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# Phosphorus and Fecal Coliform Runoff in Grazed Pasture As Function of Nutrient Management

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## ☐ ABSTRACT ☐

Simulated rain trials were conducted with the primary objective of determining the influence of nutrient management on surface runoff quality from the grazed fescue pastures. The nutrient management treatments included no add fertilizer or broiler (C), soil applied inorganic fertilizer (AIF), soil applied broiler litter (ABL) and broiler litter fed to steers (FBL). Runoff from simulated rainfall events was analyzed for dissolved inorganic P (DPi), molybdate reactive P (MRP), total dissolved P (TDP), particulate P (PP), total P (TP), and *fecal coliform* (FC) counts. Concentrations of DPi, MRP, and TDP in surface runoff, while decreasing with time, were higher in AIF, ABL, and FBL than in the control (C). Particulate P losses were lower than the MRP fraction, constituting 27, 42, and 27 % for AIF, ABL, and FBL, respectively, compared to 50% in the C treatment. Counts of FC were higher than 7000 CFU 100 mL$^{-1}$ in all treatments and constitute source of pollution. P concentrations in the soil, as determined by Mehlich-1, increased from 18 mg kg$^{-1}$ in the soil at the start of the experiment in 1995 to 27, 205, 213, and 96 mg kg$^{-1}$ in the top 0-5 cm soil depth in 2001 for C, AIF, ABL, and FBL treatments, respectively. These P concentrations were reflected in the concentrations of P in surface runoff and suggest that intensive nutrient managements of grazed pasture increase the risk of P pollution of ground and surface waters.

**Key words:** phosphorus runoff, soil properties, poultry litter, water pollution, fertility management

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# حركة الفوسفور والكوليفورم البرازية في السيل السطحي بتأثير نظام إدارة خصوبة المراعي

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**(تاريخ الإيداع 3 / 1 / 2010. قبل للنشر في 1 / 3 / 2010)**

## □ ملخّص □

تهدف الدراسة إلى تقصي تأثير نظام إدارة خصوبة المراعي على نوعية مياه السيل السطحي، حيث تضمنت معاملة الشاهد التي لم تتلق إضافة سمادية ( C )، معاملة تلقت تسميداً معدنياً (AIF)، معاملة تلقت إضافة من فضلات مزارع الدواجن (ABL)، معاملة تمت تغذية العجول بفضلات الدواجن (FBL). تم إجراء عاصفة مطرية صنعية بشدة 65-72 ملم/ساعة وتم تتبع كمية ماء السيل السطحي كل 5 دقائق ولمدة 30 دقيقة. قدر في ماء السيل السطحي كل من الفوسفور الذائب بصوره: المعدني (Dpi)، المتفاعل مع الموليبدنيوم (MRP)، الكلي (TDP)؛ والفوسفور المرتبط بالجسيمات الغروية (PP) والكلي (TP)، وكذلك تم تقدير تعداد بكتريا الكوليفورم البرازية (FC). كما وتم تقدير الفوسفور المتاح بطرق مختلفة ودرست علاقات الارتباط مع كل من الفوسفور الذائب المعدني والمتفاعل مع الموليبدات و الكلي في ماء السيل السطحي. في الوقت الذي تتناقص فيه تراكيز الفوسفور الذائب بأشكاله المختلفة Dpi, MRP, TDP في ماء السيل السطحي مع مرور زمن تشكل السيل السطحي فقد كانت أعلى في المعاملات مقارنة بالشاهد. أما بالنسبة لتراكيز الفوسفور المرتبط بالجسيمات الغروية PP فقد كان أعلى في معاملات التسميد أيضاً إلا أنه شكل 50% من الفوسفور الكلي في ماء السيل السطحي في معاملة الشاهد مقارنة بالنسب 27، 42، و 27% في المعاملات FBL, ABL, AIF على التوالي. كما سجلت بكتريا الكوليفورم معدلات عالية جداً في جميع المعاملات يزيد عن 7000 وحدة بكتيرية/100 سم3. لقد أوضحت دراسة اختبار الفوسفور المتاح في التربة (Mehlich-1) أن هنالك تراكم للفوسفور نتيجة نظام الإضافة السمادية على مدار سبع سنوات من 18 مغ/كغ إلى 27 و 205 و 213 و 96 مغ/كغ في المعاملات FBL, ABL, AIF, C على التوالي، وكان لها علاقة ارتباط وثيقة مع تراكيز الأشكال المختلفة للفوسفور الذائب في ماء السيل السطحي.

**الكلمات المفتاحية:** الفوسفور في السيل السطحي، تلوث المياه، إدارة خصوبة التربة، فضلات الدواجن، الكوليفورم البرازية

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## INTRODUCTION:

Tall fescue pastures requires substantial fertilization to provide beef producers adequate forage for efficient operation (Huneycutt et al., 1988). Nutrients in the form of inorganic fertilizers, animal manures, or broiler litter are normally broad cast applied on pasture-based grazing systems. Many beef farms in the Mid-Atlantic States use broiler litter as a cheep source of mineral nutrients that contain many essential elements needed for good forage growth, such as N, P, and K. Broiler litter is a by-product of broiler production and consists of poultry excreta, feather, wasted feed, and bedding materials (Moore et al., 1995). Researchers in Virginia have used successfully broiler litter as feeding stuff to cattle in which the animals utilize only a small fraction of the nutrients in broiler litter (Gerken, 1992) and thus most of the nutrients are returned to the pasture in the excreted manure. Excessive application of inorganic fertilizers and broiler litter in addition to intensive grazing management have been shown to threaten the health of the environment due to potential pollution of ground water and surface water with $NO_3$-N, P, and microbes (Kuykendall et al., 1999; Edwards and Daniel, 1994; Nichols et al., 1994; Edwards et al., 2000a,b).

Mature cattle can produce an average of 25 kg of feces per day in addition to 9 kg of urine (Dormaar and Willims, 1998), in which $P_2O_5$ average 0.18% and 0.01% in feces and urine, respectively (Petersen et al., 1956). Organic P forms in animal excreta generally remains in a slow-release availability mode in the surface soil layer rather than being rapidly fixed by soil minerals (Dormaar and Willims, 1998). In addition to P in animal excreta, the application of fertilizers, regardless of forms, leads to elevated levels of P in surface pasture soils and the potential of P loss in surface runoff (Hayness and Williams, 1993). Phosphorus transport in surface runoff was shown to increase with poultry litter application to fescue plots and even to a greater degree with the application of inorganic fertilizers (Edwards and Daniel, 1994), and with surface application compared to incorporated litter or inorganic fertilizers (Nichols et al., 1994). Grazing and methods of stocking seems to increase P concentrations in runoff compared to ungrazed fescue plots (Edwards et al., 2000a) whereas stocking methods (continuous or rotational grazing) have very little effect on P transport in runoff (Edwards et al., 2000a; Kuykendall et al., 1999). However, in all cases, concentrations of dissolved molybdate reactive P were in excess of proposed guidelines of 0.05 and 0.1 mg P $L^{-1}$ for lakes and streams, respectively (Sharpley et al., 1996).

The potential loss of P from soils has been assessed using soil test P methods (STP) including Mechlich-3, Bray-1, water, Olsen, Fe-oxide strip, anion exchange resin, etc., that were originally designed to estimate plant available P (Miller et al., 1993). One might think that standard soil extractable-P tests might not be expected to provide a good estimation of P loss in runoff, because these agronomic tests extract a large pool of P accessible to growing plants rather than the P fraction that might be potentially released in surface runoff or drainage water. An individual STP method might be used with certain soil type, but what would be the case when comparing a wide range of soils. Sharpley (1995) assessing P loss from 10 soils amended with poultry litter showed that two soils of 200 mg $kg^{-1}$ Mehlich-3 supported a dissolved reactive P concentration of 0.28 mg $L^{-1}$ and 1.36 mg $L^{-1}$. Several researchers have demonstrated that a relationship exists between STP levels and potential loss of P in runoff, with the variability related primarily to differences in soil type (Sharpley, 1995; Hooda et al., 2000; Pote et al., 1996; Pote et al., 1999; Sauer et al., 2000; Hooda et al., 1997).

Manure whether mechanically applied or deposited by grazing animal is typically considered nonpoint source pollution (Sistani et al., 2009). In addition to manure effects on nutrient transport in runoff and water quality, most studies have linked grazing to elevated concentrations of microorganisms in runoff and streams including *Fecal coliforms* (FC). Fescue plots receiving inorganic fertilizer were shown to increase the concentrations of FC in runoff and to a greater extent with the application of poultry litter (Edwards and Daniel, 1994), or with cattle manure (Edwards et al., 2000a). Type of grazing management, rotational or continuous grazing, has little influence on the concentrations of FC in runoff (Edwards et al., 2000a). The concentration of FC in runoff from grazed pasture varied with season during which the runoff occurred, being higher in warmer months (Edwards et al., 1997), probably as a result of regrowth in warm conditions (Tiedemann et al., 1988). The grazing effect on the FC extended to near by streams adjacent to grazed pasture and elevated concentrations were also reported (Gary et al., 1983).

## OBJECTIVES:

A field study was established in 1995 and continued through 2001 that investigated the effects of nutrient management strategies of pastures on cattle production. Nutrient management treatments included a no fertilizer control (C), soil applied inorganic fertilizer (AIF), soil applied broiler litter (ABL), and broiler litter fed to steers (FBL). For this study we conducted runoff trial using simulated rainfall during 2001, which represented the 7th year of the grazing trial. The objective of this study was to evaluate the effect of these long-term nutrient management strategies on nutrient losses in surface runoff form the grazed fescue pastures. We report the potential transport of different forms of P in surface runoff and concentrations of *fecal coliform* (FC) in surface runoff. Selected soil test P (STP) methods were evaluated for their ability to predict soluble P released in surface runoff.

## MATERIALS AND METHODS:

### *Study Site and Management*

The original experiment consisted of stocker cattle grazing endophyte-free tall fescue (*Festuca arundinacea* schrub. KY-31) established on 7.8 ha fields, located on Virginia Tech's Shenandoah Valley Agricultural Research and Extension Center, Steeles Tavern. The soil at the study site is a Frederick silt loam (clayey, mixed, mesic, Typic Paleudults), and properties of the soil are shown in Table 1. The annual treatments are as follows: no fertilizer control (i.e., no supplementary feeding of broiler litter or soil application of fertilizer or litter) (C); surface application of inorganic fertilizer (AIF); surface application of broiler litter (ABL); and feeding broiler litter (FBL) to the grazing cattle. The amount of fertilizer applied (urea, diammonium phosphate, and potassium sulfate) supplied the same amount of total nitrogen, phosphorus, and potassium as the amount in the broiler litter fed to the steers (FBL) in the previous years. The amount of broiler litter applied to the soil in treatment ABL is the same as the amount fed to the steers in treatment FBL the previous year. Poultry litter was fed during the entire trial to the steers of treatment FBL, mixed with ground corn grain. The other cattle in treatment C, AIF and ABL are fed the same amount of corn as those fed the corn-litter mixture. Concentrations of P (total P measured in acid digested solution by inductive plasma spectrophotometry) averaged 1.73 %; Mehlich-1 extractable P averaged 56.9 mg $kg^{-1}$ in broiler litter applied between 1995-2001.

**Table 1: Changes in soil properties after seven year of grazing and nutrient managements between 1995 and 2001 from 0-5 cm soil depth.**

|  | pH$_w$ | EC dSm$^{-1}$ | TN g kg$^{-1}$ | TC g kg$^{-1}$ | Mehlick-1 P mg kg$^{-1}$ | 1 *M* NH$_4$AoC Extraction (mg kg$^{-1}$) |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | K | Ca | Mg | Na | S |
| 1995 | 5.7±0.01 | 0.13±0.01 | 2.0±0.01 | 116.9±0.1 | 18±1.2 | 93±5 | 780±18 | 145±2 | 14±1 | 28±1 |
|  |  |  |  |  | **Treatments** |  |  |  |  |  |
| C | 6.1±0.2 | 0.37±0.02 | 3.2±0.02 | 29.1±0.2 | 27±2.8 | 157±34 | 1466±113 | 256±7 | 9±1 | 34±1 |
| AIF | 6.3±0.1 | 0.53±0.04 | 2.8±0.02 | 24.3±0.1 | 205±15.0 | 286±18 | 1442±73 | 261±15 | 5±1 | 34±1 |
| ABL | 6.5±0.1 | 0.50±0.04 | 3.3±0.02 | 31.4±0.2 | 213±16.3 | 307±26 | 1635±64 | 276±8 | 18±4 | 38±1 |
| FBL | 6.4±0.1 | 0.45±0.03 | 3.6±0.03 | 33.4±0.3 | 96±10.9 | 206±21 | 1656±75 | 274±9 | 8±1 | 36±1 |

± are standard error of means (n = 9).

The experimental area is divided into 12 x 0.65-ha paddocks (three paddocks per treatment), with 4 steers grazing from February through November since 1995. The amounts of litter applied to ABL and FBL treatments and inorganic fertilizers applied to AIF treatment between 1995 and 2001 are shown in Table 2. Application of broiler litter and inorganic fertilizers were made in late spring each year.

### *Runoff Sampling and Analysis*

Two runoff plots were located in each paddock with the long axis oriented down a chosen slope between 5 and 8%. Within each plot, paired 0.75 x 2-m subplots (one 1.5 x 2-m plot split up the long axis) were used, making a total of four runoff replicates in each paddock. Plots were mowed to a uniform height of approximately 10 cm immediately after installing plot frames, and grass clippings were removed from the plot areas.

The rainfall simulator used in this study was based on the design of Miller (1987) and experimental procedures were adapted based on the accepted protocol of a national P runoff project (Sharpley et al., 1999), as shown in figure 1. Prior to the simulated rainfall event, the soil was sampled from outside the plot area adjacent to the plot frame (approximately 10 soil cores) from the surface 0-5 cm soil depth. Volumetric water content of the soil was also measured in the top 15 cm inside the plots using Hydrosenser (Campbell Scientific, INC. Australia).

The simulated rainfall intensity was a constant 65-72 mm h$^{-1}$, maintained until a 30-min period of continuous runoff had occurred from each plot. The time to initiation of runoff was recorded using a stopwatch. Runoff was sampled using clean polyethylene container (approximately 1 L sample size) at 5, 10, 15, 20, 25, and 30 min after the beginning of runoff, and volume of runoff at these intervals were also recorded. The actual rain intensity, the time before runoff was initiated, and runoff volume were used to compute total volume of rainfall and percent runoff volume of total. An additional set of soil samples from the surface 0-5 and 0-15 cm soil depths were collected after the rain event was completed.

**Figure 1: The rainfall simulator used in this study was based on the design of Miller (1987) and experimental procedures were adapted based on the accepted protocol of a national P runoff project (Sharpley et al., 1999).**

After collection of runoff samples, containers were kept on ice and rushed to the AFSRC-ARS-USDA laboratory in Beaver, West Virginia for chemical analysis within 24-h from the time of collection. Runoff samples ($< 0.45\mu m$) were analyzed for dissolved inorganic P (DPi) using Ion chromatography with suppressed conductivity (Dionex, DX 500I. C., AS144 mm anion column); molybdate reactive P (MRP) was determined colorimetrically using the method of Murphy and Riley (1962); total dissolved P (TDP) was determined colorimetrically after acid-persulfate digestion (EPA, 1971), and total P (TP) was determined colorimetrically after acid digestion (Pierzynski, 2000). Particulate P (PP) was then calculated as the difference between TP and TDP, and dissolved organic P (DPo) was calculated as the difference between TDP and DPi. Runoff samples were analyzed for Fecal coliform counts (after 6 to 12-h from the collection time) by the membrane filtration methods (Clesceri, 1998). Dissolved organic carbon (DOC) was also determined in runoff samples using a modified method of Sims and Haby (1971).

Soil Extraction and Analysis

Extractable P in the soil samples collected prior to rainfall events was determined using five different methods: Water, Mehlich-3, Melich-1, Olsen, Bray-1 (Pierzynski, 2000), and anion exchange resin (Kuo, 1996). In all extracts, P was determined colorimetrically (Murphy and Riley, 1962). The Mehlich-3, Olsen, and Bray-1 methods are commonly used for soil fertility advisory purposes and the water extraction method is designed to extract easily desorbable P, whereas, anion exchange resin (similar to iron oxide-impregnated strips) acts as a P sink and has been correlated with algal biomass (Sharpley, 1993).

**Table 2: Annual rates of broiler litter fed to grazing cattle or soil applied between 1995 and 2001. Inorganic fertilizer was applied at rates to equal the rates of N, P and K applied as poultry litter. Soil applications of fertilizer and poultry litter were made in March of each year.**

| Year | Broiler litter | Inorganic fertilizer | | |
|---|---|---|---|---|
| | | N | P | K |
| | --- kg ha$^{-1}$ --- | -------------------- | kg ha $^{-1}$ | -------------------- |
| 1995 | 2266 | 88 | 28 | 22 |
| 1996 | 3393 | 96 | 40 | 81 |
| 1997 | 3234 | 94 | 35 | 50 |
| 1998 | 2197 | 61 | 28 | 37 |
| 1999 | 1891 | 68 | 18 | 56 |
| 2000 | 2880 | 117 | 33 | 103 |
| 2001 | 2701 | 97 | 20 | 85 |

***Statistical Analysis***

All variables were analyzed as a randomized complete block design using the ANOVA procedures of SAS to determine the effect of the long-term nutrient management treatments on the concentrations of different P forms in surface runoff (SAS Institute, 1999). Regression correlation analysis between dissolved organic P (DPo) and dissolved organic carbon (DOC); extractable soil P and different soluble forms of P in runoff (DPi, MRP, and TDP) were also determined using SAS to calculate the intercept, slope, correlation coefficient ($r^2$), and level of significance.

## RESULTS AND DISCUSSION:

Grazing cattle along with nutrient managements for seven years influenced soil properties in which, with the exception of Na, all nutrient levels were increased (Table1). The increase in the amounts of soil extractable P, K, Ca, Mg and S influenced the electrical conductivity of the soil which was also increased from 0.13 dSm$^{-1}$ in 1995 to as high as 0.53 in AIF treatment. With special reference to P as it is the main stream of this presentation; Mehlick-1 extractable-P was increased in the upper 5 cm soil depth from 18 to 27 mg kg$^{-1}$ in the control treatment, which received no P application. The increase in P was to a much higher concentrations in treatments AIF, ABL, and FBL and being as high as 213 mg kg$^{-1}$ (Table 1). Extractable-P in the soil of FBL treatment was at least 50% lower than those of AIF and ABL that received equal total P application. Calcium and Mg were not applied to treatments and were also increased after 7 years of grazing. This is probably due to fescue root were mining nutrients from deeper soil depth into herbage for animal feed and consequent return to soil surface as manure. It is then expected for nutrient managements of pasture to influence quality of runoff and possibly under ground water bodies. Nutrient management, grazing and consequent recycling of nutrients also increased total N and C in the soil in all treatments by at least 60 and 76% , respectively, leading C:N ratios to increase from 8.5 in 1995 up to 9.5 in ABL treatment (Table 1).

### *Runoff Hydrology*

The average volume of runoff occurring in the control treatment was higher as compared to treatments receiving application of inorganic fertilizer or broiler litter (AIF, ABL). Surface applications of broiler litter (ABL) resulted in the lowest runoff volume ($P = 0.0345$) and greater time delay for initiating runoff ($P = 0.0028$). Runoff-to-rainfall ratios were smaller ($P = 0.0351$) in the fertilizer treatments (AIF, ABL, and FBL), which were similar, as compared to the control (C). Generally, runoff-to-rainfall ratios were greater than 20% in all treatments (Edwards et al. 2000b). The difference in runoff volume or time delay to initiate runoff between treatments could not be attributed to the differences between volumetric water content (VWC) of the soil (Table 3). This observation was related to the differences in bulk density ($P = 0.0074$) and soil compaction ($P = 0.0038$) in the 0-5 cm soil depth between the long-term nutrient management treatments. Control treatment (C) had higher bulk density and soil compaction than AIF, ABL, and FBL treatments (Table 3). The lower bulk density in AIF, ABL, and FBL could have resulted from greater quantities of manure deposition compared to the control (C) and greater production of organic matter by the fescue sod. Based on the average daily weight gain of the animals between 1995-2001, number of grazing days, and pasture area, it can be calculated that manure deposition averaged 3651, 4456, 4456, and 4472 kg ha$^{-1}$ yr$^{-1}$ for treatments C, AIF, ABL, and FBL, respectively (J. Neel, personal communication). The lower bulk density in AIF, ABL, and FBL treatments may increase the infiltration rates of the soil (Sauer et al., 2000), and consequently, lesser runoff tendency in these treatments compared to the C treatment (Table 3). It was demonstrated by Edwards et al., (2000a) that the application of cattle manure at two different rates simulating rotational and conventional grazing that the rotational grazing plots generally had a greater tendency toward runoff, as indicated by the lower values of total rainfall ($R_T$) and rainfall prior to runoff ($R_R$) and higher values of runoff (Q). However, these authors did not offer any explanation to the noted differences in runoff-to-rainfall ratios in the different grazing management treatments, and they did not relate them to the differences in the amount of cattle manure applied to the tall fescue plots.

**Table 3: Selected soil physical properties and the effect of long-term nutrient management strategies of grazed pasture on the volume of surface runoff in L and as a percentage of total rain applied, and the time delay for runoff to occur.**

| Treatment | Runoff | % Runoff of total rain | Time prior to runoff | VWC* | Soil Compaction | Bulk density |
|---|---|---|---|---|---|---|
| | - liter plot$^{-1}$-- | | --- min --- | -- g kg$^{-1}$-- | --- mpa --- | -- g cm$^{3}$ --- |
| C | 31 ± 6 | 46 ± 10 | 7.9 ± 1.6 | 280 ± 3 | 15.9 ± 1.4 | 1.37 ± 0.02 |
| AIF | 24 ± 3 | 31 ± 4 | 7.5 ± 0.8 | 210 ± 13 | 13.9 ± 1.2 | 1.24 ± 0.03 |
| ABL | 19 ± 5 | 26 ± 8 | 16.9 ± 3.4 | 210 ± 21 | 9.4 ± 1.0 | 1.23 ± 0.02 |
| FBL | 23 ± 4 | 34 ± 7 | 6.2 ± 0.5 | 220 ± 18 | 11.6 ± 1.1 | 1.24 ± 0.04 |
| | | | | $F > P$ | | |
| NM Effects | 0.1345 | 0.0351 | 0.0028 | 0.0059 | 0.0038 | 0.0074 |

VWC = volumetric water content; ± are standard errors of means (n=12)

### *Phosphorus Concentrations in Runoff*

Concentrations of dissolved P (DPi, MRP, and TDP) in simulated surface runoff decreased with time ($P > 0.0001$) as runoff volume increased ($P > 0.0001$) over the time course of the 30-min runoff event (Fig. 2). The change in concentrations of DPi, MRP, and TDP in the control treatment (C) was less apparent than those of the AIF, ABL, and FBL treatments. DPi, MRP, and TDP were higher in these treatments as compared to the control at all intervals of the 30-min runoff event (Fig. 2). Concentrations of all dissolved P fractions (DPi, MRP, and TDP) in the AIF treatment were higher in the initial sampling intervals than ABL and FBL and the concentrations became similar by the end of the 30-min runoff event. It is interesting to note that concentrations of DPi, MRP and TDP were consistently higher in the ABL treatment compared to FBL. However, the higher concentrations of all dissolved P forms (DPi, MRP, and TDP) in runoff from the ABL treatment compared to FBL (Fig. 2, Table 3) could have resulted from the lower runoff volume in the ABL treatment relative to FBL (Dougherty et al., 2008; Sparago et al., 2006). Average values of DPi, MRP, and TDP in runoff, taking in account the runoff volumes are presented in Fig. 2. In general, average concentrations of all P forms in the simulated runoff were in similar order as shown in Fig. 2 in which followed the order from lower to higher: C < FBL < AIF=ABL. Phosphorus in the inorganic fertilizer treatment appeared to be equally susceptible to loss in surface runoff transport as compared to P applied as poultry litter (Velf et al., 2007). It is, for now, a matter of speculation as to why the feeding of broiler litter to cattle decreased the susceptibility of P transport in surface runoff. We propose that there are chemical changes occurring in the broiler litter as it passes through the cattle digestive system, which probably increased the turnover of inorganic P forms into organic P forms. The acidity in the animal stomach may result in a breakdown of mineral organic compounds, such as calcium phosphate, along with greater microbial activity may lead to greater utilization of inorganic P and subsequent binding in organic forms.

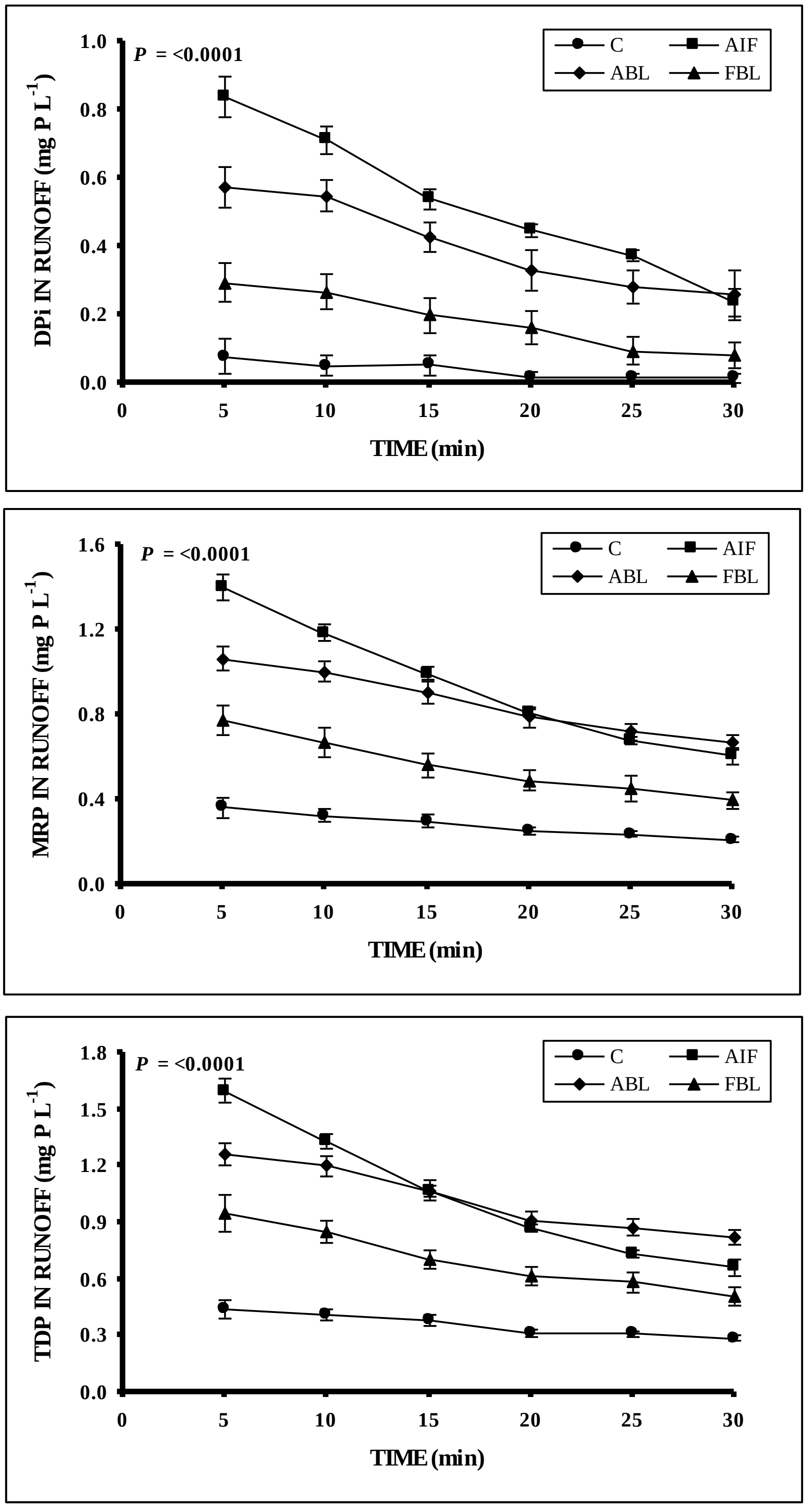

**Figure 2: Concentrations of dissolved inorganic P (DPi), molybdate reactive P (MRP), and total dissolved P (TDP) in surface runoff during 5 min intervals of a 30-min runoff event under simulated rainfall applied to over grazed pasture under different nutrient management strategies. Bars are standard errors of means (n=12).**

Dissolved organic P (DPo) in the simulated runoff was calculated as the difference between TDP and DPi (McDowell and Sharpley, 2001), was higher in broiler litter treatments (ABL and FBL) compared to AIF or C treatments (Fig. 3). The increase in concentrations of DPo in runoff followed the order ABL>FBL>AIF>C with a similar order of magnitude in the concentrations of dissolved organic carbon (DOC). The significant correlation between concentrations of DPo and DOC in simulated surface runoff from all treatments may indicate the two are linked (Table 4). The mobility of soluble organic compounds may have assisted the release and transport of organically-bound P into runoff.

**Table 4: Results of dissolved organic P (DPo, mg kg$^{-1}$) in simulated surface runoff correlated to the dissolved organic carbon (DOC, mg L$^{-1}$) in surface runoff grazed pasture under four different nutrient management strategies.**

| Treatment | Intercept | Slope | $r^2$ | *P* value |
|---|---|---|---|---|
| C | -190.2 | 714.5 | 0.806 | 0.0152 |
| AIF | -44.1 | 155.0 | 0.982 | 0.0001 |
| ABL | -375.7 | 717.2 | 0.913 | 0.0029 |
| FBL | -143.1 | 389.3 | 0.936 | 0.0016 |

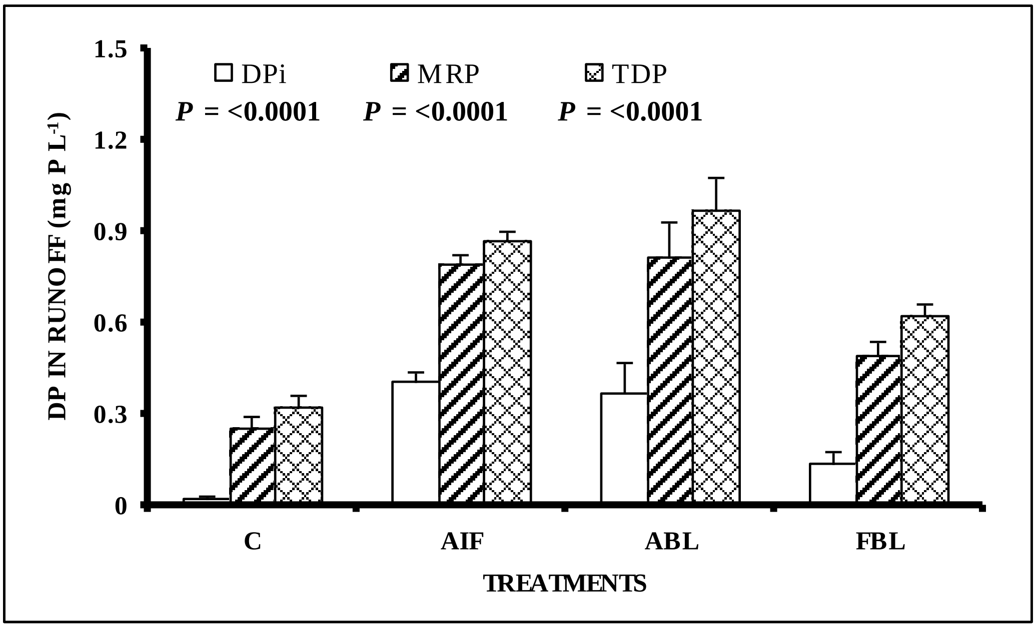

**Figure 3: Average concentrations of dissolved inorganic P (DPi), molybdate reactive P (MRP), and total dissolved P (TDP) in surface runoff during a 30-min runoff event under simulated rainfall applied to grazed pasture under different nutrient management strategies. Bars are standard errors of means (n=12).**

Phosphorus associated with organic/inorganic solids in the simulated runoff (particulate P, PP) were not significantly different between treatments and constituted only a small fraction of the total P (TP) in surface runoff (Fig. 4). Particulate P (PP) constitutes

50, 27, 27, and 42% of the TP concentrations in runoff for C, AIF, ABL, and FBL, respectively; indicating that MRP is the major form in which P is transported in runoff occurring from pastures (Nichols et al., 1994; Edwards and Daniel, 1994). The amount of applied P fertilizer over the seven years of this study averaged about 28.9 kg P ha$^{-1}$ yr$^{-1}$ and it can be calculated that 0.65, 0.89, and 0.71 % of the total applied P would be lost during a single 30 min runoff event produced from a storm event with and intensity of 72 mm hr$^{-1}$ in AIF, ABL, and FBL, respectively. These quantities of P loss from a pasture to surface water highlight the importance of monitoring the number and timing of runoff events occurring over a year. Previous work has shown that P losses are greater if runoff events occur close to the time of application of broiler litter/inorganic fertilizers (Edwards et al., 2000a).

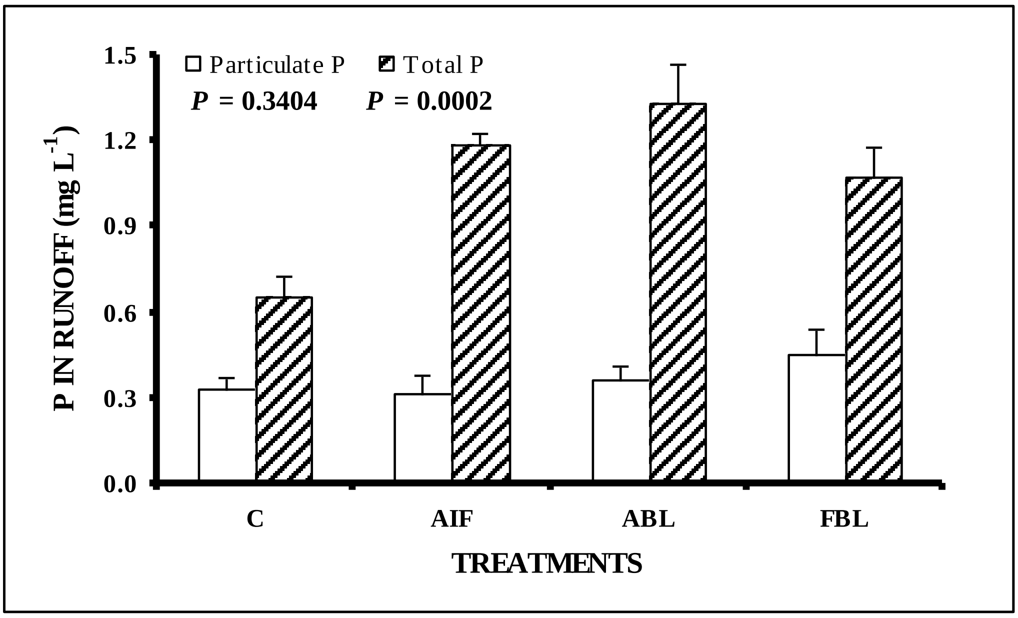

**Figure 4: Average concentrations of particulate P (PP) and total P (TP) in surface runoff during a 30-min runoff event under simulated rainfall applied to grazed pasture under different nutrient management strategies. Bars are standard errors of means (n=12).**

### *Fecal coliform concentrations in runoff*

Transport of *F. coliform* (FC) from agricultural land to surface water is another environmental issue concerning public heath safety. The simulated runoff from all treatments, regardless of nutrient management, had concentrations of FC higher than 7000 CFU 100 mL$^{-1}$ (Fig. 5). These concentrations in runoff had the tendency to be higher when broiler litter was applied (ABL and FBL) compared to the C and AIF treatments. However, there was a large variation in FC concentrations in runoff within treatments that masked any probable significant differences related to broiler litter applied directly to the soil (ABL) or fed to cattle (FBL).

In our study, FC concentrations in runoff exceeded in all treatments (Fig. 5) the primary contact standard of 200 CFU 100 mL$^{-1}$ (Edwards et al., 1997). These concentrations of FC in runoff from all treatments could be attributed to grazing activities of the cattle more than nutrient management treatments. These results supports the findings of Gary et al., (1983) linking grazing to elevated concentrations of FC in streams adjacent to pastures that are grazed by cattle. Although elevated concentrations of FC were linked to grazing, the type of grazing management did not influence levels of FC in runoff whether it was rotational or continuous grazing systems (Edwards et al., 2000a). Concentrations of FC in runoff from grazed pastures were also shown to vary between seasons with counts being higher during warmer months (Edwards et al., 1997), probably as a result of regrowth in warm conditions (Tiedemann et al., 1988). In a preliminary primary study with in grazed pasture, applying simulated rainfall over fresh vs. aged cattle manure showed at least 5 times greater concentrations of FC in runoff from plots containing aged cattle manure compared to fresh cattle manure (data not shown).

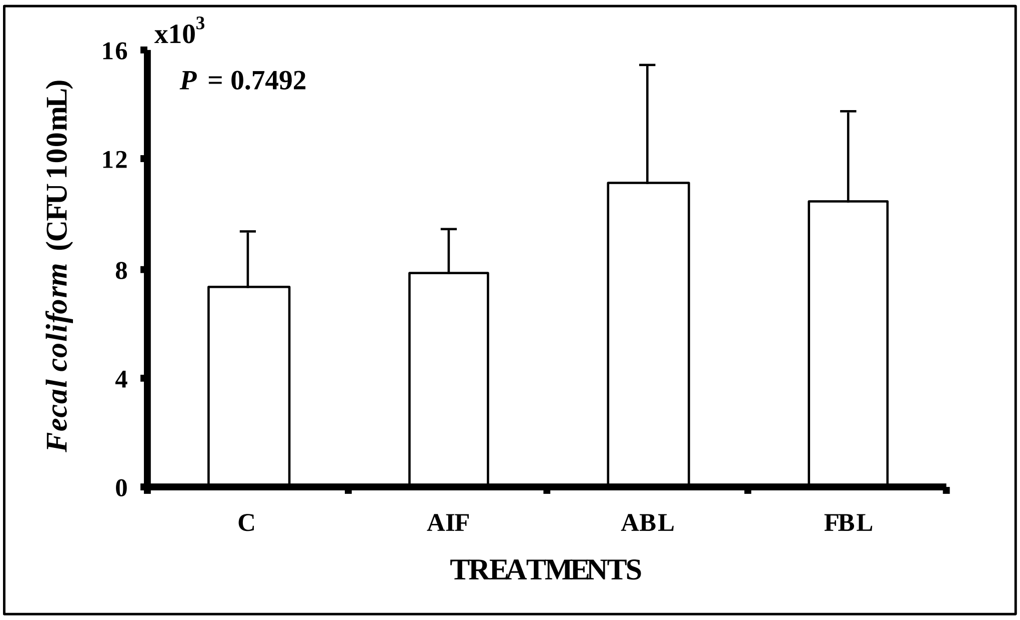

**Figure 5: Average counts of *Fecal coliform* in surface runoff during a 30-min runoff event under simulated rainfall applied to grazed pasture under different nutrient management. Bars are standard errors of means (n=12).**

### *P in runoff vs. Soil Test Phosphorus*

The amounts of P extracted from the soils by the various methods were regressed against DPi, MRP, and TDP values in simulated runoff (Table 5). Data were treated as a random block design regardless of nutrient management treatment. The soil phosphorus test (STP) values obtained by all of the extraction methods were significantly ($P < 0.0175$) correlated to DPi, MRP, and TDP concentrations in simulated surface runoff (Table 5). Yet, when the extraction methods were compared using $r^2$ values to see how closely the data points fit the linear regression models with DPi, MRP, and TDP in simulated runoff, it was apparent that some soil P test methods were more closely related to TDP in simulated runoff than other methods (Table 5). For example, Mehlich-3 extractable soil P was best correlated with TDP in surface runoff ($r^2 = 0.91$) compared to $r^2 = 0.76$ or $r^2 = 0.77$ with DPi or MRP in runoff, respectively (Table 5). Stronger correlations may have been obtained if soil samples had been analyzed from the top 0-2 cm soil depth (Vadas et al., 2005; Sharpley, 1995; Pote et al., 1996).

**Table 5: Results of soil P (mg kg$^{-1}$) extracted using five soil test phosphorus (STP) methods correlated to the P concentrations in runoff [dissolved inorganic P (DPi), molybdate reactive P (MRP), total dissolved O (TDP)] in surface runoff from grazed pasture that had been managed using four nutrient management strategies from 1995-2001.**

| STP method | Intercept | Slope | $r^2$ | *P* value |
|---|---|---|---|---|
| | DPi in runoff (mg L$^{-1}$) | | | |
| Water | -0.053 | 0.016 | 0.77 | 0.0004 |
| Anion exchange resin | -0.100 | 0.007 | 0.77 | 0.0004 |
| Mehlich-3 | -0.058 | 0.002 | 0.76 | 0.0004 |
| Mehlich-1 | -0.019 | 0.002 | 0.67 | 0.0012 |
| Bray-1 | -0.053 | 0.001 | 0.83 | 0.0001 |
| Olsen | -0.194 | 0.003 | 0.81 | 0.0001 |
| | MRP in runoff (mg L$^{-1}$) | | | |
| Water | 0.206 | 0.021 | 0.64 | 0.0030 |
| Anion exchange resin | 0.149 | 0.009 | 0.63 | 0.0038 |
| Mehlich-3 | 0.168 | 0.003 | 0.77 | 0.0004 |
| Mehlich-1 | 0.228 | 0.002 | 0.67 | 0.0021 |
| Bray-1 | 0.199 | 0.002 | 0.73 | 0.0008 |
| Olsen | -0.002 | 0.004 | 0.74 | 0.0007 |
| | TDP in runoff (mg L$^{-1}$) | | | |
| Water | 0.307 | 0.021 | 0.74 | 0.0006 |
| Anion exchange resin | 0.263 | 0.009 | 0.67 | 0.0020 |
| Mehlich-3 | 0.265 | 0.003 | 0.91 | <0.0001 |
| Mehlich-1 | 0.315 | 0.003 | 0.85 | 0.0009 |
| Bray-1 | 0.304 | 0.002 | 0.82 | 0.0001 |
| Olsen | 0.096 | 0.004 | 0.85 | <0.0001 |

In addition to runoff volume, the upper soil depth (0-2 cm) was shown to interact with rainfall influencing P concentrations in runoff (Sharpley et al., 1993). Further study is needed to justify the possible use of this relationship in Fredric soil type common in the Shenandoah Valley in Virginia and extending northwest into southern Virginia as a theoretical basis to calculate threshold or environmental STP levels, above which P enrichment of runoff become unacceptable.

## CONCLUSION AND RECOMMENDATION:

Seven years of nutrient management of grazed pasture increased P concentrations in the soil compared to the control (C) not receiving P application. P concentrations in the soil, as determined by Mehlich-1, increased from 18 mg kg$^{-1}$ in the soil at the start of the experiment to 27, 205, 213, and 96 mg kg$^{-1}$ in the top 0-5 cm soil depth in 2001 for C, AIF, ABL, and FBL treatments, respectively. These P concentrations were reflected in the concentrations of P in surface runoff in which were higher in AIF or ABL than in runoff from FBL or C treatments. Mehlich-1 extractable P in FBL treatment was lower by 46% compared to ABL and reflected lower P transport in surface runoff, although both

treatments received similar application rates of broiler litter. However, the relationship between P levels in the soil and in runoff could be used as the theoretical basis to established critical soil test P levels, above which P enrichment of runoff becomes unacceptable. Phosphorus concentrations in runoff of 0.25 mg $L^{-1}$ and 1.0 mg $L^{-1}$ corresponded to 27 to 277 mg $kg^{-1}$ P Mehlich-3 extractable P, respectively, for this Frederick soil. Concentrations of 1.0 mg $L^{-1}$ in runoff supported by a soil P test (Mehlich-3) of about 277, a concentration was not reached in the soil (0-5 cm) in any of the treatments over six years of grazing and varying nutrient management strategies. However, the speed in which P levels were elevated in the soil over seven years raise demonstrates the P levels can be increased rapidly in pastures on residual limestone soils. In addition, levels of *fecal coliform* in runoff were very high in all nutrient management treatments indicating a greater impact of grazing by cattle rather than nutrient management strategies.

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