Evaluation of some phosphorus index criteria in cultivated agriculture in clay soils

H.A. Torbert, R.D. Harmel, K.N. Potter, and M. Dozier

ABSTRACT: There are growing concerns regarding the fate of nutrients from land application of animal waste. In recent years, phosphorus (P) indices have been developed to provide information regarding nutrient loss potentials from animal waste application methods and topography. However, in many cases, these P indices have not been fully tested, especially in cultivated agriculture. Three factors commonly utilized in soil P indices for manure management are manure rate, manure incorporation, and slope. Rainfall simulations were conducted to examine the impact of these three factors on runoff losses of P on heavy clay soils under cultivated agriculture. Four manure litter (turkey litter) application rates (0, 4.5, 9.0, and 13.5 Mg ha^{-1} (0, 2, 4, and 6 tons ac^{-1})) were applied on two different slopes (5 and 9 percent) on a Heiden clay (fine, smectitic, thermic Udic Haplusterts). The litter was surface applied to a corn (*Zea mays* L.) production area, with or without incorporation. The four application rates were also applied to a permanent bermudagrass (*Cynodon dactylon* (L.) Pers.) pasture on a 5 percent slope. A rainfall simulator was used to generate water runoff for 30 minutes from 1.5 by 2.0 m (5 by 6.5 ft) plots. Runoff samples were analyzed for runoff volume, sediment, sediment nitrogen (N) and P, dissolved ammonia nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and PO_4-P. The results were analyzed using regression analysis techniques based on application rates. The dissolved NO_3-N concentration was not affected by either litter incorporation or slope in the cultivated sites, but was greatly increased with increasing litter application rate in the pasture sites. Increased losses of dissolved NH_4-N and PO_4-P were observed with increasing litter application rate, with a significant reduction in losses observed when litter was incorporated. However, increased slope did not significantly impact the level of runoff losses of dissolved NH_4-N and PO_4-P.

Keywords: Manure management, phosphorus, rainfall simulation, surface runoff, water quality

Scientists and resource managers continue to have concerns regarding the potential negative water quality impact that may result from nonpoint additions of nutrients to watersheds. The greatest potential for nonpoint phosphorus (P) contribution to surface waters usually occurs in watersheds with intensive animal production (Kellogg and Lander, 1999; McFarland and Hauck, 1999; Sims et al., 2000). Manure collected from concentrated animal feeding operations (CAFO) has traditionally been applied to fields near the operation because this is a practical means of both improving soil physical conditions and providing needed plant nutrients for crop production. However, long-term manure application to soils at rates exceeding crop uptake can result in elevated soil P levels and directly influences the amount of P in runoff (Daniel et al., 1994; Sharpley, 1995; Pote et al., 1996; Sharpley et al., 1996).

These potential nonpoint source nutrient losses can contribute to environmental degradation, eutrophication of surface waters, and possible human health risks. These concerns have been stimulated by blooms of the toxic dinoflagellate algae *(Pfiesteria piscicidia)* that have caused fish kills and human illnesses and by reports of a large [20,000 km^2 (7722 $miles^2$)] hypoxic area (low dissolved oxygen) in the Gulf of Mexico (Rabalais et al., 2001), which have been attributed to pollution from excess nutrients (Goolsby et al., 2001). Phosphorus is the most common cause of eutrophication in freshwater streams, rivers, lakes, and reservoirs, while nitrogen (N) is the most common cause in the oceans (Correll, 1998).

To address the potential of nonpoint nutrient enrichment of surface waters from land application of manure, the U.S. Department of Agriculture (USDA) and U.S. Environmental Protection Agency (USEPA) have developed a joint strategy for sustainable nutrient management (USDA and USEPA, 1999). One of the strategies eventually available to producers will be the use of a P index to limit P applications on fields at greatest risk of P loss (Sharpley et al., 2003). The principle of the P index is that all of the land available for manure application in a watershed does not have the same potential for nutrient loss. In order for surface waters to be enriched in P, there must be both a source of P and P must be transported to a sensitive location (Gburek and Sharpley, 1998; Sharpley and Tunney, 2000). The P index attempts to account for both transport and source factors controlling P loss to identify fields that are most vulnerable to P loss in runoff (Lemunyon and Gilbert, 1993; Sharpley et al., 2003).

Nationwide, most states have worked on development of P indices (Sharpley et al., 2003), with 47 states adopting the P index approach for nutrient management. While these P indices vary widely, all of them attempt to address the vulnerability of fields to P losses by evaluating the potential contributions of a site for P source and transport factors (Sharpley et al., 2003). Research has been conducted to examine the validity of using a P index approach to reduce P enrichment in surface waterways. For example, Sharpley et al. (2001) reported that the P index effectively described 88 percent of the variability in dissolved P concentrations from all sites in a watershed. Birr and Mulla (2001) evaluated the P index approach

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and found that, with certain limitations, the P index can be used to prioritize P loss vulnerability on a regional scale. However, more research on the P index is needed to examine the effectiveness of the P index in cultivated lands on heavy clay soils.

The objective of this study was to examine some of the best management practices as they may be used in a P index on their potential impact on nutrient losses in runoff in heavy clay soils. Three factors commonly utilized in P indices for manure management (manure rate, manure incorporation, and slope) were chosen for examination. These variables were also chosen because they allowed for the inclusion of best management practices that address both a nutrient source and a nutrient transport factor and their interaction.

Table 1. Rainfall simulation treatments.

Land use	Litter handling	Slope	Litter application rate			
		Percent	Mg ha^{-1}			
Cultivated	Surface	5	0.0	4.5	9.0	13.5
Cultivated	Surface	9	0.0	4.5	9.0	13.5
Cultivated	Incorporated	5	0.0	4.5	9.0	13.5
Cultivated	Incorporated	9	0.0	4.5	9.0	13.5
Pasture	Surface	5	0.0	4.5	9.0	13.5

Methods and Materials

Rainfall simulations were conducted to examine the impact of three factors on runoff nutrient losses on heavy clay soils under cultivated agriculture, ie., slope, manure litter (turkey litter) incorporation, and litter application rate. To conduct this study, runoff plots were constructed on Heiden clay (fine, smectitic, thermic Udic Haplusterts) at the USDA's Agricultural Research Service's Grassland, Soil and Water Research Center in Riesel, Texas. Protocols established by the National Phosphorus Research Project (2001) were used to construct plots and perform rainfall simulation. Each plot was 1.5 m (5 ft) wide and 2.0 m (6.5 ft) long with the long axis oriented parallel to the slope. Galvanized metal plot borders extended approximately 13 cm (5 in) below the soil surface and 7 cm (3 in) above the soil. A galvanized metal trough was located on the downslope end of each plot to collect and transport runoff to a collection point.

Runoff plots were constructed on a site utilized for corn (*Zea mays* L.), wheat (*Tritcum aestivum* L.), or grain sorghum (*Sorghum bicolor* L.) production, with corn being the most recent crop. Crop production at this site used conventional tillage systems that were typical for the Blackland Prairie Region (chisel plowing, tandem disking, and winter fallow) and recommended cultural practices (Texas Agriculture Experiment Station, 1987). Four turkey litter application rates (0, 4.5, 9.0, and 13.5 Mg ha^{-1}(0, 2, 4, and 6 tons ac^{-1})) were applied to each set of slopes (5 and 9 percent) and litter handling (with and without litter incorporation) combinations (Table 1). Turkey litter was collected from local turkey production facilities with the litter consisting of turkey manure and bedding material mixture. Slopes for the Blackland Prairie region typically range from 1 to 9 percent; therefore, plots were located on slopes which represent typical values and have sufficient slope to generate runoff. A land capacity classification will generally rank a 5 percent slope as a Class II soil while a 9 percent slope would be a classified as a Class III or IV soil (Fenton, 2002). The plots were raked to create a uniform slope throughout the plot. Eight days prior to rainfall simulation, turkey litter was applied to the surface of each plot at the designated application rate. For the plots designated as incorporated, litter was incorporated to a depth of approximately 8 cm (3 in) with a hand cultivator to simulate incorporation with tillage equipment. In addition, the four litter application rates were also applied to a permanent bermudagrass (*Cynodon dactylon* (L.) Pers.) pasture on a 5 percent slope. Three weeks prior to rainfall simulation, the pasture plots were clipped to 10 cm (4 in) and the clipped vegetation removed.

Prior to simulation, soil samples from 0 to 15 cm (0 to 6 in) were collected from the plot area to determine soil chemical characteristics (Table 2). Soil samples were dried [60 ˚C (140 ˚F)], ground to pass a 0.15 mm (0.006 in) sieve, and analyzed for total N and total P concentration colorimetrically on a Techninon Autoanalyzer[1] (Seal Analytical, Inc., Buffalo Grove, Illinois), following digestion by a salicylic acid modification of a semimicro-Kjeldahl procedure (Bremner, 1996). Soil inorganic and organic C was determined with a LECO CR12 Carbon Determinator (LECO Corporation, Saint Joseph, Michigan; Chichester and Chaison, 1992). Soil samples were analyzed for pH and extractable concentrations of P, K, Mg, Ca, by the Soil Testing Laboratory, Auburn University, using procedures outlined by Hue and Evans (1986). Briefly, the soils were extracted using a double acid or Mehlich 1

Table 2. Soil concentrations of total and extractable plant nutrients in cultivated and pasture sites averaged over soil depth.*

Land use	pH	Total N*	Total P*	Total C	Organic C	Extractable P	K	Mg	Ca
		(g kg^{-1})				(mg kg^{-1})			
Cultivated	8.0	1.5	0.9	53.5	17.8	17	266	161	22555
Pasture	7.9	2.0	0.6	70.7	19.8	11	242	130	21780

	Depth	Gravimetric soil water content (g 100g^{-1})
Cultivated	0-15 cm	25.8
	15-30 cm	30.3
Pasture	0-15 cm	21.1
	15-30 cm	23.1

* Total nitrogen (N) and phosphorus (P) determined by Kjeldahl digestion.

Table 3. Turkey litter characteristic on a dry weight basis.*

	Total N	Total P	Water extractable NO_3-N	NH_4-N	SRP*	Moisture
	(g kg^{-1})		(mg kg^{-1})			g 100 g^{-1}
Litter	33.7	55.1	461	979	747	45.8

* SRP = soluble reactive phosphorus

extractant (Mehlich, 1953) and measured by inductive coupled plasma spectrophotometry (ICP 9000, Thermo Jarell-Ash Corporation, Franklin, Massachussetts). Soil samples were collected from 0 to 15 cm (0 to 6 in) and 15 to 30 cm (6 to 12 in) from the plot area to determine antecedent soil water content (Table 2). Samples of the turkey litter were collected at the time of application and chemical analyses were conducted for total N and total P concentration by the Soil Testing Laboratory, Auburn University, using procedures outlined by Hue and Evans (1986) and water extractable ammonia nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and soluble reactive P (SRP) by the procedures of Self-Davis and Moore (2000). Results are reported in Table 3.

Rainfall simulation began on November 6, 2001. Rain was applied with a rainfall simulator (Humphry et al., 2002) at approximately 70 mm hr^{-1} (2.7 in hr^{-1}) to generate runoff. The rainfall was maintained to provide a 30 minute runoff duration. During the 30 min runoff period, 20 ml (0.01 pt) water samples were collected at 2.5, 7.5, 12.5, 17.5, 22.5, and 27.5 minutes. Flow rate was estimated by recording the time to fill a 1L (0.95 qt) sample bottle at each sampling time. Runoff was pumped from the collection basin and collected in a fiberglass tank. Upon completion of the simulation, runoff volume in the tank was measured and a cumulative water sample was collected. Samples of source water used in rainfall simulation were collected each day of the simulation.

Immediately after collection, runoff samples were acidified with concentrated HCl and iced. Runoff water samples were filtered through a 0.45 µm (0.002 in) membrane and analyzed for dissolved nitrate plus nitrate nitrogen (NO_3-N) and ammonia nitrogen (NH_4-N), concentrations using a Technicon Autoanalyzer IIC (Seal Analytical, Buffalo Grove, Illinois) with colorimetric methods (Mulvaney, 1996). Runoff samples were also analyzed for PO_4-P using the molybdenum-blue method for P in water (Pote and Daniel, 2000) with a Technicon Autoanalyzer IIC. Dissolved nutrient loads were determined by multiplying nutrient concentrations by corresponding flow volumes and summing these incremental loads for the duration of the runoff event.

Sediment concentrations were estimated from the total mass of sediment present in each sample bottle. Collected sediments were dried and weighed. Total N and total P concentration of sediment was determined colorimetrically on a Technicon Autoanalyzer IIC, following digestion of sediment by a salicylic acid modification of a semimicro-Kjeldahl procedure (Bremner, 1996). Sediment load was estimated as the sum of incremental runoff volumes multiplied by the corresponding sediment concentration.

The experimental design consisted of a set of four plots to which four litter rates were randomly assigned. This set of four plots representing litter rates were repeated for five conditions: 2 slopes by 2 soil preparations, plus "pasture area." Regression analysis explaining litter application rate effect on runoff and sediment measurements were performed for these five conditions. Statistical analysis was performed using the Mixed procedure in SAS (SAS Institute, 1996). The analysis included slopes and soil preparations as fixed classification effects and litter application as a continuous linear effect. The

Figure 1

Regression relationships of litter application rate to the concentration of P and N for sediment in runoff as affected by slope (5% or 9%) and litter soil preparation (surface application or incorporated).

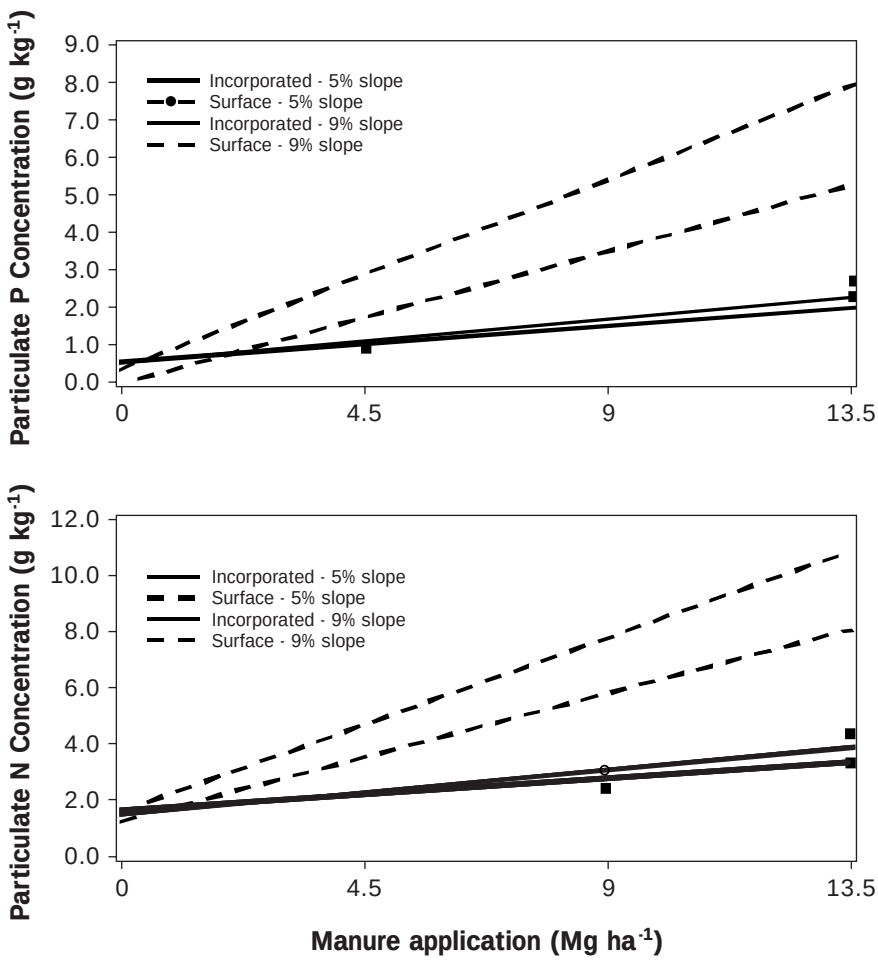


Table 4. Probability of a greater *F* for components measured in runoff water following application of turkey litter.*

Water component	Application rate	Application rate x soil preparation
Runoff volume	0.048	NS
Sediment	0.907	NS
Sediment N concentration	<0.001	0.001
Sediment N load	0.186	NS
Sediment P concentration	<0.001	0.006
Sediment P load	0.019	NS
NO_3-N concentration	0.019	NS
NH_4-N concentration	<0.001	0.001
PO_4-N concentration	<0.001	0.035
NO_3-N load	0.036	NS
NH_4-N load	<0.001	0.066
PO_4-P load	<0.001	0.071

*** Statistical analysis included the interactions of manure x slope and manure x slope x soil preparation, neither of which were significant for any of the measured runoff water components. When interactions were not significant, they were sequentially removed from the analysis and rerun to produce the correct probability.**

analysis of variance model included f-test to test for a litter application linear trend and compare the slope for this trend between the five conditions. The error term (with 10 degrees of freedom) used to construct these f-tests consisted of the 2 degrees of freedom for "lack of fit" pooled across the five conditions. The r^2 values reported are based on fitting a straight line through the means. Significance was declared at an established *a priori* level of $P \leq 0.10$. Statistical analysis was also performed for each of the time intervals measured in the study. However, no important difference was noted that was not measured for the total rainfall event, therefore these data were not presented.

Results and Discussion

Runoff sediment. The application of turkey litter to the cultivated field had a clear impact on the water runoff concentration of nutrients and the load of nutrients in the runoff events. Results of regression analysis of particulate N and P are presented in Figure 1. Analysis of the significance of the interaction between treatments using linear regression analysis is presented in Table 4. Runoff volume averaged 68 L (18 gal) for the thirty minute runoff event but was not significantly impacted by the application of litter or other treatment interactions. Relatively large sediment losses were measured with the runoff events, with an average sediment load of 1482 kg ha^{-1} (1323 lb ac^{-1}) for the runoff event, but no significant differences for litter application rate or treatment interactions were observed for sediment load for the runoff events. Application of litter has been shown to protect surface soil by reducing rain drop impact and aggregate dispersion (Barthès et al., 1999). McDowell and Sharpley (2003) showed a reduction in particulate P in overland flow from soil treated with 50 kg P ha^{-1} (45 lb P ac^{-1}) dairy manure compared to untreated soil. In this study the application of litter did not appear to impact infiltration either with or without incorporation of the litter. Long-term application of manure has been shown to increase organic matter levels, which improves porosity, aggregate stability, and infiltration (Gilley and Risse, 2000). The litter in this study was applied only eight days before the runoff event and while no significant impact could be immediately observed from the application of litter, the long-term impact on soil structure and improved water infiltration could not be assessed in this study.

The concentration of N and P in the sediment was significantly impacted by the application of litter, with an increase in the concentration of N and P in the sediment as the litter application rate increased. It has been shown that the particles carried with erosion may have greater concentration of sorbed nutrients than the bulk soil that they originated from (Sharpley and Smith, 1991). A significant interaction between the application rate and the soil preparation was also observed (Table 4). Analysis of the regression lines indicated that incorporation of litter reduced the concentration of N and P in the sediment (Table 5; Figure 1). With the incorporation of the litter, only a small increase in the P and N concentration in sediment could be noted as the rate of litter application was increased. On the other hand, with surface application of litter, a large increase in the N and P concentrations was observed as litter application rate increased (Figure 1).

The increase in P concentration resulted in a significant increase in the sediment P load with increased manure application, but no significant interaction was noted (Table 4). The increase in N concentration did not translate into a significant increase in the sediment N load (Table 4). This was likely due to the lack of significant difference (sampling variability) in the sediment loads that were measured in this study. While no significant difference in P and N loads were measured for incorporation of the manure, it is clear that an increase in the P and N concen-

Table 5. Regression equations describing relationship of litter application rate to runoff of sediment P and N concentration as affected by slope and litter surface application treatment.*

Slope (%)	Surface condition	Equation	r^2	
		Sediment P concentration		
5	Incorporation	P = 0.044 + 0.0130 * litter	0.671	a
5	Surface application	P = -0.013 + 0.0397 * litter	0.672	b
9	Incorporation	P = 0.048 + 0.0107 * litter	0.862	a
9	Surface application	P = 0.027 + 0.0566 * litter	0.978	b
		Sediment N concentration		
5	Incorporation	N = 0.155 + 0.018 * litter	0.770	a
5	Surface application	N = 0.130 + 0.052 * litter	0.682	b
9	Incorporation	N = 0.171 + 0.013 * litter	0.917	a
9	Surface application	N = 0.228 + 0.071 * litter	0.998	b

*** Equations not followed by a common letter are significantly different based on pair-wise F-test for homogeneity of slopes, Litter = Application of turkey litter (Mg ha^{-1}). Significance is declared at $P \leq 0.10$.**

tration of the sediment over time could negatively impact water quality as the sediment enters water bodies down stream of the application point.

Dissolved nutrient runoff. Results of regression analysis of dissolved NH_4-N, PO_4-P, and NO_3-N is presented in Tables 6 and 7 and Figures 2 and 3. The runoff losses of dissolved NH_4-N and PO_4-P were impacted by the application of litter to the cultivated soil. There was also a significant interaction between the litter application rate and the soil preparation for the dissolved NH_4-N and PO_4-P concentrations (Table 4). As litter application rate increased, the concentration of NH_4-N and PO_4-P in runoff increased in both incorporated and surface applied litter. However, there was a large increase in concentration of NH_4-N and PO_4-P when the litter was surface applied compared to incorporated (Figures 2 and 3). No significant interaction was observed for the concentration of NO_3-N in the runoff with slope or soil preparation (Table 4).

As was observed with the NO_3-N concentration, no significant interaction between slope or soil preparation was observed for NO_3-N loads (Table 4; Figure 3). A significant impact to the runoff event load was measured for the NH_4-N and PO_4-P concentration in the dissolved forms (Table 4). As was seen with the dissolved NH_4-N and PO_4-P concentration, a significant interaction was observed between the litter application rate and the soil preparation for the dissolved NH_4-N and PO_4-P loads (Table 4). The incorporation of litter had an important impact on reducing NH_4-N and PO_4-P loads compared to application of the litter to the soil surface (Figure 3). This clearly indicated that the incorporation of litter could significantly reduce the amount of dissolved nutrients that reach surface water bodies. Reduction in the dissolved nutrients that reach surface water bodies is important because dissolved nutrients are available for immediate biological uptake (Sharpley et al., 1991; Sharpley et al., 1992). Orthophosphate is the only form of P that can be assimilated by bacteria, algae, and plants (Correll, 1998).

Applying manure below the soil surface has been shown to reduce the loss of nutrients in runoff (Ross et al., 1979; Baker and Laflen, 1982; Eghball and Gilley, 1999; Pote et al., 2003). When the manure is in a liquid form, injection of the manure has been found to be very effective at reducing the N and P loss in runoff (Ross et al., 1979; Baker and Laflen, 1982). With solid manure such as poultry litter, injection of the litter has also been found to significantly lower the nutrient losses (Pote et al., 2003), but application equipment for injection of poultry litter is not presently available for widespread use. Incorporation of the manure has also been found to reduce nutrient losses in runoff (Eghball and Gilley, 1999), but no reduction in runoff losses was noted by Nichols et al. (1994) when the manure was incorporated into a tall fescue (*Festuca arundinacea* Schreb.) pasture due to damage to the grass. In our study, a clear reduction in the losses of NH_4-N and PO_4-P concentration in runoff (Figures 3 and 4) could be observed, indicating that incorporation would be a very effective way to reduce runoff nutrient losses from litter applied to cultivated land in heavy clay soil.

Interestingly, there was no significant impact of slope on nutrient losses. Also there was no significant interaction between the soil preparation and slope (three way interaction with litter application rate) (Table 4). This indicated that slope did not affect the observed losses in runoff from any of the measures made in this study. In fact, while some separation could be observed between the regression lines as the rate of litter application was increased, none of the lines were significantly different from each other, and no trend could be noted in the statistical analysis.

As mentioned earlier, nutrient transport from litter-applied fields into water bodies where they can contribute to eutrophication depends on both nutrient source mechanisms and transport mechanisms. The P index concept is aimed at identifying critical source areas (Gburek et al., 2000) so that application of litter can be reduced in these areas. Slope is commonly used in P indices as a indicator of increased risk for P losses. For example, of the 41 states listed in a survey by Sharpley et al. (2003) of P indices, 30 states specifically use slope as a transport factor in their adopted version of the P index. This is in addition in most cases, to the designation of the erosion class to measure erosion risk. In most cases, the erosion risk is measured using the Revised Universal Soil Loss Equation (RUSLE) which uses soil slope as a major factor in the erosion calculation (Renard et al.,1991). While it is likely that runoff may be initiated more frequently in areas with increased slope, the results from this study indicate that no increase in P losses were observed. A partial explanation for the nutrient source factor being so much more important in this study is that the litter was freshly applied to the runoff plots. Newly applied

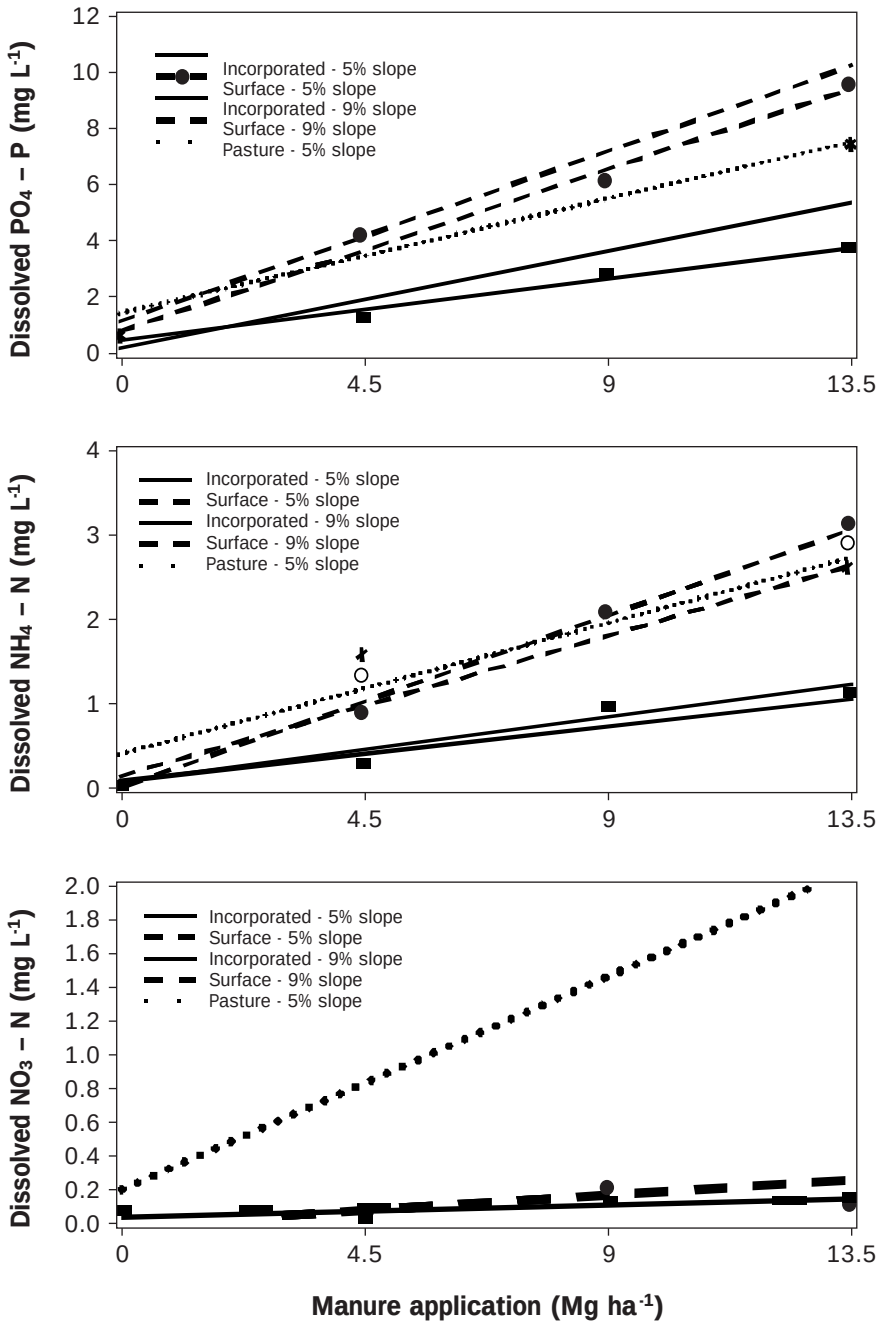
Table 6. Regression equations describing relationship of litter application rate to runoff of PO_4-P, NH_4-N, and NO_3-N concentrations as affected by slope and litter surface application.

Slope (%)	Surface condition	Equation	r^2	
		PO_4-P concentration		
5	Incorporation	Y = 0.374 + 0.248 * litter	0.987	a
5	Surface application	Y = 0.688 + 0.649 * litter	0.987	b
9	Incorporation	Y = 0.135 + 0.384 * litter	0.975	ab
9	Surface application	Y = 1.036 + 0.684 * litter	0.641	b
5	Pasture	Y = 1.361 + 0.457 * litter	0.864	ab
		NH_4-N concentration		
5	Incorporation	Y = 0.027 + 0.088 * litter	0.962	a
5	Surface application	Y = -0.035 + 0.231 * litter	0.991	b
9	Incorporation	Y = 0.045 + 0.074 * litter	0.969	a
9	Surface application	Y = 0.105 + 0.188 * litter	0.886	b
5	Pasture	Y = 0.367 + 0.176 * litter	0.930	b
		NO_3-N concentration		
5	Incorporation	Y = 0.039 + 0.008 * litter	0.836	a
5	Surface application	Y = 0.070 + 0.005 * litter	0.252	a
9	Incorporation	Y = 0.020 + 0.003 * litter	0.866	a
9	Surface application	Y = -0.016 + 0.020 * litter	0.654	a
5	Pasture	Y = 0.222 + 0.140 * litter	0.922	b

*** Equations not followed by a common letter are significantly different based on pair-wise F-test for homogeneity of slopes, Litter = application of turkey litter (Mg ha^{-1}). Significance is declared at $P \leq 0.10$.**

Figure 2

Regression relationships of litter application rate to concentration of PO_4, NH_4, and NO_3 in runoff as affected by slope (5% or 9%) and litter soil preparation (surface application or incorporated).



manure has been shown to overwhelm other aspects related to runoff losses, such as soil test P (Sharpley and Tunney, 2000). However, there was also no indication by way of interaction that the slope was impacted by the incorporation of the litter. Since incorporation removes manure from the immediate impact of rainfall and runover phenomenon (Eghball and Gilley, 1999), it stands to reason that if the initial impact of applying litter was overwhelming the P losses, then there would be a slope impact in the incorporated plots. Also, it has been shown that increased slope will increase the effective depth of interaction of soil (Sharpley, 1985). It would be expected that as the slope increased—the mechanism to move more P into the runoff known as effective depth of interaction—would also be increased. This potential increase in effective depth of interaction would be important with the incorporation of the litter because more of the litter that was buried would be potentially exposed to the runoff. However, while a trend for slope to impact PO_4-P loads can be observed in Figure 3, no significant interaction for incorporation and slope was observed (Table 4), and there was no significant difference measured between the slope for the surface applied litter regression lines (Table 7). This indicates that more research may be needed to assure that the risk associated with changes in slope is not over ascribed to P index criteria, especially in heavy clay soils. This may be especially important in P indices which separate dissolved P from particulate P, since slope differences are normally accounted for in soil erosion classification for particulate P losses.

Runoff in pasture. Litter application on pasture was also included in this study to compare litter application in cultivated agriculture to the more common practice of applying litter to pasture. With pasture application, incorporation of the litter would not be possible without severe damage to the grass; therefore, incorporation would not be a reasonable practice for farmers. Also, only one slope was available in the study area, so only one slope was used. Therefore, treatment interaction analysis could not be included for the pasture runoff portion of this study. No measurable sediment concentration was observed in the pasture runoff. Significant regression lines were developed for dissolved nutrient concentration in runoff for the pasture. Analysis of whether these lines were significantly different from the other regressions lines in the study were determined and presented in Tables 6 and 7 and shown in Figures 2 and 3.

As was observed with the application of litter to cultivated soil, the increasing rate of litter application increased the concentration (Figure 2) and load (Figure 3) of dissolved nutrients observed in runoff. How this loss in the pasture compared to the cultivated soil runoff losses was dependent on the nutrient studied. The runoff loss of NH_4-N in the pasture was very similar to the losses observed when litter was applied to the cultivated soil and not incorporated, with no significant difference observed between the regression lines for litter applied to pasture and for litter

Table 7. Regression equations describing relationship of litter application rate to runoff of PO_4-P, NH_4-N, and NO_3-N loads as affected by slope and litter surface application.

Slope (%)	Surface condition	Equation	r^2	
		PO_4-P Load		
5	Incorporation	Y = 0.090 + 0.059 * litter	0.993	a
5	Surface application	Y = 0.346 + 0.094 * litter	0.764	ab
9	Incorporation	Y = 0.078 + 0.071 * litter	0.974	a
9	Surface application	Y = 0.333 + 0.157 * litter	0.861	b
5	Pasture	Y = 0.128 + 0.096 * litter	0.878	ab
		NH_4-N Load		
5	Incorporation	Y = 0.006 + 0.021 * litter	0.987	a
5	Surface application	Y = -0.054 + 0.035 * litter	0.835	a
9	Incorporation	Y = 0.020 + 0.014 * litter	0.965	a
9	Surface application	Y = 0.022 + 0.038 * litter	0.717	a
5	Pasture	Y = 0.045 + 0.033 * litter	0.762	a
		NO_3-N Load		
5	Incorporation	Y = 0.008 + 0.002 * litter	0.913	a
5	Surface application	Y = 0.019 + 0.0007 * litter	0.065	a
9	Incorporation	Y = 0.006 + 0.0004 * litter	0.208	a
9	Surface application	Y = -0.003 + 0.004 * litter	0.612	a
5	Pasture	Y = 0.084 + 0.029 * litter	0.725	b

*** Equations not followed by a common letter are significantly different based on pair-wise F-test for homogeneity of slopes, Litter = application of turkey litter (Mg ha^{-1}). Significance is declared at $P \leq 0.10$.**

applied to the soil surface in the cultivated site (Table 6). As previously stated, the runoff losses of PO_4-P were significantly decreased when litter was incorporated compared to surface application in the cultivated soil. With the pasture, the runoff loss of PO_4-P appeared to fall between the loss observed for the incorporated and that observed for the surface application. In fact, the analysis of the regression lines indicated that pasture application was not significantly different from incorporated or surface application of litter to cultivated soil (Table 6). The loss of NO_3-N from the pasture was strikingly different than that observed for the cultivated soil. As previously noted, only a small increase in the NO_3-N levels were observed with increasing application of litter in the cultivated soil, and no difference was observed for NO_3-N concentration or load between the surface application and the incorporation of the litter (Table 4). But with the application of litter to the pasture, a large increase in the NO_3-N losses could be observed as the rate of litter application increased (Figures 2 and 3).

Summary and Conclusion

Increased losses of dissolved NH_4-N and PO_4-P in runoff were observed with increasing litter application rate in the cultivated soils. However, no significant relationship was observed for NO_3-N under cultivated conditions. Incorporation of litter greatly reduced the losses of NH_4-N and PO_4-P; however, increased slope did not significantly impact runoff losses of NH_4-N and PO_4-P. This indicates that for clay soils, more research may be needed regarding the risk ascribed to changes in slope to the P index criteria. When comparing litter application in pasture, losses of NH_4-N resembled those observed without incorporation under cultivated conditions, and the losses of PO_4-P were between losses observed for the surface application and the incorporated treatment in the cultivated field. While the NO_3-N losses in the cultivated field were not significantly affected by slope or litter incorporation, large losses were noted for NO_3-N as the application rate was increased in the pasture. The results from this study indicate that incorporation of the litter when applied to a field may have a large impact on reducing the amount of PO_4-P and NH_4-N lost in runoff.

Endnote

[1]Names are necessary to report factually on available data, however, the U.S. Department of Agriculture (USDA) neither guarantees nor warrants the standard of the production, the use of the name by USDA implies no approval of the product to the exclusion of others that may be suitable.

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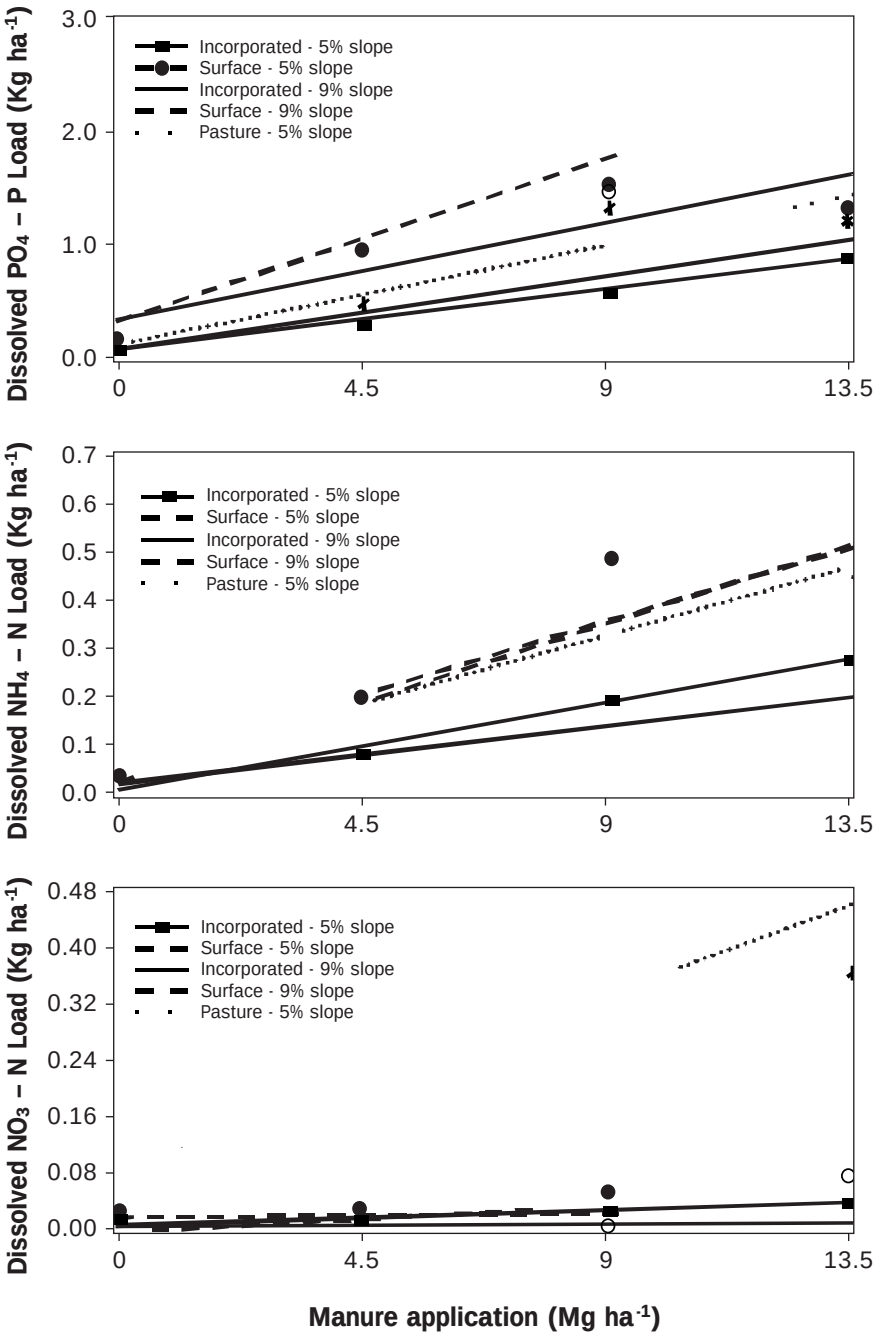
Figure 3

Regression relationships of litter application rate to PO_4, NH_4, and NO_3 loads in runoff as affected by slope (5% or 9%) and litter soil preparation (surface application or incorporated).



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