Nutrient Management Planning Effects on Runoff Losses of Phosphorus and Nitrogen

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ABSTRACT

Non-point source pollution accounts for a large proportion of surface and ground water contamination. The objective of this study was to evaluate the differences in losses from commonly-used best nutrient management practices (BMPs) involving incorporation of manures and fertilizers on an Appalachian and a Coastal Plain soil. Poultry litter and dairy manure were applied in consecutive study years on 4.6m (15ft) x 15.2m (50ft) (Appalachian site) and a 6.1m (20ft) x 15.2m (50ft) (Coastal Plain site) field plots in no-till or conventional-till corn production. The manures were incorporated into the soil for one-half of the plots and a 30-minute, 76-mm simulated rainfall event (consistent with a 2-yr. storm event) was applied to all plots after planting and harvest. Runoff samples, taken every five minutes, were analyzed for soluble phosphorus (SP), total phosphorus (TP) and sediment-associated particulate phosphorus (PP), nitrate, ammonium, and total nitrogen (TN), then converted to kg ha^{-1} load. Observed SP loads were significantly greater at the coarser textured Coastal plain site. There were minimal differences in TP losses between spring and fall simulations for both manures. P loads in runoff were significantly higher in plots that did not receive incorporation of either manure. Observed SP losses were greater from dairy manure than poultry litter treated soils. SP contributions to TP from poultry litter were much smaller than dairy manure and PP played a larger role in poultry litter TP load. Post-plant runoff volume was controlled by reduced tillage in poultry litter plots and residue cover in dairy manure plots. Sediment, nitrate, ammonium and organic nitrogen (N) loss was controlled by tillage in both years. However, this may be offset by the observed increase in leaching of N. Post-harvest nutrient losses were less than post-plant losses from both manures,

but to a lesser degree with dairy manure suggesting that, especially with wet manures, maximizing the time between application and a runoff event is critical in minimizing pollution risk to surface water.

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Introduction

Eutrophication continues to be the major problem affecting the health of the Chesapeake Bay. Nutrients that enter the Bay from point and non-point sources along tributaries increase the population of short-lived algae (Parry 1998). The death and decomposition of the algae create oxygen depleted environments, adversely affecting the health of other organisms (Sharpley et al. 1994). The nutrients mainly responsible for the bloom of algae growth are phosphorus (P) in the form of phosphate, and to a lesser degree, nitrogen (N) in the form of nitrate (Schindler 1977, Boesch, Brinsfield, and Magnien 2001). Many changes in agricultural practices within the Chesapeake Bay watershed have been implemented to help curb point source pollution, but the expected rebound in the Bay's health has not yet fully materialized. Agriculture has been recognized as the largest contributor of non-point source pollution (44% TN and TP; 65% Sediment), which will need to be addressed for the Bay's recovery to succeed (U.S. EPA Region 3 2015). The rate and method of application of nutrients and their subsequent release to surface water is important in understanding non-point source pollution from agriculture. In fact, algae growth in the Delmarva region is most limited by P due to the base load of nitrate which is leaching from historical inputs (Sharpley et al. 1994). Thus, if the P release to surface water from agricultural fields can be reduced, eutrophication should pause or decline.

Typically, P to N ratio is higher in manure than the ratio required by plants for crop production. Applications of manure that supply more P than can be removed by the crop, build up soil test P (STP) levels and are in turn increase the potential or risk of P loss to surface water. Nutrient management practices for applying nutrients from manure like timing of application, application methods, rate of application, and incorporation methods play a role in how much nutrient is lost from fields. Understanding the amount of nutrient loss to occur under respective nutrient management planning regimes will provide important information regarding the use of manure on fields and its resultant impact on water quality, and thus aid development of strategies for reducing nutrient losses and protecting water quality.

Literature Review

Phosphorus

Phosphorus (P) as a plant nutrient is found in disproportionately large ratios with N in most manures compared to the amount taken up by crops in a growing season. When applied to soil as a fertilizer for crops, P is exposed to rainfall events, resulting in the loss of some P in runoff and leaching to groundwater, albeit much smaller amounts in the latter process. The first P transport pathway is sediment-associated, or particulate phosphorus (PP), which enters water bodies by overland flow in runoff. The second method is DP moving through the soil subsurface during dry periods or the release by submerged particles. Dissolved P in runoff water is readily available to algae., P bound to sediments is released in anoxic conditions which occur at an increasing rate as surface water quality degrades (Boesch, Brinsfield, and Magnien 2001).

Some Best Management Practices (BMPs) may increase the P loss potential of agricultural soils. The majority of soils in the Chesapeake Bay watershed have P levels exceeding plant needs for corn production. Many of these high P soils utilize nutrient management plans including manure applications at a rate where more P is applied than the crop will remove (Sims, Goggin, and McDermott 1999, Coale 2000). Crop fields utilizing no-till management are known to lose less sediment to runoff because of better residue cover. However a long term study showed that dissolved P in runoff is increased with reduced till management (Staver and Brinsfield 1995).

Measureable Forms

Measurements of sediment bound P use varying strengths of extractants to illicit P bound to soil particles. These measurements all seek to quantify STP. STP is useful for determining the need for supplemental P to grow plants, but it is also useful to connect P levels in the soil to P in runoff water.

Different measurements of P in soils and manures include total phosphorus (TP), Bray 1 and 2 (B1 & 2), Mehlich 1 and 3 (M1 & 3) STP, Iron oxides strips (FeOx) and water extractable P (WEP) (Gaston et al. 2003). Other extractants include, lactate, $NaHCO_3$, NaOH, H_2SO_4, and anion exchange resin (Leinweber et al. 1999) Typically, the Bray extractants are used in higher base saturated soils than the Mehlich extractant, which is used more commonly in the eastern United States. Mehlich-1 values recorded by sampling from the University of Delaware show that 57% of soils tested 2 to 6 times higher than the agricultural threshold there for STP (Sharpley et al. 1994).

Measurements of P in runoff also use different extractants to fractionate P into forms whose bio-availability ranges from immediate to long-term. Soluble phosphorus (SP), sediment-associated, or particulate phosphorus (PP), bio-available phosphorus (BAP), bio-available particulate phosphorus (BPP) and total phosphorus (TP) are measured in water and runoff water samples (Sharpley et al. 1992, McDowell and Sharpley 2002, Haygarth 2000). BAP is a sum of the SP and the BPP. BPP is a portion of PP, P sorbed onto solids, that can be easily utilized by algae and represents a source of eutrophication (Sharpley et al. 1992). In order to better understand the effects of abatement, runoff BAP must be determined and compared to TP. SP represents the portion of P in water not adsorbed to particles and is therefore more available to algae (Peters 1981). PP comes from the solid fraction of runoff that has P closely associated and is considered a long term source of P (Ekholm 1994, Sharpley et al. 1992). PP can comprise nearly 80% of the TP loss in some overland flow events (Sharpley et al. 1992). This study focuses soled on SP, PP and TP, recognizing their dominant role in current literature.

Runoff Losses

Runoff water is responsible for delivering most of the P and some of the N contributed by crop fields to surface water. P that is applied to the soil surface tends to reside in that location as PP (Butler and Coale 2005). Rainfall events remove sediment from soil and move it to the surface of water bodies in runoff. This runoff water delivers the PP as well as soluble P that desorbs from the soil particles in situ (Andraski and Bundy 2003, Heathwaite et al. 2005). As few as a 2-3 storms a year can carry as much as 90% of the BAP attributed from approximately 10% of the land (Pionke 1997).

P levels in runoff are proportional to the P addition or fertilization rate (Roemkens and Nelson 1974). Runoff P is inversely proportional to the water flow path length. In an experiment of different soils with different levels of soil P, a 3-m runoff distance reduced the concentration of all forms of P in runoff from upwards of 20 mg L^{-1} TP to near zero (McDowell and Sharpley 2002). SP is also correlated to STP (Andraski and Bundy 2003), but the relationship varies with different management regimes (Sharpley et al. 1996). Given this information, reducing the P concentration in soil and increasing the distance the runoff must travel will decrease the loss of P.

Leaching Losses

P leaching can occur, but for a variety of reasons, this process does not typically present a significant threat to surface water quality. P has been shown to move laterally through soils that have very high levels of P. The pathway that the P takes through the profile may involve preferential flow (Butler and Coale 2005, Little, Bennett, and Miller 2005, Djodjic, Borling, and Bergstrom 2004). Zero tension lysimeters have detected P levels as high as 8.20 mgL^{-1}, but that quantity includes sediment delivered from the surface through macropore flow (Little, Bennett, and Miller 2005). Even this much P loss from soils due to leaching did not adversely affect plant growth. This is due to the fact that soils with high STP cause P leaching and high or very high STP levels do not reduce yields. Estimation of P loss is under investigation, but early trials have shown that soil tests for SP, $CaCl_2$ extractable P and FeOx-P were proportionate to actual SP in leachate (Maguire and Sims 2002). There is no evidence that the P delivered to the subsurface will continue to move with groundwater. This is likely due to the fact that local subsoils are inherently low in phosphorous and have the potential to adsorb the load of P that escapes the leaching zone. Preferential flow exists, but flow down to groundwater and then out to base flow is highly unlikely. One notable exception to the lack of a significant pathway for P leachate to surface waters is in the case of drained agricultural fields. Heckrath et al. (1995) showed that soils with very high STP are likely to continuously emit TP to surface drainage ditches exceeding 1 mgL^{-1} and anywhere from 66 to 86% of which is SP.

Nitrogen

N is a macronutrient for plant as well as algae and therefore contributes to eutrophication. It is found in high concentrations in fertilizer and agriculturally polluted surface waters compared to P, but the reverse is true for manures. N is absorbed by plant roots at a higher rate than P, at approximately 8:1 ratio (White and Collins 1982). N is more mobile than P due to its greater desorption from particles into soil water. N moves laterally through the soil profile compared to P which often remains relegated to PP. N is measured as TN in water and runoff water samples (Edwards, Simpson, and Frere 1972). Forms of N like ammonia, nitrate and nitrite interchange and become available to organisms quickly in comparison with P. These constituents are measured in solution without extractants (Power, Wiese, and Flowerday 2001). Reducing all forms of N from entering surface water is critical to preventing eutrophication, particularly in marine and estuarine environments where N is usually limiting in comparison with P. Soil testing combined with nutrient management recommendations are the main means farmers use to determine the N requirement for a crop. Crops that contribute N to the soil, like legumes, are also considered in nutrient management plan as N contributors to the soil. Implementation of nutrient management is the main reason that fertilizer N has decreased in consumption since 1991 (Power, Wiese, and Flowerday 2001). Even so, N remains a considerable threat to surface water quality.

Seasonal variations in soil N occur due to changes in mineralization, nitrification, and denitrification. Mineralization of N readily occurs following manure application because much of the N is in the form of ammonia. Ammonia must be mineralized before it can be used by plants. This slow availability makes soil N more variable in manured fields (Kanwar et al. 1995). The conversion of ammonia to nitrate through nitrification occurs at higher rates in warmer temperatures. Since nitrate-N is taken up by plants at higher rates in the spring and late summer months, soil N levels increase in the fall and winter (Woodard et al. 2002). N is also lost via denitrification to the atmosphere, but is returned to fields through rainfall in amounts ranging from 1.5 to 0.6 mg L^{-1} (Power, Wiese, and Flowerday 2001, Edwards, Simpson, and Frere 1972). While the sources and mobility of N are well understood, interactive effects of BMPs may cause unintended consequences.

Runoff losses

Runoff N is comprised of N naturally found in rain and also N assimilated from the soil surface. Runoff N originating from soil can be in the form of soluble Nitrogen (SN) or sediment-bound N (SBN) (Schuman et al. 1973). N measured in water runoff bound to the soil are in forms of ammonium-N, nitrate-N and/or total-N (Little, Bennett, and Miller 2005). The runoff N originating from the soil surface may vary seasonally with the highest rates of runoff N observed before planting when more nitrogen is at the soil surface due to organic N applications and decomposition. Once a crop has been planted, the nitrogen in the runoff decreases steadily due to plant uptake and leaching (Schuman et al. 1973). Studies have shown that soil bound nitrogen is not responsible for much of the N in runoff water and that amounts found in natural rain are greater than the N found in runoff from cropland (Edwards, Simpson, and Frere 1972, Olness et al. 1975). Additional research has shed light on which cases do contribute N to runoff and how to avoid them. Legumes like alfalfa contribute SN to runoff at a higher rate than crops like corn or cotton (Olness et al. 1975). The contribution of the plants is made as the rainwater passes through the N-rich leaves. Also, the majority of N in runoff can be avoided by preventing soil loss because SBN is responsible for up to 92% of all runoff N loss from cropland (Schuman et al. 1973). In spite of this partitioning, Alberts et al. (1993) explains that with few exceptions, N loss from runoff is minimal.

Leaching losses

Loss of N typically occurs more frequently through leaching. Leaching contributes additional N to surface water systems through base flow and drainage systems. Base flow and drainage water enriched with N deliver N to the surface water continuously and thus pose a long lasting threat to surface water quality and ecosystem health. Woodard et al. (2002) found that years of N leaching additions contributed to an increased soil water N at 150 centimeter (cm) or more down the soil profile. At this depth, groundwater is affected and can move into a surface stream by base flow or more expeditiously through a drainage system.

Volatilization losses

Fresh manure of any source is typically high in ammonium which easily transforms and volatilizes to the atmosphere as ammonia gas. Manure types have different rates of volatilization which may be influenced by environmental factors like air and soil temperature, moisture and pH. When surface applied, plant available nitrogen (PAN) is reduced about 57% in broiler litter and 65% from dairy manure (Devereux 2009) through volatilization losses. Poultry manure may lose as much as 90% of its ammonium to volatilization if it is not incorporated and is applied in hot, dry conditions (Meisinger and Jokela 2000). Incorporation of manures by moldboard plow, tandem disk and chisel-plow reduced volatilization losses to less than 3%, 2 to 8% and 8 to12%, respectively (Thompson and Meisinger 2002). Incorporation of manure within hours of application can reduce the volatilization loss to over 90%. Volatilization represents a significant loss of N from manure, but it does not directly affect water quality and can be nearly eliminated with proper management.

Nutrient and Land Management effects on Phosphorus and Nitrogen losses

Manure

Manure is a source of N, P and organic matter, among other constituents, that are applied to fields as a soil amendment for the benefit of crops. Manures used as soil amendments include swine, poultry, bovine and human sewage, in the U.S., the latter is usually in the form of a byproduct of wastewater treatment. The kind of manure applied on cropland may affect the way nutrients behave in the soil. N may leach more quickly in fields where manure has been applied because of earthworm-produced macropores (Gupta et al., 1995). P from manure is lower in SP than mineral fertilizers and may have different impacts on eutrophication (Withers et al., 2001). Bio-availability of P is estimated as 100% in poultry and swine manure, dairy manure is estimated at 80% and P in treated manure or biosolids is roughly 50% plant available (Sharpley et al. 2003). This review will only consider the impacts of poultry and dairy or cattle manure additions.

When sufficient rainfall in excess of the infiltration capacity of a soil, it produces runoff, which releases sediment from cropland and delivers it to surface waters, increasing turbidity and associated nutrient loads. Tillage may contribute to large quantities of sediment in runoff because it exposes the soil surface and reduces residue cover. Residue may reduce runoff and can facilitate settling of sediment in runoff (Little, Bennett, and Miller 2005). The same factors contribute to higher sediment losses from silage-producing fields than from grain-producing fields (Grande et al. 2005).

Manure is a contributor to increased particulates in runoff because surface application of manure contributes organic matter to total suspended solids (TSS), but not necessarily increased sediment (Edwards and Daniel 1994). Manure application can actually impede the release of sediment from the soil surface due to increases in cover and water absorbing capacity or hydrophobic characteristics (Grande et al. 2005). Nutrients are also found adsorbed to sediment in runoff. The turbidity of soil extracts has been strongly correlated to the TP concentration of the sediment extracts, so the amount of sediment contributed to runoff affects the amount of TP in runoff (Heathwaite et al. 2005). This thinking is logical based on the affinity of P cations to attach to negatively charged soil colloids, especially in high cation exchange capacity (CEC) environments.

Poultry

Poultry litter is higher in P than dairy and cattle manure. Kleinman and Sharpley (2003) found that poultry manure contributes to higher SP, TP and TSS in runoff compared to dairy manure for the first 24 days after field application. Applied at the same rate, poultry manure was responsible for more than 6 times as much TP and (soluble reactive phosphorus (SRP) runoff as dairy manure in the same 24 days in one soil and 2 times as much in another soil. However, poultry litter has been shown to be less responsible for P in runoff on grass plots than inorganic fertilizer at comparable rates (Edwards and Daniel 1994, Gaudreau et al. 2002). Compared to a natural system, runoff P rates are higher in response to litter application, but were found to decline significantly over two year period of observation (Pierson et al. 2001). Poultry litter applied to sandy soil-filled columns did not have higher TP leached in comparison to a control column with mineral fertilizer applied at either P- or N-based application rates (Elliott, O'Connor, and Brinton 2002). Poultry litter applied at significantly high enough rates was responsible for levels of P higher than the control to a depth of 120 cm(Johnson et al. 2004).

Poultry litter is available in two forms, fresh and composted. Composted litter has been determined to be less variable as a source of plant available N (Pierson et al. 2001). Composted litter is a much smaller source of N because fresh litter mineralizes more N, but at more variable rates due to volatilization factors. Composted poultry litter has already lost considerable amounts of N to volatilization. Composting litter has been found to have little to no effect on P availability (Pierson et al. 2001).

Dairy/Cattle

Dairy manure has been shown to have greater subsurface leaching of N and P (Little, Bennett, and Miller 2005, Woodard et al. 2002). The most common form of P in leaching of manure is SP, but TP has also been influenced. Total P load in runoff decreased by September in comparison to a control after dairy manure was applied in the spring (Bundy, Andraski, and Powell 2001). This decrease in P runoff loss was reportedly attributed to an increase in the organic matter content of the soil affecting the soil infiltration rate and reducing runoff quantities. Andraski et al. (2003) reported that no-till soil with manure applied had significantly higher soil organic matter, surface cover and lower runoff than no-till soil without manure and/or chisel-plow soil with or without manure applied, respectively. Andraski et al. (2003) reported that manure application increased runoff TP compared to manure-free fields under chisel-plow and no-till management systems.

BMPs

Tillage/Incorporation of Manures

Ammonium-N runoff can be controlled by tillage in some cases (Seta et al. 1993, Eghball 1999, Zhao et al. 2001), although Little et al. (2005) found no differences in ammonium-N runoff attributable to tillage systems. Little et al.'s results contrasted with the finding of Angle et al. (1993) who found that tillage increases ammonium-N losses. These losses are likely a combination of physical and chemical effects on the manure from the amended soil. Nitrate-N loss has been found to be greater in fields that were double-disked compared with fields under no-till management (Little, Bennett, and Miller 2005, Eghball 1999). Moldboard plow treatments has been shown to have the least TN loss because of how deeply the N was mixed, but this deeper incorporation resulted in higher leaching losses (Zhao et al. 2001, Little, Bennett, and Miller 2005). Double-disking and cultivation resulted in the highest runoff losses, with no-till management being intermediate between those and other deep tillage practices. No-till was found to have the least amount of N loss to leaching.

Different tillage management systems have been shown to be significantly responsible for the runoff of P. Moldboard plowed soil was shown to have the least quantity of P in runoff while ridge-till and no-till managed soils had the largest (Gaynor and Findlay 1995, Daverede et al. 2003). Double-disking, chisel-plow and cultivator practices resulted in intermediate P losses in runoff. Reductions in TP and TN were found to be commensurate with the aggressiveness of the tillage method. These results contrast with the results of Andraski et al. (2003) which showed no-till corn released significantly less TP than chisel-plow corn. Tillage management systems have not been previously connected to leaching of P.

Tillage is responsible for more nutrient loss in comparison to no-till fields. From a nutrient loss perspective, cultivation is only advisable for soils that receive manure application. Fewer nutrients are lost in overland flow when the manure is double-disked or cultivated, but plowing will yield an increase in leaching of nutrients (Little, Bennett, and Miller 2005). Alternatively, soils with long-term manure addition benefit from a chisel-plow treatment with cover cropping (Sharpley 2003, Griffith, Mannering, and Moldenhauer 1977). Soils that receive no incorporation following surface application of P can have twice as much STP in the upper 2 cm depth than at 6 cm in depth (Guertal et al. 1991). Kleinman et al. (2002) found that soils with manure mixed with the soil surface did not have significantly higher SP loss compared to a control. More intense management of fields is responsible for increased SP, TP and P leachate (Coale 2000).

Incorporation of liquid soil amendments, like anhydrous ammonia and manure slurry has been shown to reduce the amount of P in runoff (Tabbara 2003). Putting liquid manure and fertilizer below the soil surface was more influential on the amount of total P in runoff than was the application rate.

Rates of Application

The application rate of manure is normally closely related to the amount of nutrient loss on cropland. In all manure types, the rate of application was directly linked to the amount of P in the runoff (Kleinman and Sharpley 2003, Butler and Coale 2005, Tabbara 2003). N loss in runoff is also significantly affected by the rate of N application (Gaudreau et al. 2002, Rostagno and Sosebee 2001). Many fertilizers are applied to fields in amounts determined by soil tests in accordance with a nutrient management plan. However, manure is often applied in order to fulfill crop N requirements. The associated over-application of P has saturated soil to very high levels, increasing the eutrophic potential of runoff that enters surface water (Sharpley et al. 1994). A better strategy is needed for manure application to effectively reduce the buildup of P in the soil and the amount that enters surface water. Applying manure at a rate that does not exceed the P requirements for growing a crop (i.e. P-based nutrient management planning) would be the best way to avoid building up STP levels. However, the N needs of the crop would generally require supplemental mineral fertilizer. Sharpley et al. (1994) suggests that P-based nutrient management planning is the best strategy for soils with high or very high STP levels, but soils in the low to medium range may not warrant this restriction because of the reduced environmental risk. These soils lower in STP could continue to receive manure at the N rate until the STP rises to a high threshold and then poses a potential eutrophication hazard.

Timing of Application

The length of time between the application of manure to cropland and the first runoff event is critical. A long period of time between runoff and application of manure has reduced sediment load (Grande et al. 2005). Spring-applied manure was compared to fall-applied manure to determine reductions in sediment losses during spring runoff events. Fall-applied manure had little to no effect on sediment in runoff. Thus, the crop planting season is the time of most significant P runoff because of the bare surface soil, simultaneous nutrient applications, and increased precipitation (Burwell, Timmons, and Holt 1975). Westerman and Overcash (1980) simulated runoff on a manured field at 1 hour and again at 3 days from application, and found that P loss was reduced by 90% by increasing the time between application and a runoff event. BMPs suggest the application of manure in the spring versus fall to reduce N and P through the winter months. In addition, during spring application, planning for several days to elapse between application and a potential runoff event is imperative for reducing pollution risk. N applied in the fall increases leaching compared to spring applications (Aldrich 1984). Temperature ranges during the year also affect the overland flow losses of nutrients. Ammonium in runoff water was 20% lower in poultry litter dried at 35ºC than 4ºC and P runoff increased 20% over the same temperature range (Robinson and Sharpley 1995). The differences in N runoff were attributed to ammonium lost to volatilization during the drying of the litter at the higher temperature. Therefore, lower temperatures for manure application are better at preventing nutrient loss from the critical application period, but obviously frozen soils will increase the risk of loss, so it is recommended that application begin during low temperature, after the soil is thawed, and with a forecast of dry weather with slowly increasing temperatures.

Watershed Representation

Experiments utilizing runoff boxes like Kleinman et al. (2002) and/or lysimeters are likely too simplistic of a model for agricultural loads because tillage is a key component in overland flow. Furthermore, these boxes eliminate integrated elements of natural soil systems where cropping takes place. Runoff boxes also eliminate lateral flow and replication of tillage treatments would be difficult. Lysimeters only record changes at specific depths and on nutrients that move laterally. To identify BMPs for cropping systems with various inputs and outputs, scientists have employed plot-sized trials , e.g., Daverede et al. (2003), Tarkalson and Mikkelsen (2004), Kleinman and Sharpley (2003). These types of studies are also particularly useful for short time interval experiments and when making relative comparisons addressing the effects of BMPs.

Simulated Rainfall

Rainfall simulators have been used to measure relative P losses from cropping systems because the small scale helps reduce variability from rainfall (Gaston et al. 2003, Bundy, Andraski, and Powell 2001, Andraski and Bundy 2003, Humphry et al. 2002). Runoff generating simulated rainfall that shares physical characteristics with natural rainfall generates runoff losses comparable to natural losses and would be appropriate to use for estimating relative nutrient and sediment loss potential. Meyer and Harmon (1979) built a rainfall simulator that was capable of creating variable rates of rainfall and used agricultural spray nozzles at a 41.4kPa (6 lb/in^2) which generated droplets with a size distribution close to that of natural rainfall. Measurements indicated that the simulated droplets impacted the ground with 78% of the kinetic energy of natural rainfall. Humphry et al. (1997) built a smaller, more portable, simulator that produced rainfall with physical characteristics similar to natural rainfall, but the simulator could not vary its rainfall rate . Varying the rate is important for achieving equilibrium of antecedent moisture conditions before producing runoff because too strong of a pre-wetting event could discharge additional load and not be indicative of natural conditions.

Summary of Research and Objectives

The loss of nutrients from cropland contributes to the eutrophication of surface waters. In order to protect surface waters from the wide ranging and damaging effects of eutrophication, management practices should be aimed at preventing nutrient losses. Field experiments of various BMPs utilizing different tillage managements systems on cropland with respect to manure application is needed to identify the best strategies to protect water quality in the Chesapeake Bay watershed. Various manures should be used to understand the effects of different manure sources due to nutrients behaving differently as a result of changes in the animal source.

The experiment should test different manure application rates and methods. Methods of application should consider incorporation options for the manure to mitigate loss of nutrients to runoff and/or leaching. Different soils should be used in the experiment to determine physical properties that are most important in estimating nutrient loss potential. The study should report different kinds of P like TP, SP and PP because of the distinct effects each has on the environment.

The experiment should use runoff generated by a rainfall simulator because of the variety of factors that the simulator can be subjected to in comparison with waiting on natural rainfall to occur. The type of simulator, length of simulation and method of collecting runoff should be chosen to best recreate natural conditions.

Finally, advances in understanding the movement of N far outweigh the knowledge on P. For this reason, P research should be emphasized in a BMP study on interactive effects of incorporation of soil amendments. The purpose of this study was to identify, for two fields in Maryland, the tillage method and P application rate that maintained corn yields while contributing the least amount of N and P to surface waters during a simulated 2-year storm event. The study investigated the overland and subsurface losses from corn fields at an Eastern Shore and Appalachian site to identify difference in P management strategies for common agricultural soils in the state. The study identified difference in P management strategies between composted poultry litter as an N and P source in comparison with fresh dairy manure.

Materials and Methods

Experimental design & plot placement

The experiment was conducted on two experiment stations in Maryland. A Coastal Plain site was chosen on the Eastern Shore at the Wye Research and Education Center in Queenstown, MD (Wye site) and an Appalachian site was chosen at the Western Maryland Research and Education Center in Keedysville, MD (Kville site). Both sites had 18 plots established in a randomized complete block design (RCBD) of 3 blocks with 6 treatments within the blocks. Plots at the Coastal Plain site were 15.2m long and 6.1m wide (50x25ft) and the Appalachian site plots were 15.2m long and 4.6m (50x15ft) wide to accommodate smaller field and row equipment.

Treatments were assigned randomly to achieve a RCBD. A soil amendment factor at three levels and an incorporation factor with two levels were combined to create six treatments. The six treatments were assigned randomly three times to plots, once for each block of six plots.

Study Sites

The two study sites, on both the Coastal Plain (Eastern Shore) and Appalachian physiographic regions, were chosen due to their wide differences in agricultural practices, predominant animal types, and characteristic soils. The former site drains to the Wye River and the latter to the Potomac River, both of which are in the Chesapeake Bay watershed. The Eastern Shore and Appalachian regions of Maryland commonly utilize manure as a soil amendment because the agriculture in these regions includes livestock, egg and milk production.

Experimental plots at both study sites were established on soils that are typical to the physiographic region. The soils at the “Wye” Coastal Plain loam site were a Nassawango series, fine-silty, mixed, semiactive, Mesic Typic Hapludult (Soil Survey Staff, 1999). Soils at the “Kville” Appalachian site were from the Hagerstown series, fine, mixed, semiactive, Mesic Typic Hapludalf.

Plots at the Kville Appalachian clay loam site were cover-cropped each fall (10/16/06 and 10/31/07) in a rye grass which was killed with Paraquat™ in the spring and then planted in corn. Paraquat™ was used because Round-up™ was found to be ineffective. Tillage at this site was previously performed with a moldboard plow during the fall prior to the start of the study. The site had previously been under no-till for two years prior to the experiment. Seed corn planted in 2007 was Mycongen “2K350” 93-day. The corn was planted 5/24 at 24,000 plants per acre with 0.76 m interrows. In 2008, 101-day corn was planted at the same rate on 5/30, and the variety used was Unity seed 2200.

Coastal Plain plots had two years of no-till with November planted winter wheat cover crop that was killed in the spring with Round-up™. Two weeks were allowed between the application of the herbicide and the preparation of the experimental plots to ensure complete kill of the cover. Corn planted was DeKalb DKC 61-45 with 0.76 m interrows on 5/23/07 and 5/30/08. Interrows that received wheel traffic were noted, so they could be avoided for the rainfall simulation. Care was taken to plant corn in the same row as the preceding crop.

Manure and fertilizer application

Poultry litter was used during the first year while dairy manure was applied to a separate set of plots in the second year. Since poultry and dairy manure were applied in different years and different plots, direct comparisons are not possible. Poultry litter was delivered to the Appalachian site from source local farmer near the Coastal Plain site and the dairy manure was delivered to the Coastal Plain from a local farmer near the Appalachian site. Manure and fertilizer were applied manually to the surface of the plots. Poultry litter was weighed and broadcast evenly by hand over the plots. Dairy manure was weighed in tared bins and applied by spreading evenly across the plots using a grading rake after the bins were dumped on the plot. Weighed fertilizer was broadcast evenly across field plots by hand.

Manure and fertilizer application rates

Manure was applied at two rates, an N utilization rate and a P removal rate. The N utilization rate used enough manure to supply the estimated amount of N to be used by the crop based upon the projected mineralization rate for the manure. The Maryland Cooperative Extension (MCE) advised 1.12 kg ha^{-1} for every estimated bushel per acre corn yield (MCE 2010). Both sites had an estimated yield of 130 bushels per acre. The total plant available N application rate from manure or inorganic fertilizer was 146 kg ha^{-1}. The phosphorus removal rate was an estimate of the total P used by the crop using Nutrient Management for Professionals (NuMan Pro) software (University of Maryland, version 3.0) with yield estimates and soil test P. NuMan Pro estimated that 58 kg ha^{-1} of P from manure should be applied in both locations. In order to not jeopardize crop yields by under applying N, commensurate commercial fertilizer was applied supplementing the P reduction rate manure to supply plant available N at the same rate as the N utilization rate manure application. The difference tested between these rates is that the N utilization rate of manure over applies P by 2 to 4 times the amount used by a corn crop.

Next, the Agriculture Analytical Services Lab at Pennsylvania State University analyzed the manures for TN, ammonia-N and phosphate-P content. From those measurements, mineralization rates for organic-N were used to calculate plant available N (PAN). All mineralized organic-N was assumed to be plant available. Poultry manure was estimated to achieve 50% organic-N mineralization and dairy manure, 33% mineralization (Maryland Cooperative Extension, 2010). Although 100% of the ammonium in the manure was assumed to be plant available, this was a small part of TN, so volatilization would have minimal impact. Total PAN is equivalent to the sum of ammonia-N and plant available organic-N. The rates of application for the three levels of treatment during the poultry and dairy manure applications are presented in Table 1.

Table 1 Nutrient Application Rates for Both Studied Manure Sources.

Manure (year)	Nutrient Management Plan	Assumed Mineralization Rate of Organic N from Litter(w/w)	Manure (kg/ha)	NH_4NO_3-N Fertilizer (kg/ha)	Nitrogen from Manure (kg/ha)	P Application (kg/ha)
Poultry (2008)	N rate	50%	9327	0	146	228
	P removal rate	50%	2377	108	38	58
	No P added – Fertilizer	NA	0	146	0	0
Dairy (2009)	N rate	33%	52642	0	146	107
	P removal rate	33%	25558	75	71	58
	No P added – Fertilizer	NA	0	146	0	0

Incorporation

The incorporation factor was used to compare the effects of tilling under the surface-applied manure. The fields had not been chisel or moldboard plowed before the cover crop was planted (or two years before in the case of the dairy manure), as the fields were planted using no-till management. Half the plots at each site received an incorporation that is typical to the region. Incorporation at the Coastal Plain site was performed on plots for both years of this experiment with a single pass of a chisel-plow and double-disking. The first year of the experiment at the Kville site, a single disking was performed, leaving the soil rough. The second year, plots were double-disked and rolled to reduce the surface roughness. Sites were not compared for roughness, however roughness will be discussed in the results section anecdotally.

Rainfall Simulation

The first of two rainfall simulation events took place after the crops were planted between the V2 and V3 stage. The first simulation, “post-plant,” was designed to produce runoff that was very high in nutrients when manure was still visible on the soil surface and the crop had not removed significant N or P from the soil. The second rainfall simulation occurred post-harvest in the fall after the crop had been harvested and only crop residue remained. The second simulation was designed to estimate nutrient losses from a storm event and estimate how much mobile nutrient remained at the soil surface.

Both simulations were conducted the same way; a 20-minute pre-wet, a 10-minute equilibration period, and a 30-minute storm event. To account for any conditions that might change over time, the simulations were completed on blocks one at time in geographic succession.

Figure 1 Steel weir frame used to isolate runoff for delivery to covered flume for collection.

Two identical stainless steel weirs were constructed and used in tandem, i.e., one weir could be installed while simulation on another plot was conducted. The weirs measured 0.5-m in width by 1-m in length. The short side spans the distance between crop rows and a one-meter length of inter-row is isolated for runoff. The simulator was positioned to concentrate the vertical rainfall in the center of the weir. The generated runoff traveled through an opening at the soil surface on down slope end of the weir and exited through a covered steel flume (see Figure 1). Weirs are installed using a rubber-face 2.5 kg dead blow hammer so as to disturb the soil surface as little as possible. Weirs were driven into the soil 10 cm in depth. The rainfall simulation cycle used the rainfall intensity rates previously discussed. First, the pre-wet rain event phase was applied at a 54 millimeters per hour (mm hr^{-1}) rate of rainfall for 20 minutes. This step combined with the following 10 minute "equilibration period" without rainfall is used to achieve uniform antecedent moisture conditions inside the weir portion of the plot. If runoff occurred from the weir before the pre-wet phase was complete, the phase was stopped immediately and the equilibration period was reinitiated. The runoff generating rainfall event was applied at a 76 mm hr^{-1} rate, equivalent to a 2-yr return frequency storm in Maryland. The 76 mm hr^{-1} rate was applied until runoff exited the weir at a rate greater than 5 ml min^{-1} to ensure recovered sample was sufficient to analyze in the lab and then, at the same rate, a 30-minute storm event commenced.

At the end of the weir flume, 1 liter (L) HDPE wide mouth bottles were used to collect runoff. The sub-samples were measured independently for chemical and sediment concentration, and then summed for event-scale loss data. When runoff in the interval exceeded 1L, additional bottles were used to capture all runoff. In preparation for analysis, these sub-samples were measured off-site to determine total runoff volume and once remixed, a single 1L from this total was retained for further testing. Between collection and measurement time periods, samples were stored at $4^{o}C$ on ice and in a lab refrigerator.

Runoff Sample Measurement

Runoff samples were measured for SP, nitrate-N (NO_3-N), ammonia-N (NH_4-N), TN and TP using a Lachat in-line spectrophotometer. PP was found by difference by subtracting SP from TP. Runoff sub-sample aliquots were vacuum filtered through a 0.45 micrometer filter membrane until the sample appeared dry. Filtered aliquots were measured for SP, NO_3-N and NH_4-N. Unfiltered aliquots were digested using the acid-persulfate method, decanted and then measured for TN and TP (Bowman 1989). SP and TP were colorimetrically determined using the molybdenum blue method (Murphy and Riley 1962). The NO_3-N and TN (after digestion) were measured colorimetrically following cadmium column reduction of forms to NO_2^- using the Greiss-Ilosvay method (Keeney and Nelson 1982). Colorimetrically measurements were also utilized for NH4-N using salicylate-hypochlorite method (Crooke and Simpson 1971). Measurements were made in the range of 0.05 mg L^{-1} and 10.00 mg L^{-1}. Samples that were measured above this range were diluted by a factor of 5 so they would fall within the designated range.

Samples were collected each day from the water supply for the simulation. Simulator water supply samples were measured with the runoff samples to determine background levels of analytes. Background levels were averaged and subtracted from the measured concentration in the samples from that site's sample in the season the sample was collected.

Soil sample Measurement

Soil sub-samples were air-dried, crushed, sieved through a 2-mm screen and sent to the University of Delaware Soil Testing Program for analysis. The analysis measured NH_4-N, NO_3-N, WSP, Melich-3 P, and P saturation. Nitrate- and ammonium-N in soil were extracted using 2M KCl (1:10 w:V) and analyzed colorimetrically using a Bran & Luebbe Auto Analyzer 3 (Bran & Luebbe, Buffalo Grove, IL) (Griffith, Mannering, and Moldenhauer 1977, Mulvaney 1996). Water Soluble P was extracted from soil with di-ionized water (1:10 w:V) and analyzed for ortho-phosphate-P colorimetrically using the Modified Murphy –Reilly Method(Murphy and Riley 1962, Self-Davis, Moore, and Joern 2000). Plant available macro and micro-nutrients (P, K, Ca, Mg, Mn, Zn, Cu, Fe, B, S and Al) were determined by extracting soils with Mehlich 3 (1:10, V:V) and analyzing the extracts using an Inductively coupled plasma-optical emission spectrometer (Model Iris Intrepid II Duo-View XSP, Thermo Electron Corporation, Madison, WI)(Sims 1995, Wolf and Beegle 1995) Results of the soil sample analysis are discussed in the results and discussion section anecdotally.

Statistical Analysis

To express nutrient losses from the plots as 30-minute loadings using a weight per unit area field scale, measured concentrations from the 1 square meter (m^2) plot area were extrapolated and multiplied by the runoff volumes recorded from the simulated rainfall event. Differences between N and P losses in gram per hectare ($g\ ha^{-1}$) were analyzed using a repeated measures analysis of variance (ANOVA) using the mixed procedure (PROC MIXED) as described in Keppel (1991) using the Statistical Analysis Software (SAS) (SAS SAS and Institute 2007). Effects from site, incorporation and nutrient management plan (NMP) were assessed in the statistical model, including all interactions. Three way interactions significant to the 5% level ($p<0.05$) were separated by site for comparison. Poultry and dairy manure were applied in different years and different plots, so they were not compared. Also, the post-plant and post-harvest simulated rainfall events were not compared because the sampling events occurred temporally different, a basic statistical assumption of homogenous variance could not be satisfied.

Results

Poultry Litter

Total runoff loss for the post-plant simulated rainfall event had a mean near 1 ML ha-1. Post-plant runoff losses had a significant difference between the incorporation treatments. Not incorporated (no-till) plots lost 50% more runoff water, on average, than plots receiving tillage (Figure 2). The difference in runoff volumes generated between tillage treatments early in a growing season suggests that when tissue cover is lowest in a season, no-till soils perform poorly at infiltrating intense rainfall. Means of site locations and nutrient management plans were not significantly different. Runoff loss for the post-harvest rainfall event did not have significant differences. The post-plant simulated rainfall did hit the soil surface at its most bare state of the year, so not observing as much runoff yield in the post-harvest simulation suggests that a

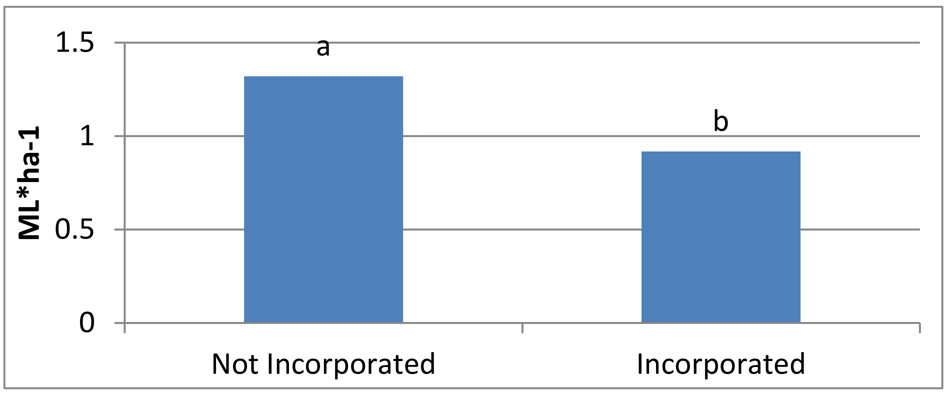


Figure 2 Effect of Incorporation on runoff volume (ML ha-1) from the post-plant simulated rainfall event. Different letters indicate significant difference (n= ;p<0.05; MIXED; n=36).

relatively small amount of surface residue was available to contribute absorption, and the relative roughness of the micro-topography in tilled plots could have trapped some rainfall from runoff.

The average runoff volume in the post-harvest simulated rainfall event were higher than the post-plant simulated rainfall event, but statistics were not performed because of heterogeneous variances between seasonally different data sets. However, in the case of a large application of poultry litter, the surface soil macropores controlling the infiltration, lose capacity due to infill or sealing by the hydrophobic litter.

Despite significantly lower runoff volume losses, sediment loss from the incorporated treatment was 3 times higher than the not incorporated treatment in the post-plant rainfall simulation event at the Wye site (Figure 3). Fresh tillage, consistent with a long record of observations in the field, is generating the most runoff from this coarse textured site. Upon transformation of means using

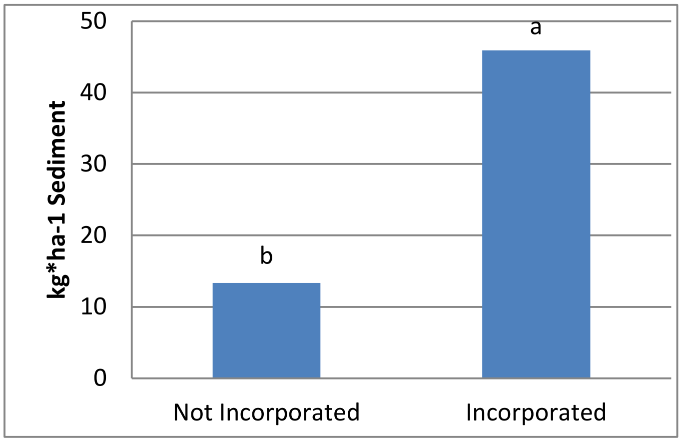


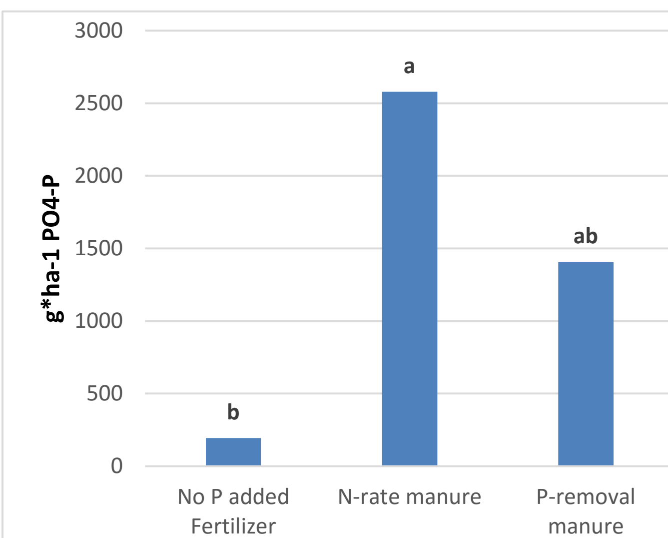
Figure 3 Effect of Incorporation on runoff volume (ML ha-1) from the post-plant simulated rainfall event. Different letters indicate significant difference (n= ;p<0.05; MIXED; n=36).

the natural log, a site effect and incorporation effect were observed. The finer textured Kville site had less sediment loss than the coarser textured Wye site and tilled plots yielded more sediment in runoff than no-till plots (see Table 2). Perhaps clay loam soils in this location was less detachable than the sandy loam of the Wye under this intense rainfall simulation.

P losses examined are SP, PP, and TP from post-plant and post-harvest losses. Soluble P losses from post-plant rainfall simulation had a significant interactive effect from incorporation and NMP, where incorporated plots yielded an order of magnitude less soluble P than not incorporated plots (see Figure 4). Where manure remained on the surface due to lack of mixing in a treatment factor, SP loss was significantly higher from the N utilization rate manure than no-P added fertilized plots. P-removal rate manure lost SP at a rate between the high and low levels, but not significantly different from either. Post-harvest mean SP losses were consistent with the lowest mean treatment losses from the post-plant simulation, representing the only significant difference in analytes from this season of simulated rainfall (Table 3).

Table 2 Effect of site and incorporation on sediment in runoff generated by simulated rainfall following planting. Different letters indicate significant difference (p<0.05; MIXED; n=36)

Treatment	**Mean of Natural Log Transformed Sediment loss**	**Back-transformed Sediment loss mean (kg/ha)**
Location		
Kville	**9.1b**	**9**
Wye	**11a**	**38**
Incorporation		
Not Incorporated	**10a**	**24**
Incorporated	**9.5b**	**14**



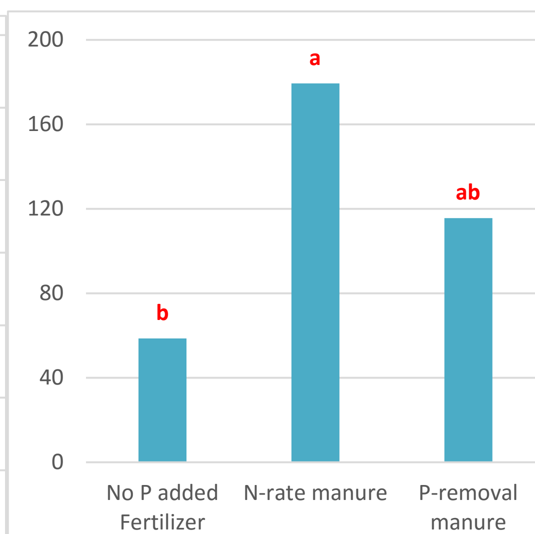


Figure 4. Not incorporated on the left of incorporated means of NMP treatment factors for PO4-P (g ha^{-1}). Different letters indicate significant differences (p<0.05; MIXED; n=36).

Table 3 Small losses of PO4-P (g ha-1) in runoff form simulated rainfall following harvest. Different letters indicate significant difference (p<0.05; MIXED; n=36).

Treatment Location	Mean of Natural Log Transformed Soluble P Loss	Back-transformed Soluble P loss mean (g PO_4-P/ha)
Kville	1.19b	3
Wye	5.40a	222

Following a complete growing season, the average SP in runoff collected was on par with the amount generated from the disturbed surface from earlier in the season. Coarser soils, with lower CEC, were likely driving the greater loss of SP from the Wye compared to Kville site. NMP had an effect on PP loss in the post-plant rainfall simulation (see Figure 5). Consistent

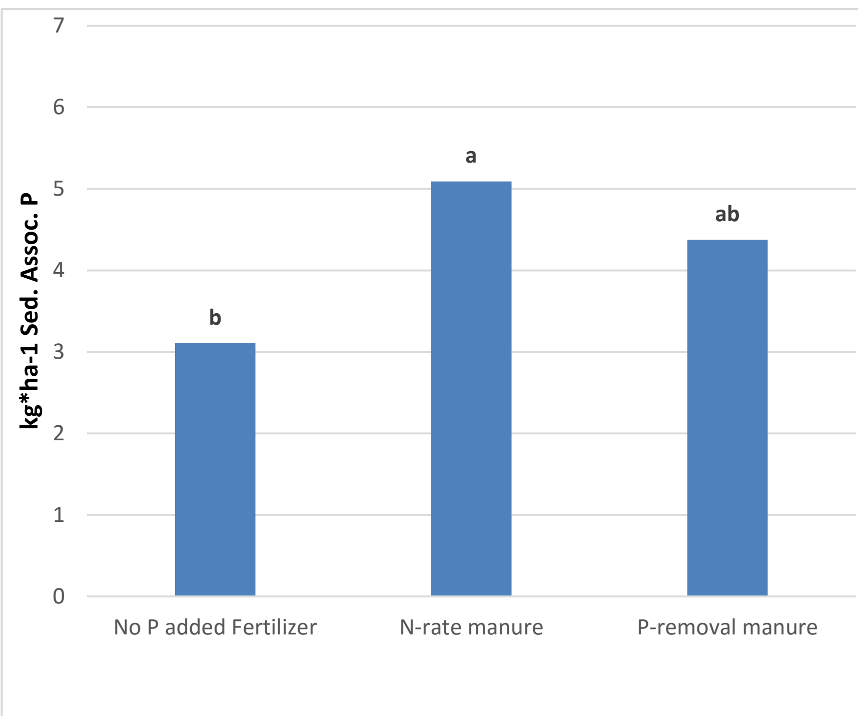


Figure 5 Effect of nutrient management plan type on sediment associated phosphorus (kg ha-1) from the post-plant rainfall simulation. Different letters indicate significant different (p<0.05; MIXED; n=36)

observations with SP losses, PP losses were greater in the highest application sites and lowest where no P was added with commercial fertilizer. Following these results, the combined TP means were ordered, N utilization rate manure, P removal rate manure and no P added fertilizer, but P removal rate manure was not significantly different from N utilization rate manure. No P added fertilizer had the lowest contribution to runoff at just under 3 kg ha^{-1}. The addition of P to the soil, in this case from a manure source, elevated the TP loss regardless of the type of nutrient management recommendation for P application. PP and SP behaved similarly following application and planting, but effects of factors were lost for SAP and TP after the growing season.

A site effect was detected as well for TP. Kville soils lost more TP than the Wye site in the post-plant season. It is likely that the adsorption of the phosphate molecules to the higher CEC soils in the finer texture Kville soil accounted for this difference. The CEC is likely contributing to the difference, because sediment yields were lower at the Kville site in the runoff, but PP was higher than the Wye site where greater P free sediment ran off.

Nitrate losses in the post-plant rainfall simulation had significant differences from all treatment factors. Nitrate presents in the field as a highly mobile nutrient and therefore was more readily contributing to runoff contamination in the post-plant rainfall simulation. Table 4 shows shows the site effect, where Kville lost more nitrate to runoff compared to the Wye site. The cause of this was unknown, but indications from the farm manager were that the pumped groundwater used to generate runoff was variably contaminated with nitrates and the background sample taken each day to offset the contribution in the analysis may not have been representative of the thousands of liters used to simulate the runoff during each day of the season.

Table 4 Effect of location, incorporation and nutrient management plan types on nitrate in simulated runoff from post-plant rainfall simulation. Different letters indicate significant difference (p<0.05; MIXED; n=36)

Treatment	**Mean of Natural Log Transformed Nitrate Loss**	**Back-transformed Nitrate loss mean (kg-N/ha)**
Location		
Kville	8.86a	7
Wye	7.41b	1
Incorporation		
Not-incorporated	8.98a	8
Incorporated	7.30b	1
Nutrient Management Plan		
No P added – Commercial Fertilizer	7.74b	2
N utilization rate manure	7.81b	2
P-removal rate manure w/ fertilizer	8.88a	7

Similar to the runoff volume difference, not incorporated plots yielded the highest load of nitrate, the load is driven in this case, by the volume, so these results are expected. The effect of the nutrient management plan was presumed to be negligible based on the experimental design to deliver the same PAN in each NMP level, but the highly soluble, inorganic ammonium nitrate fertilizer in the P-removal rate yielded more load than the plots with manure or a mixture of manure and fertilizer. The organic nature of the manure may have contributed to a stronger retention of the nitrate with the associated anion exchange sites added with the organic amendment. In TN loss, where measured ammonia load was included, the only significant differences were at Kville. Here, P removal rate manure lost the most TN, followed by N utilization rate manure then no P –added fertilizer (see Figure 6).

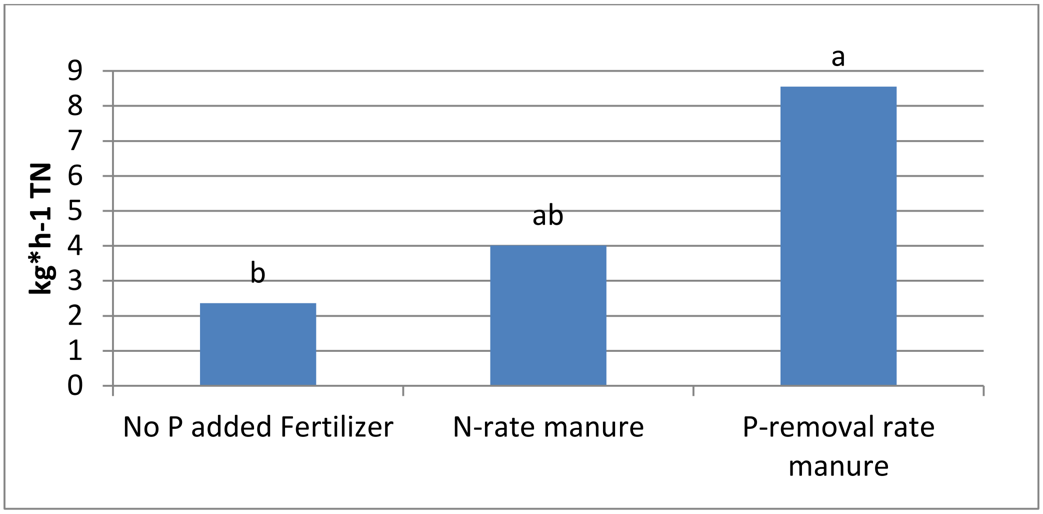


Figure 6 Effect of NMP type on TN load (kg ha^{-1}) runoff from simulated rainfall on Kville site post-plant. Different letter indicates significant difference ($p<0.05$; MIXED; n=36).

Incorporation reduced Kville TN loads by a factor of 4, where an average 8 kg-N ha^{-1} was lost on no-till sites compared to just 2 kg-N ha^{-1} on conventionally tilled plots. Following application of nutrients, and especially composted broiler litter, the results of this, early season simulated storm, indicate runoff presents a serious risk to surface water quality. In general, there was a trend for SP and TP increases with increased P application. Tillage applications yielded less SP, but did not have a statistically significant effect on TP. Sediment and PP yielded opposite responses at the two site locations. This indicated the influence of finer textured soils adsorbing disproportionately higher cations like phosphate. Applications of P from poultry litter, beyond crop need, can increase the amount of soluble P in a runoff event after harvest.

Dairy Manure

Results from second study year (again, on different plots) mimicked results from the poultry litter in the second year for runoff losses of SP, PP, TP and TN for post-plant. Runoff volume and sediment loss showed no significant difference in means, but were similar in magnitude to the poultry litter results.

TN and NH4 load for post-harvest showed a difference by site, where following the growing season, a surplus of N was readily released to runoff at Kville (Appalachian clay loam) three times the magnitude of the Wye (Coastal Plain loam) site (Figure 7). This was mostly driven by the organic fraction of N, in blue.

This result is indicative of an abundance of the N available during the growing season at Kville, likely the result of a mismatch of an application rate based on an estimate of yield and lower than actual yield. This in informed by the fact that there was no site effect observed in TN in the post-plant simulation period. These differences were the only differences observed following the growing season between the treatments.

In the early part of the growing season, rainfall simulation took place shortly following planting. During this period of simulation, sediment loss load was observed to be influenced by

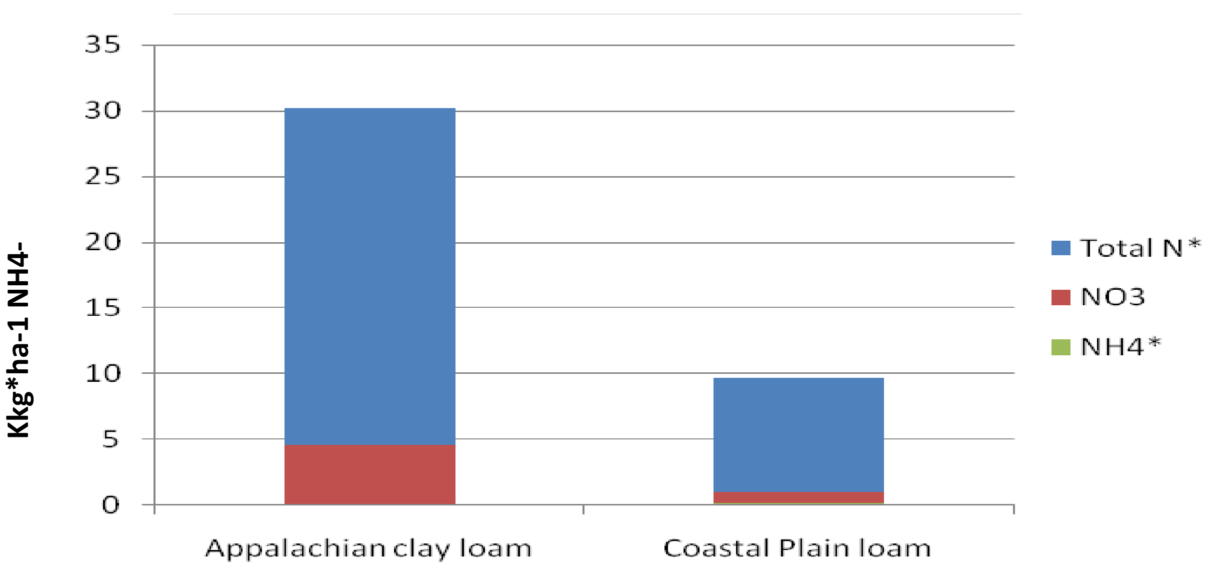


Figure 7 Effects of study site on TN, NO3 and NH4 (kg ha^{-1}) in post-harvest runoff from simulated rainfall. Significant differences among sites for each constituent of N are indicated by asterisk in the key (p<0.05; MIXED; n=36).

incorporation and NMP factors (Figure 9 and Figure 8). Magnitudes of both incorporation levels (none and conventional) were slightly higher than those observed in the poultry litter runoff and visual indicators of color and turbidity between those samples indicated the mass of manure in the Dairy year influenced this change in means. Olfactory observations between samples also supports this conclusion. The effect of NMP on sediment somewhat disputes these observations. In the highest application rate of manure, the least amount of sediment was collected in runoff samples and the highest manure application rate. Manure mixed with fertilizer and fertilizer only plots yielded similarly high sediment in runoff (Figure 8).

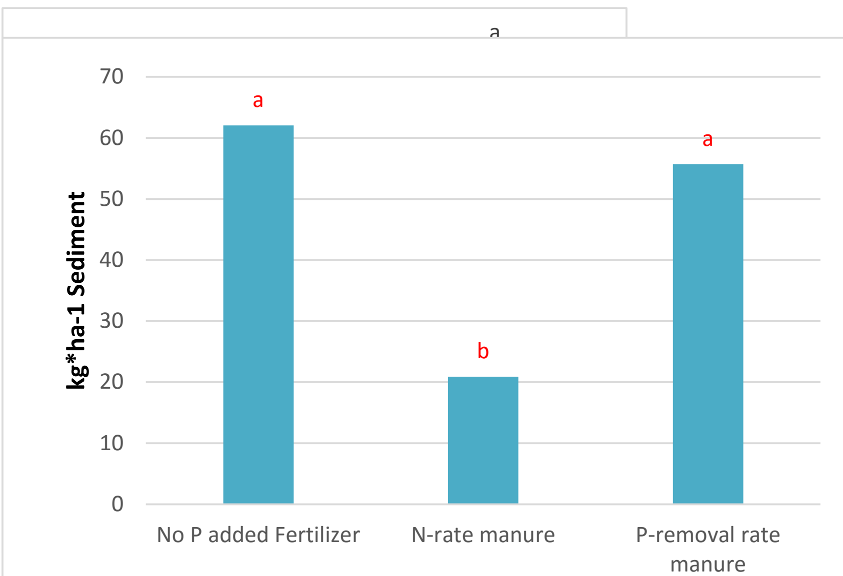


Figure 8 Incorporation effect on sediment loss (kg ha^{-1}) from the post-plant simulated rainfall event following dairy manure application. Different letters indicate significant difference (p<0.05; MIX

During the rainfall simulation, the high rate of manure, even when mixed into the surface, appeared to absorb rainfall and seal the surface from sediment runoff at the high rate of application. This result is consistent with similar field experiments (Smith, Jackson, and Pepper 2001, Smith, Jackson, and Withers 2001). Both in the absence of manure and in the light manure treatment level, the lack of manure appears to be insufficient to produce that result. P bound to

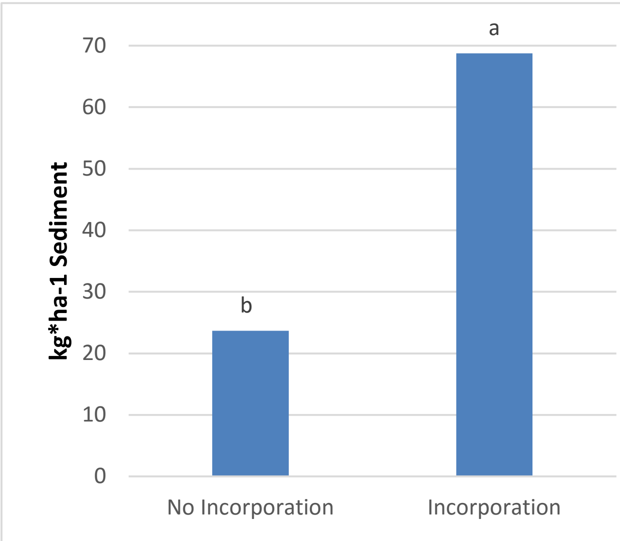


Figure 9 NMP effect on sediment loss (kg ha^{-1}) from the post-plant simulated rainfall event following dairy manure application. Different letters indicate significant difference ($p<0.05$; MIXED; n=36).

this sediment supports this observation, as there was no significant increase in the amount of PP from the manured plots compared to the plots receiving no manure. This physical dynamic was unique to the dairy manure, where the poultry litter had a propensity to contribute to the PP in proportion to the amount applied. While the PP loss was a minority of the TP loss, the finer textured soil, with higher CEC, produced more PP (see Figure 10).

Runoff loss of SP contributed the majority of the load to the TP and both of these constituents have significant effects from NMP and site on their mean loads where tillage did not mix the NMP treatment levels with soil (see Figure 10 and Table 5).

SP load was directly influenced by the amount of P applied, where N utilization rate manure produced the highest SP load and the P-removal rate manure load was less than the N-rate, but more than the No P added fertilizer rate. No P added fertilizer loaded an order of magnitude less SP than the highest, N utilization rate manure application. Mixing of the soil with the NMP treatments at both sites caused homogenization of the NMP and location factors, so that

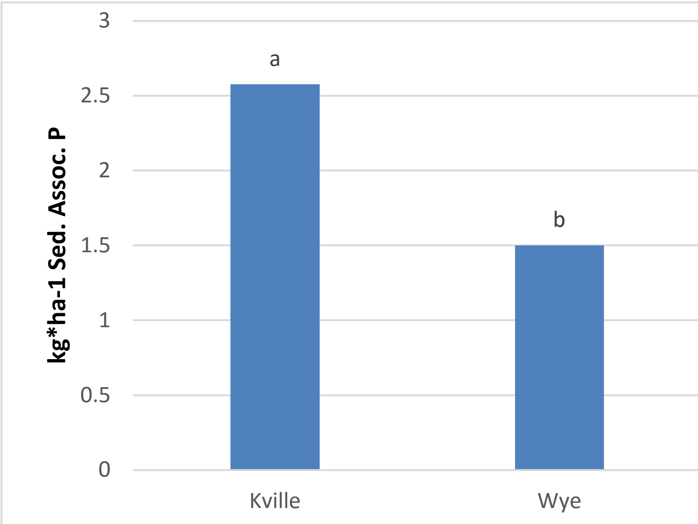


Figure 10 Effect of site on sediment associated P loss (kg ha-1) from the post-plant simulated rainfall event. Different letters indicate significant differences (p<0.05; MIXED;n=36).

Table 5 Effects of NMP and location site on SP and TP load (kg PO4-P ha-1) from post-plant simulated runoff where incorporation was not applied. Different letters indicate significant differences (p<0.05; MIXED; n=36).

Not incorporated treatment	**Soluble P Load**		**Total P Load**	
	Mean of Natural Log Transformed Loss	**Back-transformed loss mean**	**Mean of Natural Log Transformed Loss**	**Back-transformed loss mean**
Nutrient Management Plan				
N- rate manure	8.46c	5	8.85a	6.9
P-removal rate manure	7.68b	3	8.33a	4.2
No P added fertilizer	6.108a	0.4	7.48b	1.8
Location				
Kville	6.80b	0.9	7.95b	2.8
Wye	8.01a	3	8.49a	4.9

no statistically significant difference was found in the SP and TP load means. This is consistent with current BMP recommendations on sites with low environmental risk for runoff to till under manure applications to minimize environmental exposure to agricultural P.

Nitrate and TN load means needed to be statistically separate by location in the post-plant simulation season due to interactive effects. This separation yielded significant TN differences by NMP at the Kville sire and by incorporation-only at the Wye site. Incorporation differences in Kville were perhaps masked by relative lack of mixing due to the light tillage treatment applied by the farm manager to plots at that location. There was considerably more manure exposure on the surface of plots at Kville compared to plots at Wye. The highest TN load was generated by the manured Kville plots under the NMP levels P-removal rate manure plots and N utilization rate manure (Figure 11). The no P added fertilizer, despite receiving the same amount of PAN, yielded less TN load. At the Wye site, the mean load of TN from incorporated plots was half of not incorporated (no-till) plots. These treatment levels yielded approximately 19 and 9 kg N ha^{-1}, respectively. Nitrate load at Kville and Wye yielded similar to poultry litter, where at both sites, No P added fertilizer plots yielded the highest mean load of nitrate (Table 6).

In Kville, the manure plots were significantly less, although the mixed plot (P-removal rate) mean fell between the full manure and full fertilizer treatment levels. The P-removal rate had some fertilizer applied and therefore more readily soluble nitrate. The mean was sufficiently low to be not statistically higher than the N utilization rate manure. In contrast, at the Wye site, the P-removal rate was lumped with the high loading No P added mean, but still fell arithmetically between the manure only and fertilizer only plots (Table 7).The no P added

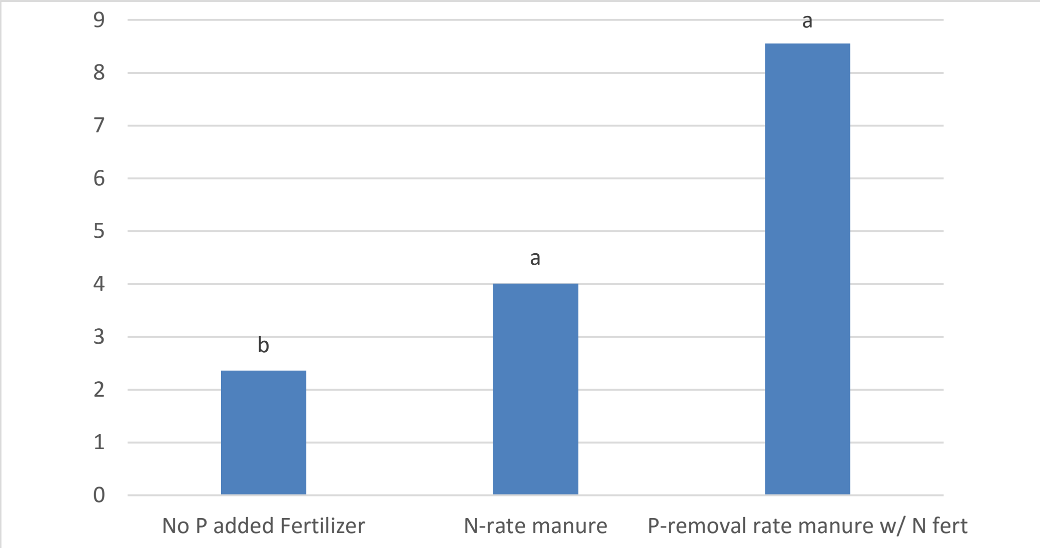


Figure 11 Effect of NMP on TN load (kg ha-1) from post-plant simulated rainfall event at the Kville site. Different letters indicate significant difference ($p<0.05$; MIXED; n=36).

Table 6 Effect of NMP at Kville site on Nitrate runoff load (kg ha-1) from the post-harvest simulate rainfall event. Different letters indicate statistical difference ($p<0.05$; MIXED; n=36).

Kville - Nutrient Management Plan Treatment	**Mean of Natural Log Transformed Nitrate Loss**	**Back-transformed Nitrate loss mean (kg/ha)**
No P added Fertilizer	**10.04a**	**23**
N-rate manure	**8.97b**	**8**
P-removal rate manure	**9.61b**	**15**

fertilizer, despite receiving the same amount of PAN, yielded less TN load. At the Wye site, the mean load of TN from incorporated plots was half of not incorporated (no-till) plots. These treatment levels yielded approximately 19 and 9 kg N ha-1, respectively. Nitrate load at Kville and Wye yielded similar to poultry litter, where at both sites, No P added fertilizer plots yielded the highest mean load of nitrate (Table 6).

The incorporation effect detected shows not incorporated plots yielded more nitrate load and this component in TN, drove the aforementioned difference in TN. Finally, ammonia loss difference was detected between location sites, without interactive effects (Figure 12). The positively charged ammonium ion appears to have been sediment bound in the high CEC Kville (Appalachian clay loam) soil. An order of magnitude difference in runoff was observed from Kville than the Wye (Coastal Plain loam) site due to the chemical adsorption just after application and simulated rainfall.

Table 7 Effects of NMP and Incorporation at the Wye site on nitrate load (kg ha-1) from the post-harvest rainfall simulation event. Different letters indicate significant difference ($p<0.05$; MIXED; n=36).

Wye - Treatment	**Mean of Natural Log Transformed Nitrate Loss**	**Back-transformed Nitrate loss mean (kg/ha)**
Nutrient Management Plan		
No P added Fertilizer	**8.64a**	**6**
N-rate manure	**7.43b**	**2**
P-removal rate manure	**8.52a**	**5**
Incorporation		
Not Incorporated	**9.07a**	**9**
Incorporated	**7.33b**	**2**

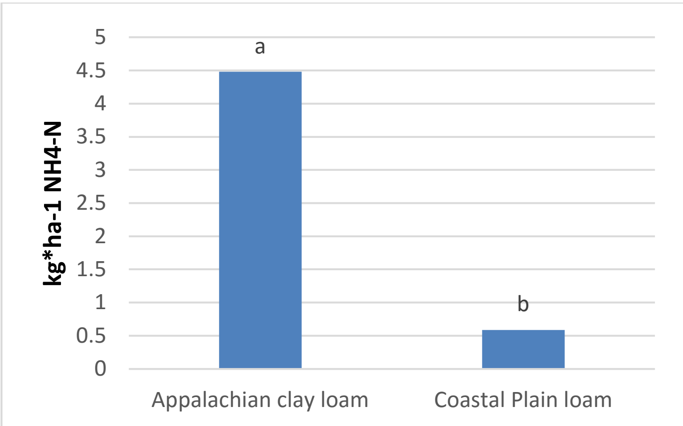


Figure 12 Effect of location site and likely soil texture on NH4-N load (kg ha-1) from the post-harvest simulated rainfall event. Different letters indicate significant difference (p<0.05 MIXED; n=36).

N utilization rate manure had significantly less runoff than No P added plots after planting. This is perhaps attributable to the manure residue cover. Sediment loss from N utilization rate manure was also less due to this absorptive layer of thick manure application to the surface. Although no significant difference in load from incorporated plots was found, not incorporated plots yielded significantly more SP than was lost where more P was applied; similar to poultry litter, but in a more expected and distinct response. SP contributed a larger proportional component to the TP in manured plots and played a more significant role in the post-plant simulation than the post-harvest runoff simulation.

Summary and Recommended Research

The Wye site with coarser textured surface soil had significantly more SP load in both post-plant seasons compared to Kville site. It can be inferred that soil differences contributed to the observed losses. To confirm this conclusion, an additional field trial is recommended with multiple (more than two) soil textures with a protocol similar to this study, keeping all other parameters fixed as much as possible. Observed SP losses were greater from dairy manure than poultry litter treated soils. SP contributions to TP from poultry litter were much smaller than dairy manure and PP played a larger role in poultry litter TP load. Further study is recommended to explore the behavior of different chemical forms of the P in combination with treatment agents to prevent SP loss following field application of manures. In this experiment, there were minimal differences in TP losses between spring and fall simulations for both manures. The physical properties controlling the loss of sediment and PP between manure times and a range of soil texture classes should be further investigated to determine the mechanisms driving this difference early in a growing season which would provide better guidance on how to manage pre-plant applications. N constituents, nitrate, ammonium and organic N loads in runoff were reduced by tillage application. However, this was at a cost of an increase in leaching. This environmental tradeoff should be examined quantitatively to determine parameters of a site that determine BMPs for N retention in the field during normal growing season conditions.

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