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NUTRIENT AND BACTERIAL TRANSPORT IN RUNOFF FROM SOIL AND POND ASH AMENDED FEEDLOT SURFACES

John E. Gilley
Adjunct Professor, Biological Systems Engineering, john.gilley@ars.usda.gov

Jason R. Vogel
Oklahoma State University - Main Campus, jason.vogel@okstate.edu

Elaine D. Berry
USDA MARC, Clay Center NE, elaine.berry@ars.usda.gov

Roger Eigenberg
USDA MARC, Clay Center NE, roger.eigenberg@ars.usda.gov

David B. Marx
University of Nebraska-Lincoln, david.marx@unl.edu

See next page for additional authors

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Authors
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J. E. Gilley, J. R. Vogel, E. D. Berry, R. A. Eigenberg, D. B. Marx, B. L. Woodbury

ABSTRACT. *The addition of pond ash (fly ash that has been placed in evaporative ponds and subsequently dewatered) to feedlot surfaces provides a healthier environment for livestock and economic advantages for the feedlot operator. However, the water quality effects of pond ash amended surfaces are not well understood. The objectives of this field investigation were to: (1) compare feedlot soil properties, and nutrient and bacterial transport in runoff, from pond ash amended surfaces and soil surfaces; (2) compare the effects of unconsolidated surface materials (USM) (loose manure pack) and consolidated subsurface materials (CSM) (compacted manure and underlying layers) on nutrient and bacterial transport in runoff; and (3) determine if the measured water quality parameters are correlated to soil properties. Simulated rainfall events were applied to 0.75 m wide × 2 m long plots with different surface materials and surface conditions. Measurements of calcium, magnesium, sulfur, and pH were found to be significantly greater on the pond ash amended surfaces. In comparison, the soil surfaces contained significantly greater amounts of Bray 1-P. The runoff load of NH_4-N was significantly greater on the pond ash amended surfaces, while the total phosphorus (TP) load was significantly greater on the soil surfaces. The NO_3-N and total nitrogen (TN) loads in runoff were significantly greater on the feedlot surfaces containing CSM. Concentrations of* E. coli *in runoff were similar on the pond ash amended surfaces and soil surfaces. The dissolved phosphorus (DP), particulate phosphorus (PP), and TP load of runoff were all significantly correlated to Bray 1-P measurements.*

***Keywords**. Bacteria, Beef cattle, Feedlots, Manure management, Manure runoff, Microorganisms, Nutrient losses, Phosphorus, Runoff, Water quality.*

The importance of animal manure management has increased with the intensification of livestock production in concentrated animal feeding operations. Runoff from beef cattle feedlots contains microorganisms, nutrients, organic materials, and sediment (Eghball and Power, 1994). Research information is needed to determine if feedlot runoff water quality characteristics are acceptable based upon established environmental regulations.

Accumulated manure is typically removed from feedlot pens between cattle production cycles, usually once or twice a year. Beef cattle feedlots contain unconsolidated surface materials (USM) (loose manure pack) and consolidated subsurface materials (CSM) (compacted manure and underlying layers) (Woodbury et al., 2001). It may be necessary to bring fill material into the feedlot pen after manure removal to return the pen to its original grade and elevation. Even with this type of feedlot management, however, manure enrichment, compaction, and water content, which depend upon the location of the feed and water sources, will vary spatially and temporally across the pen surface during the production cycle.

Unconsolidated surface materials are thought to be the source of feedlot dust (Miller and Woodbury, 2003). Dust potential is related to moisture and organic matter content (Razote et al., 2006). Maximum dust potential and airborne residence time vary among pen locations.

Feedlot pen surfaces become saturated during high moisture conditions, and the health and performance of cattle may be affected. The stirring action of cattle hooves mixes the soil and manure, creating unhealthy conditions for cattle (Clanton et al., 2005). Removing manure to maintain adequate feedlot pen surfaces is time-consuming and expensive (Parker et al., 2004).

Kalinski et al. (2005) investigated the use of fly ash, a byproduct from coal-fired electrical generation, as an amendment in feedlot pens. The placement of fly ash in feedlots was shown to improve daily gain and reduce hoof disease in cattle. Pond ash is fly ash that has been placed in evaporative ponds for storage and subsequently dewatered (ACAA, 2008). The ash is periodically dredged from storage ponds and used to make concrete or to build roadbeds. Pond ash provides a relatively stable surface and has been used as an amendment on feedlot surfaces (Parker et al., 2004).

Manure that accumulates within feedlot pens where pond ash is added as an amendment is more easily removed than in pens with soil surfaces (Parker et al., 2004; Woodbury et al., 2007). In pens with soil surfaces, accumulated manure is

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The authors are **John E. Gilley, ASABE Member Engineer,** Agricultural Engineer, USDA-ARS, University of Nebraska, Lincoln, Nebraska; **Jason R. Vogel, ASABE Member Engineer,** Assistant Professor, Department of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, Oklahoma; **Elaine D. Berry,** Microbiologist, and **Roger A. Eigenberg, ASABE Member Engineer,** Agricultural Engineer, USDA-ARS U.S. Meat Animal Research Center, Clay Center, Nebraska; **David B. Marx,** Professor, Department of Statistics, University of Nebraska, Lincoln, Nebraska; and **Bryan L. Woodbury, ASABE Member Engineer,** Agricultural Engineer, USDA-ARS U.S. Meat Animal Research Center, Clay Center, Nebraska. **Corresponding author:** John E. Gilley, USDA-ARS, Room 251 Chase Hall, University of Nebraska, Lincoln, NE 68583-0934; phone: 402-472-2975; fax: 402-472-6338; e-mail: John.Gilley@ars.usda.gov.

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mixed with soil by the action of cattle hooves, especially during muddy conditions. Therefore, substantial amounts of soil are removed when the feedlot pens are scraped and cleaned. Since there is less mixing with soil, the surface material from pond ash amended pens has a greater value for use in land application (Sweeten et al., 2006).

Woodbury et al. (2007) compared the performance of feedlots with soil and pond ash amended surfaces. Following the feeding cycle, animals were removed and the pens were cleaned. The pens amended with pond ash had a 70% reduction in total mass removed compared to pens with a soil surface. Therefore, substantially more material was required to return the surface to original grade in the pens containing only soil material.

FEEDLOT SOIL PROPERTIES

Soil properties have been shown to vary spatially and temporally within a feedlot. McCullough et al. (2001) examined soil properties of a feedlot recently established on a sandy loam soil near Canyon, Texas. Saturated hydraulic conductivity within the feedlot varied by one to two orders of magnitude during the first nine months of stocking. However, bulk density of the upper 15 cm of the feedlot surface did not change significantly due to compaction of the feedlot surface prior to stocking. Limited infiltration occurred after the feedlot surface had sealed.

Gilley et al. (2008) found no significant differences in selected soil characteristics between USM and CSM in feedlot pens located near Clay Center, Nebraska. However, concentrations of *E. coli* were significantly greater in the USM than the CSM. Runoff measurements of dissolved phosphorus (DP), EC, and NH_4-N were significantly influenced by pen location.

FEEDLOT RUNOFF CHARACTERISTICS

Feedlot soil properties have been shown to affect the water quality characteristics of runoff from beef cattle feedlots. Miller et al. (2006) examined bedding and within-pen location effects on feedlot runoff quality in southern Alberta, Canada. Pen location had a significant impact on selected water quality parameters. The physical and chemical characteristics of runoff from beef cattle feedlots were influenced by animal age and condition, animal density and size, climate, diet, feedlot surface condition, handling and storage of manure, and soil type. Thus, conventional methods of treating the pen surface as a single uniform nutrient source oversimplifies its complexity and may hinder the development of methods to predict and minimize runoff nutrient losses.

Olson et al. (2006) examined the effects of selected types of bedding materials and pen locations on feedlot runoff parameters in southern Alberta, Canada. The type of bedding material had no significant affect on runoff characteristics. However, pen location significantly influenced clod bulk density, gravimetric water content, manure depth, slope gradient, and surface roughness.

Gilley et al. (2008) found that only the EC of runoff was significantly affected by surface condition (USM vs. CSM). However, location within the pen significantly influenced runoff measurements of DP, EC, and NH_4-N. Several runoff water quality parameters were found to be correlated to selected feedlot soil properties.

Computer modeling procedures have been developed to predict nutrient transport from beef cattle feedlots (Eigenberg et al., 1998; Williams et al., 2006). Information provided by these computer programs can be used to identify economical and practical ways to reduce impacts on surface water quality. Improved procedures for estimating nutrient and bacterial runoff potential within a feedlot, including pond ash amended surfaces, could improve the reliability of simulation models.

Existing environmental regulations require some combination of clean water diversion, irrigation systems, runoff collection ponds, and settling basins for control of feedlot runoff. Therefore, there is usually no direct hydrologic connection between feedlot runoff and downstream water bodies. Holding ponds serve to collect and store runoff from feedlots until it can be land applied.

Vegetative treatment areas (VTA) are sometimes used as an alternative method for treating runoff. A VTA uses forage or grass species to filter contaminants and capture runoff (Koelsch et al., 2006; Woodbury et al., 2005). During high precipitation events, unplanned releases from holding ponds and VTA may occur. Reducing delivery of nutrients and bacteria to holding ponds and VTA would enhance system operation and reduce environmental impacts if storage capacity is exceeded.

BACTERIAL TRANSPORT IN RUNOFF

Runoff from beef cattle feedlots has been shown to contain relatively large populations of bacteria. Miner et al. (1966) measured concentrations of total coliforms, fecal coliforms, and fecal streptococci in runoff from beef cattle feedlots near Manhattan, Kansas. The largest bacterial counts occurred during warm weather and under conditions that produced maximum solubility of feedlot surface materials. Bacterial populations in runoff from soil and concrete surfaces were found to be similar.

Rhodes and Hrubrant (1972) identified microbial populations in runoff from a beef cattle feedlot near Peoria, Illinois. Greater runoff volume was found to substantially increase general microbial population patterns.

Young et al. (1980) determined runoff concentrations of total coliforms, fecal coliforms, and fecal streptococci for two consecutive years from a beef cattle feedlot in west central Minnesota. Vegetated buffer strips were found to serve as an effective method for controlling feedlot runoff.

Miller et al. (2004) measured microbial populations within a catch basin below a beef cattle feedlot in southern Alberta, Canada. Water in the catch basin had continually high populations of total heterotrophs, total coliforms, and *E. coli* bacteria. The *E. coli* in the feedlot runoff demonstrated lower persistence characteristics than those in the total coliform population.

E. coli are found primarily in the mammalian gastrointestinal tract. However, this bacterium can survive for long periods in manure, feedlot surface materials, and soils. Generic *E. coli* were found by Berry et al. (2007) to persist at significant levels in soil for 171 days after runoff from a feedlot was diverted into a VTA containing brome grass. Cattle may serve as a host of the pathogen *E. coli* 0157:H7. Berry and Miller (2005) found that *E. coli* 0157:H7 can persist in feedlot soils over a wide range of water and manure contents.

STUDY OBJECTIVES

A healthier environment for livestock may exist within feedlot pens amended with pond ash because of drier feedlot conditions. The addition of pond ash to feedlot surfaces would also provide an economic benefit because much less soil material would need to be replaced following a feeding cycle (Woodbury et al., 2007). However, little information is currently available concerning the water quality characteristics of runoff from pond ash amended feedlot surfaces.

Contributions of USM and CSM to nutrient transport in runoff from feedlot surfaces are not well defined. The source of potential contaminants must be identified before practices for managing runoff within feedlot pens can be adopted. One management alternative that has been proposed is the periodic removal of USM from feedlot surfaces. In this study, the runoff water quality implications of this feedlot management practice were examined.

The specific objectives of this study were to: (1) compare feedlot soil properties, and nutrient and microbial transport in runoff, from pond ash amended surfaces and soil surfaces; (2) compare the effects of USM and CSM on nutrient and microbial transport in runoff; and (3) determine if runoff nutrient and microbial transport from pond ash amended surfaces and soil surfaces are correlated to feedlot soil characteristics.

MATERIALS AND METHODS

STUDY SITE DESCRIPTION

This study was conducted at the U.S. Meat Animal Research Center near Clay Center, Nebraska during the summer of 2008 within eight 7.3 m wide × 20.7 m long feedlots pens (fig. 1). Average annual precipitation at the study site is 728 mm (NOAA, 2006). Four of the feedlot pens contained pond ash amended surfaces, and four of the pens had soil surfaces. Pairs of pens sharing a water trough contained the same surface material, and the pens were arranged such that alternating pairs had pond ash amended surfaces or soil surfaces. Steer calves born during the spring of 2007 were placed in the feedlot in September 2007 at a rate of 8 head per pen (19 m^2 $head^{-1}$). The initiation of feeding period and the feed rations used within each of the pens were identical. The feedlot management practices conducted during this study, including manure removal, are representative of those used in this region.

The study sites were established in upslope pen locations within areas with a mean slope gradient of 4.8% that allowed overland flow to drain uniformly from the experimental plots. Two adjoining 0.75 m wide × 2 m long plots were established within each of the eight pens (fig. 1). Unconsolidated surface material was removed from one of the two adjoining plots to create the CSM treatment. Four of the pens contained a soil surface, and a pond ash amendment had been placed on the surface of the remaining four pens. Thus, a total of 16 plots were examined; the surface condition of eight of the plots was USM, while CSM was contained on the surface of the other eight plots.

Livestock from an individual pen were removed just prior to plot establishment. The pen remained unstocked for the duration of the testing period. Livestock in the adjoining pens were left undisturbed until the plot borders were installed just prior to rainfall simulation testing. By using this procedure, the length of time that expired following removal of cattle among individual pens remained constant. However, the period of time that cattle had been on feed varied slightly among experimental pens by a maximum of three weeks.

COLLECTION AND ANALYSES OF FEEDLOT SOIL MATERIALS

The mass of USM collected by hand from eight of the plots was measured on-site. A subsample of the USM was obtained and stored in a cooler at 4°C for subsequent analyses. Feedlot soil samples were collected from the outside perimeter of each of the eight test plots with surfaces containing CSM. A small shovel was used to remove the feedlot soil samples from a depth of approximately 0 to 1.5 cm (after the USM had been removed). Composite samples of USM and CSM were

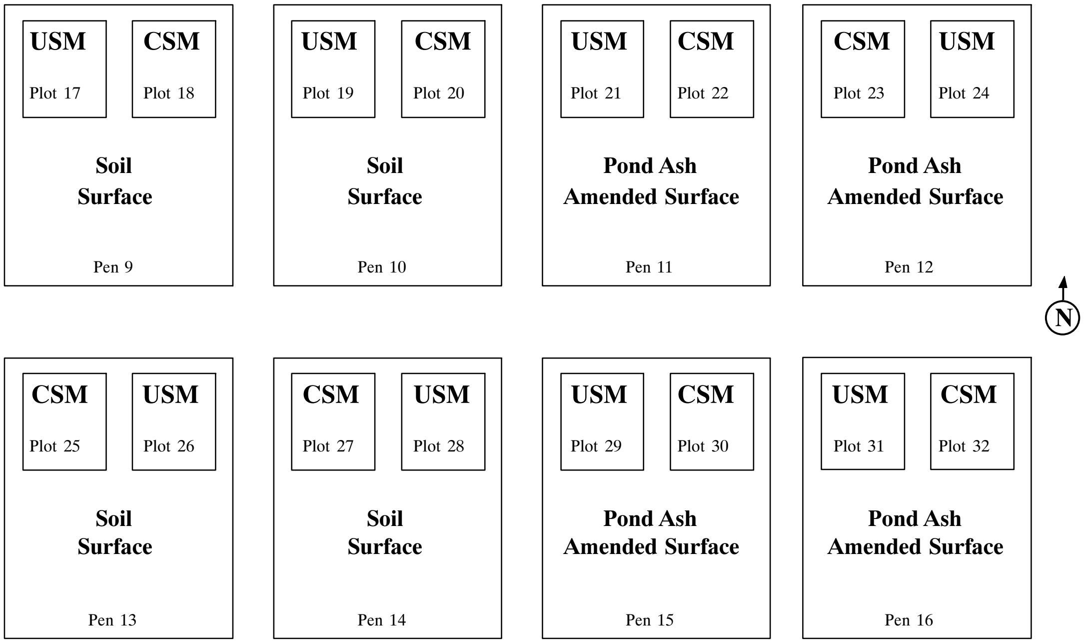

Figure 1. Schematic of the feedlot pens and plot layout showing locations of the pond ash amended surfaces and soil surfaces (CSM = consolidated subsurface material; USM = unconsolidated surface material).

sent to a commercial laboratory and analyzed for calcium, chloride, magnesium, NH_4-N, organic-N, phosphorus, potassium, sodium, sulfur, total N (TN), and water content. Electrical conductivity (EC) and pH also were measured at the commercial laboratory in a 1:5 soil/water ratio.

A USDA-ARS analytical laboratory in Lincoln, Nebraska, was used to measure Bray and Kurtz No. 1 P (Bray 1-P), loss on ignition, NO_3-N, and water-soluble P (WSP). Soil NO_3-N concentrations (extracted using a 2 molar KCl solution) were determined with a flow injection analyzer using spectrophotometry (Lachat system from Zellweger Analytics, Milwaukee, Wisc.). As an index of P availability, the Bray 1-P test (Bray and Kurtz, 1945) provides a relative estimate of the P concentration in the soil that limits the growth of plants. Water-soluble P was measured by shaking 2 g of soil for 5 min with 20 mL of deionized water using the Murphy and Riley (1962) procedure. *E. coli* and *E. coli* O157:H7 in USM and CSM were determined as described below.

RAINFALL SIMULATION PROCEDURES

Water used in the rainfall simulation tests was obtained from a hydrant near the feedlot complex and stored in a 3800 L trailer-mounted plastic tank. Water samples were collected from the storage tank each day, so the reported nutrient concentrations represent the difference between runoff measurements and nutrient content of the applied water. Measured mean concentrations of DP, NO_3-N, and NH_4-N in the well water were 0.16, 2.33, and 0.07 mg L^{-1}, respectively.

Rainfall simulation procedures adopted by the National Phosphorus Research Project were employed in this study (Sharpley and Kleinman, 2003). Plot borders consisted of prefabricated sheet metal boundaries enclosing three sides of each plot and a sheet metal lip located at the bottom that emptied into a collection trough. The trough extended across the plot and diverted runoff into plastic drums. The collection trough was lined with clean plastic liner sheeting that was replaced after each simulation run. Two rain gauges were placed along the outer edge of each plot, and one rain gauge was located between the paired plots.

A portable rainfall simulator based on the design by Humphry et al. (2002) was used to apply rainfall simultaneously to paired plots. The rainfall simulator operated for 30 min at an intensity of approximately 70 mm h^{-1}. A storm in this area with this intensity and duration has approximately a 5-year recurrence interval (Hershfield, 1961). Two additional rainfall simulation runs were then conducted for the same duration and intensity at approximately 24 h intervals.

After completion of a rainfall simulation test, the plastic drums were weighed to determine total runoff volume. Runoff was then placed in a sterile Teflon churn to ensure a well-mixed representative sample. All tubing and churns were cleaned and sterilized after each rainfall simulation event. Samples were obtained for analysis of total solids, water quality measurements, and bacterial analysis. The samples obtained for total solids were dried in an oven at 105°C and then weighed. Centrifuged and filtered runoff samples were analyzed for DP (Murphy and Riley, 1962), NO_3-N, and NH_4-N using a Lachat system (Zellweger Analytics, Milwaukee, Wisc.). Non-centrifuged samples were analyzed for chloride, EC, pH, total dissolved solids (TDS), total nitrogen (TN; Tate, 1994), and total P (TP; Johnson and Ulrich, 1959).

LABORATORY BACTERIAL MEASUREMENTS

Subsamples of USM, CSM, and unfiltered runoff were analyzed within 2 h of collection to determine concentrations of generic *E. coli* and prevalence and concentrations of *E. coli* O157:H7. Ten gram or 10 mL samples were diluted 1:10 in tryptic soy broth, serially diluted further as needed in 2% buffered peptone, and spiral-plated onto each of two different types of agar plates using an Autoplate 4000 spiral plater (Spiral Biotech, Inc., Norwood, Mass.). For the determination of generic *E. coli* populations, CHROMagar ECC agar plates (DRG International, Inc., Mountainside, N.J.) were incubated at 37°C for 24 h, and characteristic blue *E. coli* colonies were enumerated.

Populations of *E. coli* O157:H7 were identified using CHROMagar O157 agar plates containing 5 mg L^{-1} novobiocin and 1 mg L^{-1} tellurite that were incubated at 42°C for 24 h prior to examination for characteristic flat, mauve-colored colonies. To determine the presence of *E. coli* O157:H7, the remaining 1:10 tryptic soy broth dilutions of USM, CSM, and runoff were subjected to enrichment and immunomagnetic separation as described by Berry et al. (2007).

STATISTICAL ANALYSES

Populations of *E. coli* were converted to $\log_{10}$ colony forming units (CFU) g^{-1} (USM or CSM) or $\log_{10}$ CFU ha^{-1} (runoff) prior to statistical analyses. Statistical analyses were conducted using the Mixed procedures of SAS (SAS, 2003) to determine the effects of surface material (pond ash or soil) and surface condition (USM or CSM) on feedlot soil and runoff characteristics. Differences among treatment means were identified using the least significant difference (LSD) test. A probability level less than 0.05 was considered significant. Correlation analysis was used to test the relative relation between runoff constituents and chemical and physical feedlot soil characteristics.

RESULTS AND DISCUSSION

SOIL PROPERTIES

The feedlot soil surfaces contained significantly greater amounts of Bray 1-P than the pond ash amended surfaces (table 1). Measurements of calcium, magnesium, pH, and sulfur were significantly greater on the pond ash amended surfaces. None of the measured feedlot soil properties showed significant differences based only on surface condition (USM or CSM). However, significant surface material by surface condition interactions were found for organic N, phosphorus, total N, and water-soluble P.

For the feedlots that were amended with pond ash, the TN content of the surfaces containing CSM was significantly greater than the surfaces with USM (fig. 2). For the feedlots with soil surfaces, no significant difference in TN content was found between the plots containing USM and CSM. The statistical results obtained (not shown) for organic N were the same as those reported for TN.

The WSP content of USM within the pens amended with pond ash was significantly less than the other experimental treatments (fig. 3). On the feedlots with soil surfaces, no significant differences in WSP content were found between the plots containing USM and CSM. Similarly, no significant differences (not shown) in phosphorus content (P_2O_5) were found between the feedlot soil surfaces containing USM and CSM.

Table 1. Effects of surface material and surface condition on selected soil characteristics.

	Soil Characteristic									
Surface Material and Condition	Bray 1-P (mg kg^{-1})	Calcium (g kg^{-1})	Chloride (g kg^{-1})	EC (dS m^{-1})	*E. coli* (log CFU g^{-1})	Loss on Ignition (g kg^{-1})	Magnesium (g kg^{-1})	NH_4-N (g kg^{-1})	NO_3-N (mg kg^{-1})	Organic N (g kg^{-1})
Surface material[a]										
Pond ash amended surface	34 b	42.8 a	5.4	17.1	6.32	355	10.5 a	0.4	0.001	12.7
Soil	452 a	13.4 b	4.7	16.2	6.49	273	6.5 b	0.3	0.003	11.2
Surface condition[b]										
USM	266	26.4	4.5	15.4	6.42	317	8.4	0.3	0.004	11.2
CSM	220	29.9	5.6	17.8	6.39	311	8.6	0.4	0.000	12.7
Analysis of variance (Pr > F)										
Surface material	0.01	0.01	0.50	0.68	0.76	0.30	0.02	0.41	0.67	0.61
Surface condition	0.19	0.65	0.16	0.18	0.96	0.90	0.88	0.25	0.23	0.34
Surface material × surface condition	0.15	0.63	0.13	0.09	0.11	0.13	0.44	0.37	0.67	0.03

	Soil Characteristic								
Surface Material and Condition	pH	Phosphorous (g kg^{-1} P_2O_5)	Potassium (g kg^{-1} K_2O)	Sodium Adsorption (ratio)	Sodium (g kg^{-1})	Sulfur (g kg^{-1})	Total N (g kg^{-1})	Water Content (g kg^{-1})	Water-Soluble P (mg kg^{-1})
Surface material[a]									
Pond ash amended surface	8.6 a	10.4	15.0	5.58	4.9	4.0 a	13.1	330	63.3
Soil	8.3 b	8.4	15.4	5.79	3.2	2.4 b	11.5	397	101
Surface condition[b]									
USM	8.4	9.1	14.8	5.36	3.6	3.0	11.5	381	80.7
CSM	8.5	9.7	15.6	6.01	4.6	3.4	13.1	346	83.7
Analysis of variance (Pr > F)									
Surface material	0.02	0.17	0.78	0.77	0.07	0.01	0.58	0.28	0.18
Surface condition	0.63	0.20	0.32	0.30	0.12	0.36	0.30	0.57	0.71
Surface material × surface condition	0.12	0.01	0.06	0.14	0.33	0.56	0.02	0.05	0.02

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

[b] USM = unconsolidated surface material; CSM = consolidated subsurface material.

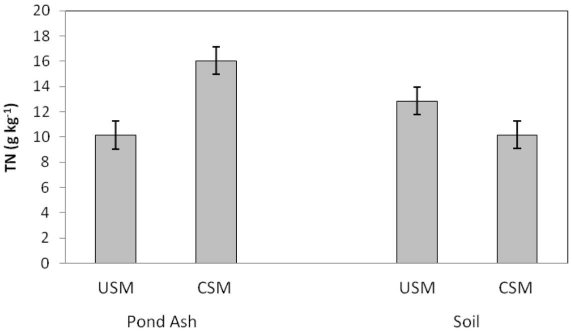

Figure 2. Total nitrogen (TN) content as affected by unconsolidated surface material (USM) and consolidated subsurface material (CSM) for the pond ash amended surfaces and soil surfaces. Values for TN content are averages from four plots. Vertical bars are standard errors.

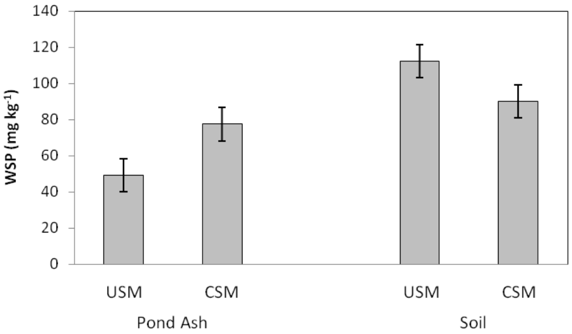

Figure 3. Water-soluble phosphorus (WSP) content as affected by unconsolidated surface material (USM) and consolidated subsurface material (CSM) for the pond ash amended surfaces and soil surfaces. Values for WSP content are averages from four plots. Vertical bars are standard errors.

The relatively high mean pH value of 8.6 for the pond ash amended feedlot surfaces is assumed to result from the presence of calcium carbonate. Measurements of sodium adsorption ratio (SAR) on the feedlot surfaces containing pond ash would have been larger if calcium carbonate was not present since an increase in calcium content results in smaller SAR values.

The chemical reactions that may have occurred between the pond ash and soil materials were not examined in this study. Further investigations are needed to characterize chemical complexation that may have resulted by the addition of pond ash to the feedlot surfaces.

RUNOFF CHARACTERISTICS

Significant interactions of surface material with surface condition were found for DP and total runoff (table 2). The DP load was significantly less on the pond ash amended surfaces (fig. 4). For the plots containing pond ash, no significant differences in DP load were found between the USM and CSM treatments (fig. 4).

The type of surface material was also found to significantly affect TP and NH_4-N load (table 2). The runoff load of TP was significantly greater on the soil surfaces, while NH_4-N load was significantly greater on the pond ash amended surfaces.

Table 2. Effects of surface material and surface condition on selected runoff characteristics.

Surface Material and Condition	DP (kg ha^{-1})	PP (kg ha^{-1})	TP (kg ha^{-1})	NH_4-N (kg ha^{-1})	NO_3-N (kg ha^{-1})	TN (kg ha^{-1})	CL (kg ha^{-1})
	Runoff Characteristic						
Surface material[a]							
Pond ash amended surface	0.27	1.01	1.28 b	1.16 a	0.31	6.13	129
Soil	0.72	1.85	2.56 a	0.50 b	0.12	4.91	103
Surface condition[a], [b]							
USM	0.55	1.52	2.07	0.80	0.12 b	3.52 b	125
CSM	0.44	1.34	1.77	0.86	0.32 a	7.53 a	107
Analysis of variance (Pr > F)							
Surface material	0.03	0.06	0.04	0.04	0.09	0.34	0.42
Surface condition	0.02	0.20	0.07	0.77	0.01	0.01	0.33
Surface material × surface condition	0.01	0.68	0.19	0.12	0.15	0.10	0.19

Surface Material and Condition	TDS (dS m^{-1})	EC (dS m^{-1})	pH (dS m^{-1})	Runoff (mm)	Erosion (Mg ha^{-1})	*E. coli* (log CFU ha^{-1})
	Runoff Characteristic					
Surface material[a]						
Pond ash amended surface	645	2.85	7.78	24.4	0.74	14.1
Soil	510	2.45	7.68	23.9	1.17	13.9
Surface condition[a], [b]						
USM	511	3.15 a	7.68 b	21.3	0.95	14.0
CSM	643	2.16 b	7.78 a	27.0	0.96	13.9
Analysis of variance (Pr > F)						
Surface material	0.23	0.53	0.28	0.85	0.05	0.15
Surface condition	0.24	0.02	0.03	0.01	0.86	0.21
Surface material × surface condition	0.37	0.78	0.12	0.01	0.21	0.74

[a] Values followed by different letters are significantly different at the 0.05 probability level based on the LSD test.
[b] USM = unconsolidated surface material; CSM = consolidated subsurface material.

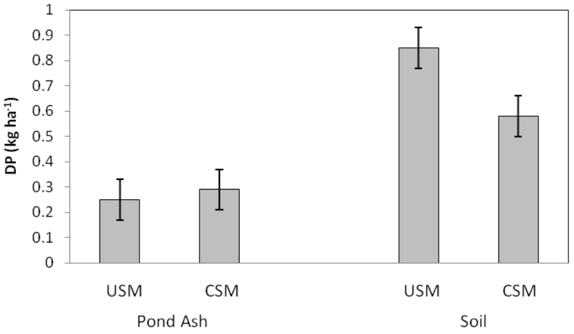

Figure 4. Dissolved phosphorus (DP) load as affected by unconsolidated surface material (USM) and consolidated subsurface material (CSM) for pond ash amended surfaces and soil surfaces. Values for DP load are averages from three rainfall simulation runs conducted on four separate plots. Vertical bars are standard errors.

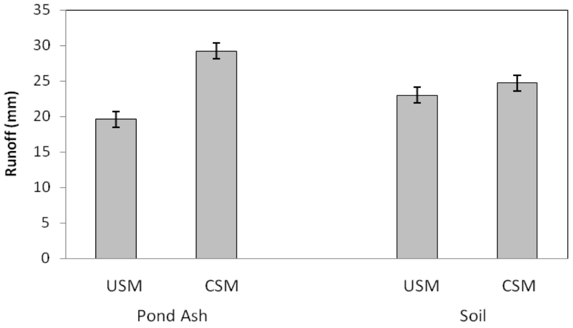

Figure 5. Runoff quantity as affected by unconsolidated surface material (USM) and consolidated subsurface material (CSM) for the pond ash amended surfaces and soil surfaces. Runoff values are averages from three rainfall simulation runs conducted on four separate plots. Vertical bars are standard errors.

Surface condition significantly affected measurements of NO_3-N, TN, EC, and pH (table 2). The runoff loads of NO_3-N and TN were significantly greater on the surfaces with CSM. Measurements of EC were larger on the plots with USM, while runoff pH values were larger on the plots with CSM.

No significant differences in runoff amounts were found between the USM treatments located within the pond ash amended pens and soil pens (fig. 5). However, runoff amounts for the CSM treatments were significantly greater on the pond ash amended surfaces. A healthier environment for livestock would result within feedlot pens with enhanced surface drainage.

Mass loads rather than concentration values were reported in this study. With the current emphasis on TMDL prediction, it was felt that information on runoff loads would be most valuable. However, it is recognized that concentration values are often used in established water quality standards. The mass load information shown in figure 5 can be used along with plot dimensions to provide estimates of runoff concentrations for the various experimental treatments.

In this study, mean values for runoff and erosion from the pond ash amended surfaces and soil surfaces were 24 mm (approximately 35 mm of rainfall was applied) and 0.96 Mg ha^{-1}, respectively. Gilley et al. (2007) measured runoff and erosion from a cropland site during the year following application of beef cattle manure. Runoff on the no-till cattle manure treatments was 20 mm and erosion was 0.31 Mg ha^{-1}, compared to 23 mm and 0.52 Mg ha^{-1} for tilled conditions (approximately 35 mm of rainfall was applied). Thus, the quantity of runoff from these particular feedlot and cropland

Table 3. Correlation coefficients of soil characteristics with runoff characteristics.[a]

Runoff Characteristic	Soil Characteristic									
	Bray 1-P	Calcium	Chloride	EC	*E. coli*	Loss on Ignition	Magnesium	NH_4-N	NO_3-N	Organic N
DP	**0.85** **(0.01)**	-0.44 (0.09)	-0.03 (0.90)	0.13 (0.62)	0.37 (0.15)	0.13 (0.62)	-0.48 (0.06)	-0.24 (0.38)	0.40 (0.13)	0.29 (0.27)
PP	**0.78** **(0.01)**	-0.35 (0.18)	-0.23 (0.40)	-0.04 (0.88)	0.25 (0.35)	-0.01 (0.99)	-0.37 (0.16)	-0.29 (0.28)	0.45 (0.08)	0.14 (0.61)
TP	**0.82** **(0.01)**	-0.39 (0.14)	-0.17 (0.54)	0.12 (0.95)	0.29 (0.27)	0.04 (0.87)	-0.42 (0.11)	-0.27 (0.30)	0.44 (0.09)	0.19 (0.48)
NH_4-N	**-0.56** **(0.02)**	0.48 (0.06)	0.37 (0.16)	0.28 (0.29)	0.04 (0.89)	0.25 (0.34)	0.44 (0.09)	0.16 (0.54)	-0.22 (0.42)	0.13 (0.64)
Total N	-0.19 (0.47)	0.07 (0.79)	0.19 (0.49)	0.23 (0.40)	0.04 (0.89)	0.20 (0.45)	-0.01 (0.99)	0.33 (0.21)	0.14 (0.61)	0.38 (0.15)
CL	-0.39 (0.13)	0.19 (0.47)	-0.11 (0.67)	-0.18 (0.51)	-0.18 (0.50)	-0.26 (0.34)	0.29 (0.27)	0.13 (0.63)	-0.14 (0.62)	-0.37 (0.15)
NO_3-N	**-0.52** **(0.04)**	0.35 (0.19)	**0.52** **(0.04)**	0.49 (0.08)	-0.01 (0.99)	0.36 (0.18)	0.27 (0.32)	0.18 (0.49)	-0.26 (0.33)	0.34 (0.19)
TDS	**-0.59** **(0.02)**	0.15 (0.57)	-0.41 (0.11)	**-0.51** **(0.04)**	**-0.73** **(0.01)**	**-0.52** **(0.04)**	0.28 (0.29)	0.37 (0.16)	-0.12 (0.65)	**-0.55** **(0.03)**
EC	-0.28 (0.30)	0.09 (0.72)	-0.09 (0.73)	-0.19 (0.47)	-0.16 (0.55)	-0.17 (0.53)	0.18 (0.50)	-0.07 (0.80)	-0.20 (0.47)	-0.36 (0.17)
pH	**-0.56** **(0.02)**	0.21 (0.44)	0.26 (0.33)	0.06 (0.82)	-0.35 (0.18)	-0.16 (0.55)	0.24 (0.38)	0.03 (0.91)	-0.45 (0.08)	-0.13 (0.63)
E. coli	-0.18 (0.52)	0.41 (0.11)	-0.03 (0.92)	0.06 (0.83)	0.16 (0.57)	0.46 (0.08)	0.36 (0.18)	0.08 (0.77)	0.35 (0.18)	0.21 (0.44)

Runoff Characteristic	Soil Characteristic								
	pH	Phosphorous	Potassium	SAR	Sodium	Sulfur	Total N	Water Content	Water-Soluble P
DP	**-0.61** **(0.01)**	0.14 (0.60)	0.08 (0.77)	0.14 (0.61)	-0.26 (0.34)	-0.45 (0.08)	0.29 (0.28)	0.46 (0.07)	**0.83** **(0.01)**
PP	**-0.54** **(0.03)**	0.07 (0.81)	-0.18 (0.49)	-0.05 (0.85)	-0.33 (0.21)	-0.47 (0.07)	0.13 (0.64)	0.41 (0.12)	**0.73** **(0.01)**
TP	**-0.57** **(0.02)**	0.09 (0.73)	-0.10 (0.72)	0.01 (0.96)	-0.31 (0.24)	-0.47 (0.07)	0.18 (0.50)	0.43 (0.10)	**0.78** **(0.01)**
NH_4-N	0.42 (0.10)	0.22 (0.40)	0.20 (0.45)	0.19 (0.48)	**0.51** **(0.04)**	0.55 (0.03)	0.13 (0.62)	0.12 (0.65)	-0.34 (0.20)
Total N	0.01 (0.96)	0.47 (0.07)	0.20 (0.46)	0.08 (0.77)	0.26 (0.34)	0.25 (0.36)	0.39 (0.13)	0.22 (0.42)	0.20 (0.47)
CL	0.31 (0.25)	-0.36 (0.17)	-0.07 (0.82)	-0.04 (0.88)	0.04 (0.89)	0.14 (0.60)	-0.37 (0.16)	-0.18 (0.50)	**-0.59** **(0.02)**
NO_3-N	0.30 (0.26)	0.39 (0.14)	0.41 (0.11)	0.34 (0.20)	**0.59** **(0.02)**	**0.51** **(0.04)**	0.35 (0.18)	-0.22 (0.42)	-0.13 (0.64)
TDS	0.46 (0.08)	-0.40 (0.13)	-0.32 (0.22)	-0.49 (0.06)	-0.17 (0.54)	0.04 (0.89)	**-0.54** **(0.03)**	-0.17 (0.53)	**-0.70** **(0.01)**
EC	0.28 (0.30)	-0.41 (0.11)	-0.01 (0.98)	-0.02 (0.95)	-0.04 (0.90)	0.05 (0.85)	-0.36 (0.17)	-0.26 (0.34)	**-0.53** **(0.03)**
pH	0.43 (0.09)	-0.17 (0.53)	0.21 (0.42)	0.19 (0.48)	0.32 (0.23)	0.36 (0.17)	-0.13 (0.63)	**0.68** **(0.01)**	**-0.62** **(0.01)**
E. coli	0.17 (0.54)	0.44 (0.09)	-0.16 (0.55)	-0.18 (0.51)	0.21 (0.43)	0.26 (0.33)	0.21 (0.43)	0.10 (0.71)	0.18 (0.50)

[a] A correlation coefficient is significant at the 95% level (shown in **bold**) if |correlation| > 0.50 for *n* = 16. Values in parentheses represent Pr > |r|.

sites was similar. However, transport of particulate materials was larger from the feedlot surfaces.

BACTERIAL TRANSPORT

Concentrations of generic *E. coli* in the feedlot soil were similar on the pond ash amended surfaces and soil surfaces (table 1). In addition, no significant differences in generic *E. coli* concentrations were found between the plots containing USM and CSM. Correspondingly, no significant differences in runoff concentrations of *E. coli* were found among the experimental treatments (table 2).

In our study, the log of generic *E. coli* load in runoff from the pond ash amended surfaces was 14.1 CFU ha^{-1}. Thus, the direct transport of feedlot runoff to receiving waters could result in the introduction of substantial bacterial populations. Therefore, it is important that feedlot runoff be retained in holding ponds or VTA to allow for the containment and removal of these bacteria.

E. coli O157:H7 was not recovered from USM, CSM, or runoff from any of the pens. Berry and Miller (2005) studied the impacts of cycling moisture levels and different drying rates on naturally occurring *E. coli* O157:H7 in feedlot soils. Low initial levels of *E. coli* O157:H7 were reduced to below enumerable levels after 21 days. However, indigenous *E. coli* populations were found to persist up to 133 days.

CORRELATION ANALYSES

The total dissolved solids load (TDS) in runoff was significantly correlated to seven feedlot soil parameters (table 3). In comparison, runoff loads of TN and *E. coli* were not significantly correlated to any of the measured feedlot soil characteristics. The DP, PP, and TP loads in runoff were all significantly correlated to soil Bray 1-P and pH measurements. Thus, it may be possible to predict runoff phosphorus load from soil P measurements.

Electrical conductivity is a critical variable used to determine the suitability of water for use in irrigation (USDA, 1954). The total concentration of soluble salts in runoff can be estimated from EC measurements of runoff. Use of high EC water can have detrimental effects on soils and vegetation. The long-term sustainability of VTA will be influenced by the quantity of soluble salts transported in runoff from feedlot areas.

CONCLUSIONS

The feedlot soil surfaces contained significantly greater amounts of Bray 1-P than the pond ash amended surfaces. Soil measurements of calcium, magnesium, pH, and sulfur were significantly greater on the feedlot pens amended with pond ash. The measured feedlot soil characteristics were not significantly affected by surface condition (USM or CSM). No significant differences in concentrations of *E. coli* were found between the pond ash amended surfaces and soil surfaces.

The DP load was significantly less on the pond ash amended surfaces. On the pond ash amended surfaces, no significant differences in DP load were found between the surfaces containing USM and CSM. The runoff load of NH_4-N was significantly greater on the pond ash amended surfaces, while the TP load was significantly greater on the soil surfaces.

The NO_3-N and TN loads in runoff were significantly greater on the surfaces containing CSM. No significant differences in the concentrations of *E. coli* in runoff were found between the pond ash amended surfaces and soil surfaces. *E. coli* O157:H7 was not recovered from USM, CSM, or runoff from any of the experimental treatments.

The DP, PP, and TP loads were significantly correlated to Bray 1-P and pH measurements. Thus, it may be possible to predict runoff phosphorus load from measurements of the P content of the feedlot surface materials.

The removal of USM from feedlot surfaces was found to have only a minimal impact on surface water quality. Therefore, removal of USM is not recommended as a feedlot management practice. With the exception of NH_4-N, the use of pond ash as a feedlot soil amendment did not negatively impact measured water quality parameters.

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