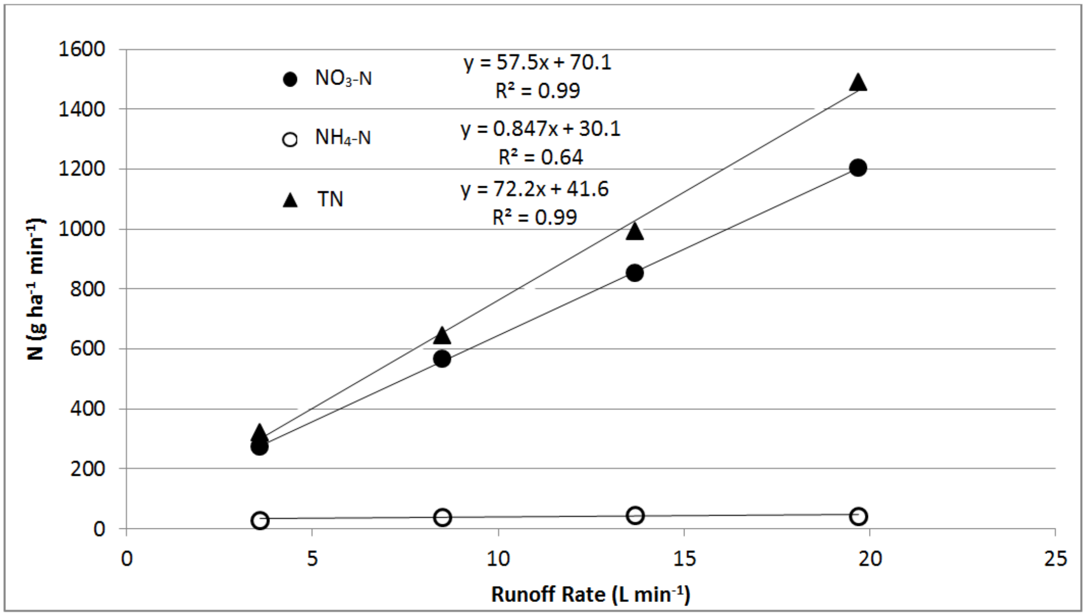


Figure 6. NO_3-N, NH_4-N, and total nitrogen (TN) transport rate as affected by runoff rate.

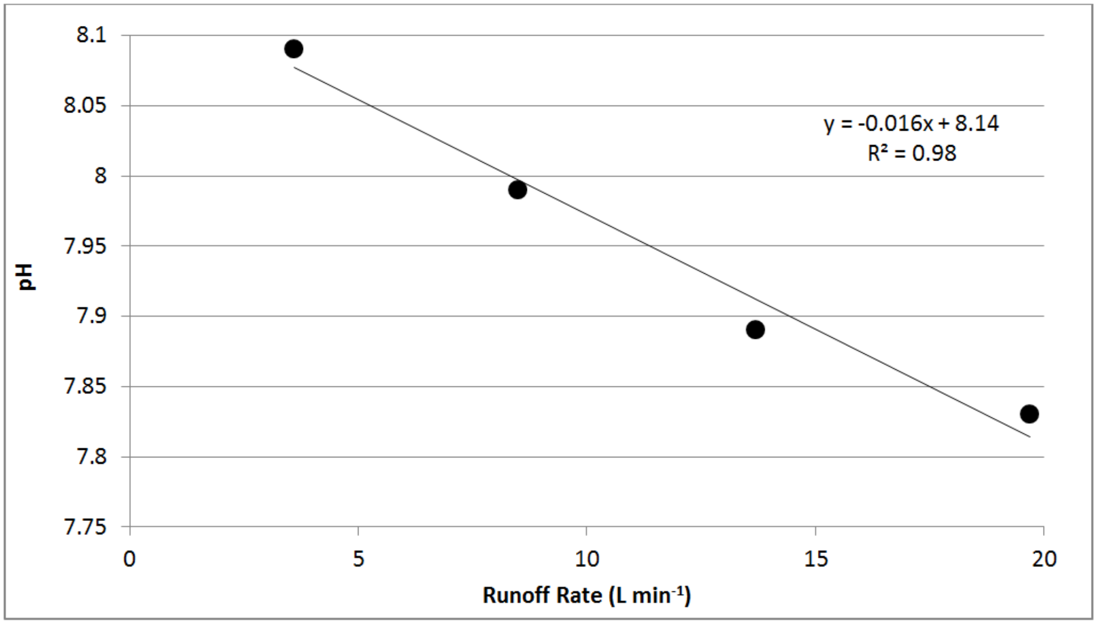


Figure 7. pH values as affected by runoff rate.

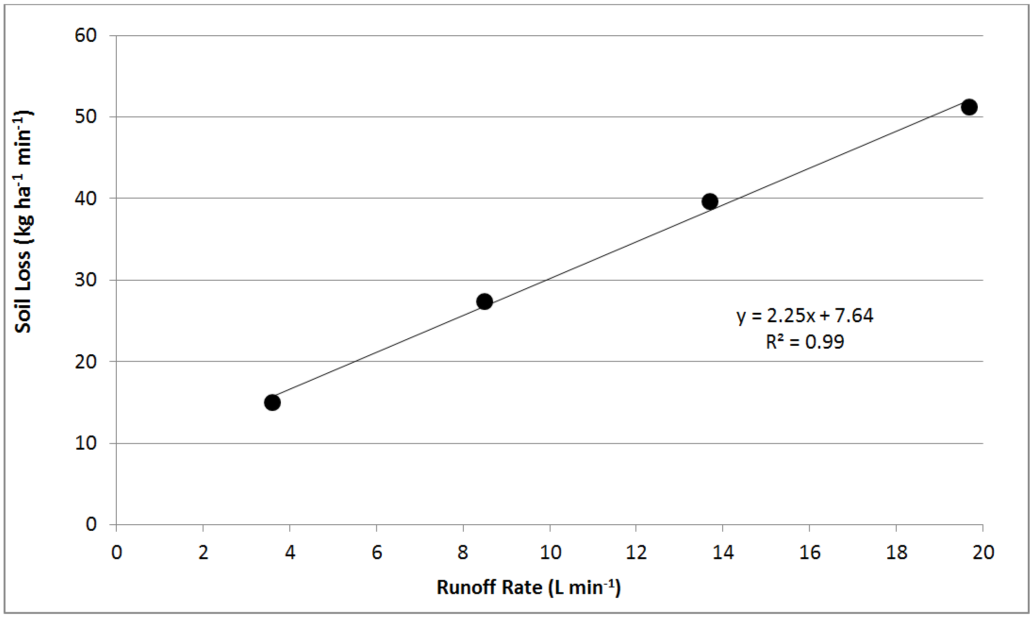


Figure 8. Soil loss rate as affected by runoff rate.

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