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SPATIAL VARIATIONS IN NUTRIENT AND MICROBIAL TRANSPORT FROM FEEDLOT SURFACES

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

ABSTRACT. *Nutrient and microbial transport by runoff may vary at different locations within a beef cattle feedlot. If the areas making the largest contributions to nutrient and microbial transport can be identified, it may be possible to institute site-specific management practices to reduce runoff nutrient and microbial transport. The objectives of this study were to: (1) measure selected feedlot soil properties and nutrient and microbial transport in runoff from various feedlot locations, (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 microbial transport, and (3) determine if nutrient and microbial transport in runoff are correlated to selected feedlot soil characteristics. Simulated rainfall events were applied to 0.75 m wide by 2 m long plots. No significant differences ($P < 0.05$) in feedlot soil characteristics or nutrient transport in runoff were found between USM and CSM. However, concentrations of* E. coli *were significantly greater in the USM than the CSM. Pen location was found to significantly influence feedlot soil measurements of Bray-1 P, calcium, chloride, copper, electrical conductivity (EC), loss on ignition, organic N, phosphorus, potassium, sodium, sulfur, total N (TN), water-soluble P, and zinc. Runoff measurements of dissolved phosphorus (DP), EC, and NH_4-N were significantly influenced by pen location and were correlated to selected feedlot soil characteristics. Thus, it may be possible to estimate DP, EC, and NH_4-N in runoff from selected feedlot soil parameters.*

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

The intensification of livestock production in concentrated animal feeding operations has increased the importance of animal manure management. Runoff from beef cattle feedlots may contain microorganisms, nutrients, organic materials, and sediment (Eghball and Power, 1994). Environmental regulations have been established that define acceptable standards for runoff control from open-lot livestock production facilities.

A standard feedlot management objective is to maintain a black interface layer of compacted manure above the mineral soil to enhance surface runoff and limit infiltration, thus helping to reduce wet feedlot conditions (Mielke et al., 1974; Mielke and Mazurak, 1976). 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). Manure is removed from the feedlot between cattle production cycles, usually once or twice a year. Manure enrichment, compaction, and moisture content, which depend upon the location of feed and water sources, may vary across the pen surface with time during the production cycle.

FEEDLOT SOIL PROPERTIES

McCullough et al. (2001) measured selected soil properties of a feedlot recently established on a sandy loam soil near Canyon, Texas. Saturated hydraulic conductivity on 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.

Woodbury et al. (2001) determined the seasonal denitrification enzyme activity of a feedlot soil. Electromagnetic (EM) induction mapping was performed to establish a transect extending along the length of a feedlot pen. It was assumed that varying electrical conductivities would correlate with high nutrient concentrations and associated microbial activity. Denitrification enzyme activity of USM varied significantly among feedlot locations.

Geophysical sensors have been used to measure soil electrical conductivity (EC_a) (Doran, 2002). The output provided by EC_a sensors can be interfaced with data loggers and Global Positioning Systems, and integrated using Geographic Information Systems to produce spatial maps of EC_a (Johnson et al., 2005). Clay content, salinity, temperature, and water content influence EC_a measurements (Rhoades et al., 1989). It may be possible to use EC_a technology to identify the accumulation of nutrients and salt within beef cattle feedlots.

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FEEDLOT RUNOFF CHARACTERISTICS

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, 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 two types of bedding materials and two pen locations on feedlot runoff parameters in southern Alberta, Canada. The type of bedding material had no significant effect on runoff characteristics. However, pen location significantly affected clod bulk density, gravimetric water content, manure depth, slope gradient, and surface roughness. Little information is currently available comparing the effects of USM and CSM on the transport of nutrients in runoff from feedlot surfaces.

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 surface water quality impacts. Improved procedures for estimating nutrient runoff potential at varying locations within a feedlot could improve the reliability of these simulation models.

With present environmental regulations there is usually no direct hydrologic connection between feedlot runoff and a downstream water body. Some combination of clean water diversion, irrigation systems, runoff collection ponds, and settling basis are typically used for feedlot runoff control. Holding ponds serve to collect and store runoff 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 consume runoff (Koelsch et al., 2006). During high precipitation events, unplanned releases from holding ponds and VTA may sometimes occur. Reducing delivery of nutrients and microbes to holding ponds and VTA would enhance system operation and reduce environmental impacts if storage capacity is exceeded.

MICROBIAL TRANSPORT IN RUNOFF

Miner et al. (1966) measured concentrations of total coliforms, fecal coliforms, and fecal streptococci in runoff from beef cattle feedlots near Manhattan, Kansas, with soil and concrete surfaces. The largest bacterial counts occurred during warm weather and under conditions that produced maximum solubility of feedlot surface materials. Bacterial populations in runoff from the soil and concrete surfaces were similar.

Rhodes and Hrubant (1972) identified microbial populations in runoff from a beef cattle feedlot near Peoria, Illinois. Runoff volume was found to substantially impact 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. Nonstructural feedlot discharge control practices were found to serve as an alternative method for controlling feedlot runoff.

Miller et al. (2004) measured microbial populations in 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 differential and lower persistence characteristics than those in the total coliform population.

STUDY OBJECTIVES

At present, the relative contributions of USM and CSM to nutrient and microbial transport in runoff from feedlot surfaces are not well defined. The source of potential contaminants must be identified before within-pen practices for managing feedlot runoff can be adopted. One management alternative that has been proposed is the more frequent removal of USM from feedlot surfaces. The effect of removal of USM on runoff water quality was examined in this study.

Unconsolidated surface materials are thought to be a 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. The removal of USM has also been proposed as a best management practice for feedlot dust control. In this study, the runoff water quality implications of this feedlot management practice were determined.

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

MATERIALS AND METHODS

PLOT ESTABLISHMENT

This study was conducted at the U.S. Meat Animal Research Center (USMARC) near Clay Center, Nebraska, during the summer of 2006 within four 30 m wide × 90 m long feedlots pens. Annual precipitation at USMARC is approximately 728 mm. The pens were rebuilt and reshaped in 2000, and they received routine maintenance. Cattle were placed at a rate of 75 to 85 head per pen (32 to 36 m^2 $head^{-1}$) and were fed a corn-based diet. A stocking rate of 28 to 37 m^2 $head^{-1}$ has been recommended for areas with annual precipitation over 750 mm (Sweeten, 1998). No significant difference in cattle performance in Nebraska was found between stocking densities of 9.3 and 18.6 m^2 $head^{-1}$ (Nienaber et al., 1974).

Apparent soil electrical conductivity (ECa) measurements were collected using a Dualem-1S instrument (Dualem, Inc., Milton, Ontario, Canada). The equipment operates in the horizontal and vertical dipole modes simultaneously, but only the horizontal mode (with measurement depth centered at about 0.75 m) is reported in this study. The Dualem-1S was mounted on a non-conductive sled and pulled by an all-terrain vehicle, with passes made every 3 m. Apparent soil electrical conductivity was recorded and stored four times per second, with corresponding GPS coordinates provided by a Trimble AgGPS 332 (Trimble Navigation Limited, Sunnyvale, California). This procedure has been used to identify areas of nutrient buildup on feedlot surfaces (Eigenberg et al., 2005).

The field tests were conducted using a randomized complete block design. Each of the four pens was considered an individual block. Stocking density, initiation of feeding period, and feed rations used within each of the pens were identical. Three study locations (main plots) were selected within each feedlot pen in the upper, middle, and lower slope positions of the feedlot. The study sites were established in areas that allowed overland flow to drain uniformly from the experimental plots. The range in EM readings among study sites provided the opportunity to examine correlations between EC_a readings and runoff characteristics.

The experiment employed a split-plot design with within-pen location the main plot factor and surface condition the subplot factor. Two adjoining 0.75 m wide × 2 m long plots were established at selected study locations for a total of six plots per pen. Unconsolidated surface material was removed from one of the two adjoining plots at each of the three pen locations. Thus, a total of 12 locations were evaluated (4 pens × 3 locations/pen × 2 surface conditions/location). The surface condition of 12 of the plots was USM, while the other 12 test plots were CSM.

Livestock from an individual pen (experimental block) were removed just prior to plot establishment, and the pen remained unstocked for the duration of the testing period. Livestock remained in the adjoining pens until initiation of testing within a particular pen. 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 among experimental pens.

COLLECTION AND ANALYSES OF FEEDLOT SOIL MATERIALS

The mass of USM collected from 12 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. Cores containing CSM were obtained from the outside perimeter of each of the 24 test plots. A hand-held, slide-hammer soil probe was used to collect cores (after the USM has been removed) from a depth of 0 to 0.10 m. Composite samples of USM and CSM were sent to a commercial laboratory and analyzed for calcium, chloride, copper, EC, iron, magnesium, manganese, NH_4-N, organic N, pH, phosphorus, potassium, sodium, sulfur, total N, water content, and zinc. Electrical conductivity and pH were measured 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. 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, Wisconsin). 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 solution 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. *Escherichia coli* (*E. coli*) populations in USM and CSM were identified 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 3780 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 0.15, 4.68, 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 aluminum washtubs.

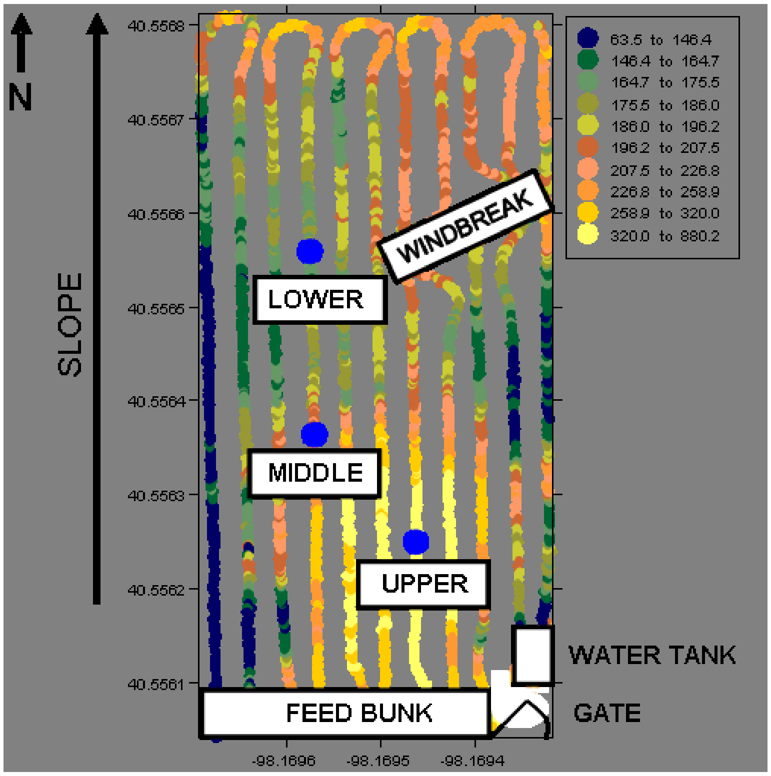
Two rain gauges were placed along the outer edge of each plot, and one rain gauge was located between the paired plots. To provide more uniform antecedent soil water conditions among treatments, water was added to the plots with a hose until runoff began. A flowmeter was used to measure the quantity of water required to initiate runoff. Burlap material was placed on the plot surface to reduce the kinetic energy of the added water.

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 five-year recurrence interval (Hershfield, 1961). Two additional rainfall simulation runs were then conducted for the same duration and intensity at approximately 24 h intervals.

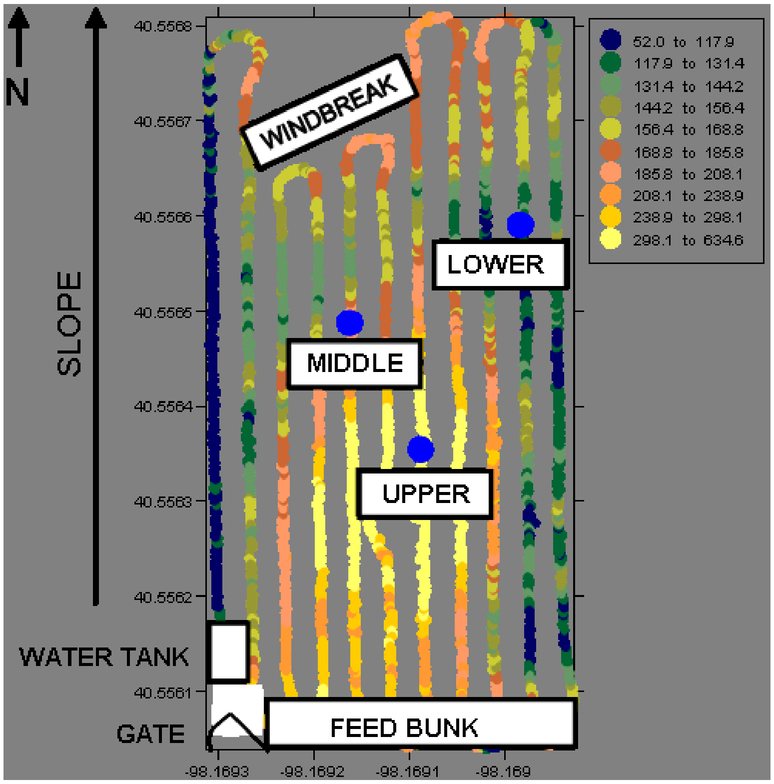
Following the initial precipitation event, rainfall and runoff-monitoring equipment remained in place to measure any input of natural rainfall between simulation events. During the testing period, only one significant natural rainfall event occurred between simulation tests. The water quality characteristics of runoff from the natural precipitation event and rainfall simulation tests were similar.

After completion of a rainfall simulation test, the washtubs were weighed to determine total runoff volume. The runoff water was agitated to maintain suspension of solids, and then one runoff sample was obtained for sediment analysis and an additional sample was collected for water quality measurements. 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, Wisconsin). Non-centrifuged samples were analyzed for chloride, EC, pH, total nitrogen (TN) (Tate, 1994), and total P (TP) (Johnson and Ulrich, 1959). The samples obtained for sediment analysis were dried in an oven at 105°C and then weighed to determine sediment concentration.

Subsamples of USM, CSM, and unfiltered runoff were analyzed within 2 h of collection for determination of concentrations of generic *E. coli*. Ten gram or 10 mL samples were serially diluted in 2% buffered peptone and plated onto CHROMagar ECC agar plates (DRG International, Inc., Mountainside, New Jersey) using an Autoplate 4000 spiral plater (Spiral Biotech, Inc., Norwood, Massachusetts). The plates were incubated at 37°C for 24 h, and characteristic blue *E. coli* colonies were enumerated. Populations of *E. coli* were converted to $\log_{10}$ CFU g^{-1} (USM or CSM) or $\log_{10}$ CFU ha^{-1} (runoff) prior to statistical analyses.

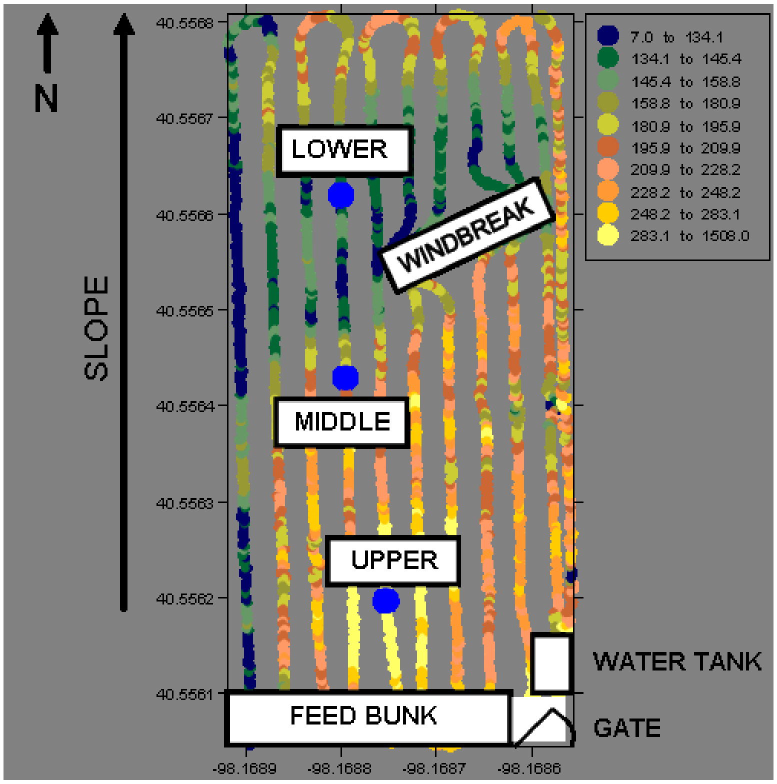


(a) Pen 1

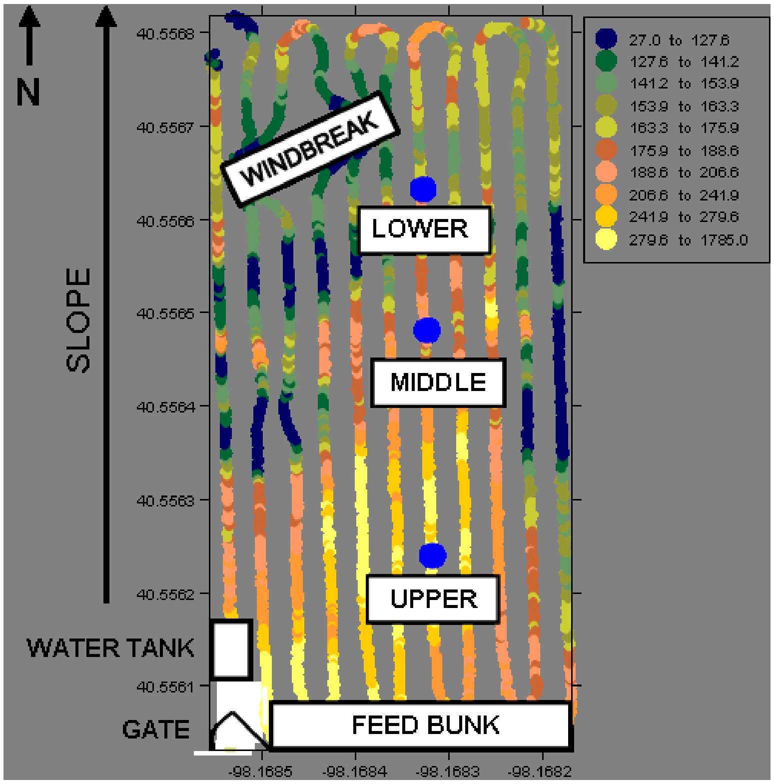


(b) Pen 2

Figure 1. Study locations for each individual pen were based on apparent soil electrical conductivity measured immediately before runoff tests. Within individual pens, study locations were selected to provide a broad range of conductivity values. Conductivities for lower, medium, and upper slope positions, respectively, were (a) 169, 200, and 423 mS m^{-1}; (b) 124, 176, and 362 mS m^{-1}; (c) 132, 194, and 410 mS m^{-1}; and (d) 186, 192, and 314 mS m^{-1} (continued on next page).



(c) Pen 3



(d) Pen 4

Figure 1 (continued from previous page). Study locations for each individual pen were based on apparent soil electrical conductivity measured immediately before runoff tests. Within individual pens, study locations were selected to provide a broad range of conductivity values. Conductivities for lower, medium, and upper slope positions, respectively, were (a) 169, 200, and 423 mS m^{-1}; (b) 124, 176, and 362 mS m^{-1}; (c) 132, 194, and 410 mS m^{-1}; and (d) 186, 192, and 314 mS m^{-1}.

Statistical Analyses

Statistical analyses were conducted using the Mixed procedures of SAS (SAS, 2003) (ANOVA) to determine the effects of pen location (main plot) and surface condition (USM or CSM) (subplot) on feedlot soil and runoff characteristics. Differences among treatment means were identified using the least significant difference (LSD) test. A probability level <0.05 was considered significant. Correlation analysis was used to test the relative relation between nutrient and microbial transport and chemical and physical characteristics of USM and CSM.

Results and Discussion

Feedlot Soil Properties

Soil conductivity maps for each pen are shown in figure 1. Soil conductivity values were measured immediately before runoff tests and ranged from a low of 124 mS m^{-1} in pen 2 to a high of 423 mS m^{-1} in pen 1(fig. 1).

There were no significant pen location × surface condition interactions for any of the measured feedlot soil characteristics (table 1). Surface condition did not significantly affect any of the measured feedlot soil characteristics except the concentration of *E. coli* per gram of feedlot soil. However, pen location was found to significantly influence Bray-1 P, calcium, chloride, copper, EC, loss on ignition, organic N, phosphorus, potassium, sodium, sodium adsorption ratio (SAR), sulfur, total N, USM, water-soluble P, and zinc. Concentrations of feedlot soil constituents were significantly greater at the upper than the lower slope positions for each of the chemical constituents for which significant differences were found.

The amount of USM at the upper portion of the feedlot pens was significantly less than that measured at the other slope positions. However, the amount of organic material, as indicated by loss on ignition, followed the trend upper > middle > lower slope position. The cattle appeared to have spent more time in the upper portion of the pen near the feed bunk and water supply, depositing a greater amount of manure and causing a larger composition of organic material. However, increased cattle activity in the upper portion of the feedlot apparently caused greater compaction and resulted in smaller amounts of USM at the soil surface.

Calcium carbonate ($CaCO_3$) is commonly added to cattle diets as a source of calcium at the recommended level of 7 g

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

Variable	Bray-1 P (mg kg^{-1})	Calcium (g kg^{-1})	Chloride (g kg^{-1})	Copper (mg kg^{-1})	EC (dS m^{-1})	EC$_a$ (dS m^{-1})	*E. coli*[a] (log CFU g^{-1})	Iron (mg kg^{-1})	Loss on Ignition (g kg^{-1})	Magnesium (g kg^{-1})	Manganese (mg kg^{-1})	NH$_4$-N (g kg^{-1})
Pen location[b]												
Upper	1670 a	19.4 a	5.3 a	59.4 a	18.2 a	3.14a	5.66	16400	384 a	6.30	299	1.3
Middle	1530 a	17.2 a	3.7 b	52.7 b	14.1 b	1.93b	5.76	11100	314 b	6.00	307	1
Lower	1060 b	13.0 b	2.8 b	38.8 c	9.4 c	1.87c	5.91	17300	196c	6.30	342	0.8
Surface condition[c]												
USM	1450	16.6	4	50.6	14		6.14 a	16700	300	6.10	316	1
CSM	1390	16.5	3.9	49.9	13.9		5.42 b	13100	296	6.20	316	1.1
Pr > F												
Pen location	0.01	0.02	0.01	0.01	0.01	0.01	0.62	0.34	0.01	0.38	0.06	0.07
Surface cond.	0.28	0.88	0.66	0.78	0.87		0.01	0.34	0.85	0.53	0.94	0.75
Pen location × surface cond.	0.25	0.99	0.30	0.89	0.78		0.85	0.29	0.62	0.58	0.31	0.36

[a] Soil mass was measured on the basis of dry weight.

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

[c] USM is unconsolidated surface material, and CSM is consolidated subsurface material.

Table 1 (continued). Effects of pen location and surface condition on selected soil characteristics.

Variable	NO$_3$-N (mg kg^{-1})	Organic N (g kg^{-1})	pH	Phosphorus (g kg^{-1} P$_2$O$_5$)	Potassium (g kg^{-1} K$_2$O)	SAR	Sodium (g kg^{-1})	Sulfur (g kg^{-1})	Total N (g kg^{-1})	USM (kg m^{-2})	Water Added (mm)	Water Content (g kg^{-1})	Water-Soluble P (mg kg^{-1})	Zinc (mg kg^{-1})
Pen location[b]														
Upper	26.4	16.4 a	8.04	16.4 a	20.5	5.84 a	3.7a	4.4 a	17.7 a	4.23 b	16	193	514 a	261 a
Middle	20.7	15.1 a	8.38	15.0 a	17.7	4.72 b	2.8 b	3.7 b	16.1 a	7.15 a	14	184	308 b	233 b
Lower	24.4	9.1 b	8.36	9.7 b	15.3	3.41 c	1.9 c	2.9 c	9.9 b	7.67 a	12	133	153 b	167 c
Surface condition[c]														
USM	20.6	13.7	8.24	13.8	17.7	4.81	2.8	3.6	14.7		15	164	342	220
CSM	27.1	13.4	8.28	13.6	17.9	4.51	2.8	3.7	14.5		13	176	308	221
Pr > F														
Pen location	0.86	0.01	0.08	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.53	0.13	0.01	0.01
Surface cond.	0.47	0.80	0.47	0.72	0.64	0.12	0.65	0.94	0.78		0.12	0.65	0.15	0.95
Pen location × surface cond.	0.29	0.96	0.64	0.77	0.91	0.17	0.86	0.68	0.94		0.09	0.90	0.51	0.87

[a] Soil mass was measured on the basis of dry weight.

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

[c] USM is unconsolidated surface material, and CSM is consolidated subsurface material.

kg^{-1} of ration (Klemesrud et al., 1998). Much of the $CaCO_3$ contained in the diet is excreted in manure. The pH of manured soils can be increased (become more basic) as a result of land application (Eghball, 1999). For soils requiring lime application, the amount of $CaCO_3$ required could be reduced on fields where manure has been applied.

The relatively large mean pH of 8.26 for the feedlot soil is attributed to the presence of calcium carbonate. Measurements of SAR would have been larger if calcium carbonate were not present. The quantity of calcium in the feedlot soil was significantly greater at the upper than at the lower slope positions. Greater manure deposition near the feed bunk and water supply would account for increased feedlot soil calcium content.

At a given feedlot location, the USM and CSM appeared to contain the same amount of chemical constituents. However, the 1,380,000 CFU g^{-1} of *E. coli* measured in the USM was significantly greater than the 263,000 CFU g^{-1} found in the CSM. The manure contained in the USM was more recently deposited and, therefore, contained a greater bacterial population.

FEEDLOT RUNOFF CHARACTERISTICS

To maintain relatively uniform antecedent soil water conditions among experimental treatments, water was added to each plot prior to the initial rainfall simulation test until runoff began. A mean quantity of 14 mm was required to initiate runoff. This value did not vary significantly among pen locations. In general, rainstorms less than 10 mm do not produce runoff from unsurfaced feedlots in the southern Great Plains (Clark et al., 1975). Gilbertson et al. (1980) reported that it took approximately 20 mm of rainfall to induce runoff from a beef cattle feedlot in southeastern Nebraska.

Clark et al. (1975) reported a linear relationship between precipitation and runoff from seven beef cattle feedlots located in the Great Plains. Feedlot slope and stocking rates have been shown to have little influence on runoff amounts (Gilbertson et al., 1970). Depressions are created in wet manure by beef cattle in non-paved feedlots. As a result, runoff volumes from feedlots may be less when precipitation has occurred the previous day.

There was no significant pen location × surface condition interaction for any of the measured runoff characteristics (table 2). Only EC was significantly affected by surface condition. Runoff EC measurements were significantly greater for the USM than the CSM. Analysis of the feedlot soil materials indicated that concentrations of chemical constituents in the USM and CSM were similar. However, the USM had a greater surface area in contact with overland flow; therefore, there was an increased opportunity for salts to be transferred into solution.

Pen location was found to significantly affect runoff measurements of DP, EC, and NH_4-N, as shown in table 2. Values for these variables were found to follow the trend upper > middle > lower slope position.

In this study, mean values for runoff and erosion from the feedlot surfaces were 21 mm (approx. 35 mm of rainfall was applied) and 0.90 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 (approx. 35 mm of rainfall was applied). Thus, the quantities of runoff from the feedlot and cropland sites were similar. However, transport of particulate materials was larger from the feedlot.

MICROBIAL TRANSPORT IN RUNOFF

Laboratory results indicated that there were significantly greater concentrations of *E. coli* in the USM than the CSM (table 1). However, only a small amount of the feedlot soil material was detached and transported by runoff. As a result, no significant differences in runoff concentrations of *E. coli* were found between the plots containing USM and CSM (table 2). Thurston-Enriquez et al. (2005) found that only 0.01% to 6.99% of the fecal indicator microorganisms contained in beef cattle manure were transported in runoff from 0.75 m wide × 2 m long plots.

In the present study, the mean log of *E. coli* concentrations in runoff was 14.0 CFU ha^{-1} . The direct transport of feedlot runoff to receiving waters could result in the introduction of substantial microbial populations. Thus, it is important that feedlot runoff be initially retained in holding ponds or VTA.

CORRELATION ANALYSES

Concentrations of DP in runoff were significantly correlated to 14 feedlot soil parameters (table 3). In comparison, runoff concentrations of particulate phosphorus (PP) and TP were not significantly correlated to any of the measured feedlot soil characteristics. Runoff concentrations of NH_4-N

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

Variable	DP (kg ha^{-1})	PP (kg ha^{-1})	TP (kg ha^{-1})	NH_4-N (kg ha^{-1})	TN (kg ha^{-1})	CL (kg ha^{-1})	EC (dS m^{-1})	pH	Runoff (mm)	Erosion (Mg ha^{-1})	*E. coli* (log CFU ha^{-1})
Pen location[a]											
Upper	3.50 a	14.4	17.9	3.50 a	26.2	154	3.48 a	7.97	18.3	0.975	14.1
Middle	3.36 a	10.1	13.5	1.90 ab	27.4	127	3.22 a	8.08	21.8	0.841	13.9
Lower	1.41 b	15.5	16.9	0.57 b	20.9	88.1	2.21 b	8.07	23.0	0.878	13.8
Surface condition[b]											
USM	3.31	15.9	19.2	2.77	28.0	157	3.40 a	8.05	21.8	0.985	14.0
CSM	2.20	10.8	13.0	1.21	21.7	89.0	2.54 b	8.03	20.3	0.811	13.9
Pr > F											
Pen location	0.03	0.69	0.79	0.03	0.47	0.38	0.01	0.16	0.18	0.81	0.32
Surface condition	0.05	0.24	0.18	0.07	0.17	0.08	0.01	0.64	0.39	0.25	0.22
Pen location × surface condition	0.34	0.69	0.78	0.26	0.59	0.36	0.33	0.55	0.38	0.51	0.83

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

[b] USM is unconsolidated surface material, and CSM is consolidated subsurface material.

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

Runoff Constituent	Bray-1 P	Calcium	Chloride	Copper	EC	EC_a	*E. coli*	Iron	Loss on Ignition	Magnesium	Manganese	NH_4-N	NO_3-N
DP[b]	0.57	0.50	0.48	0.63	0.61	0.38	0.02	-0.54	0.38	-0.15	-0.37	0.28	0.11
	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.07)	(0.92)	(0.01)	(0.06)	(0.48)	(0.08)	(0.18)	(0.63)
PP	0.12	0.12	0.06	0.09	0.01	0.10	0.22	-0.10	0.07	0.07	-0.07	-0.11	0.05
	(0.58)	(0.58)	(0.80)	(0.68)	(0.95)	(0.65)	(0.31)	(0.65)	(0.74)	(0.76)	(0.76)	(0.61)	(0.80)
TP	0.20	0.19	0.12	0.18	0.10	0.15	0.21	-0.17	0.13	0.04	-0.12	-0.07	0.07
	(0.35)	(0.38)	(0.57)	(0.40)	(0.63)	(0.49)	(0.32)	(0.42)	(0.56)	(0.85)	(0.58)	(0.76)	(0.76)
NH_4-N	0.47	0.25	0.64	0.48	0.66	0.39	0.13	-0.42	0.41	0.27	-0.37	0.55	-0.01
	(0.02)	(0.24)	(0.01)	(0.02)	(0.01)	(0.06)	(0.56)	(0.04)	(0.05)	(0.20)	(0.08)	(0.01)	(0.98)
Total N	0.29	0.16	0.40	0.26	0.39	0.06	0.10	-0.32	0.19	-0.28	-0.38	0.36	-0.09
	(0.17)	(0.45)	(0.05)	(0.22)	(0.06)	(0.77)	(0.64)	(0.13)	(0.38)	(0.19)	(0.06)	(0.09)	(0.66)
CL	0.39	0.17	0.24	0.34	0.26	0.26	0.21	-0.29	0.17	-0.16	-0.14	0.10	-0.07
	(0.06)	(0.43)	(0.27)	(0.10)	(0.22)	(0.21)	(0.33)	(0.16)	(0.43)	(0.44)	(0.51)	(0.63)	(0.73)
EC	0.58	0.52	0.59	0.72	0.73	0.39	0.23	-0.64	0.55	-0.23	-0.51	0.41	-0.07
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.06)	(0.28)	(0.01)	(0.01)	(0.27)	(0.01)	(0.04)	(0.74)
pH	-0.30	-0.26	-0.33	-0.31	-0.17	-0.26	0.65	0.18	-0.30	-0.18	-0.08	-0.10	-0.20
	(0.16)	(0.23)	(0.11)	(0.14)	(0.42)	(0.22)	(0.01)	(0.39)	(0.15)	(0.39)	(0.70)	(0.62)	(0.36)
E coli	0.24	0.49	0.27	0.31	0.37	-0.03	0.60	0.33	0.21	0.01	0.49	0.02	0.02
	(0.26)	(0.01)	(0.20)	(0.14)	(0.07)	(0.90)	(0.01)	(0.12)	(0.32)	(0.98)	(0.01)	(0.94)	(0.92)

[a] A correlation coefficient is significant at the 95% level if |correlation| > 0.40 for $n = 24$.

[b] The value in parentheses represents the Pr > |r|.

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

Runoff Constituent	Organic N	pH	Phosphorous	Potassium	SAR	Sodium	Sulfur	Total N	USM	Water Added	Water Content	Water-Soluble P	Zinc
DP[b]	0.70	0.38	0.64	0.39	0.48	0.51	0.57	0.70	-0.24	0.38	-0.14	0.58	0.65
	(0.01)	(0.07)	(0.01)	(0.06)	(0.02)	(0.01)	(0.01)	(0.01)	(0.26)	(0.07)	(0.50)	(0.01)	(0.01)
PP	0.13	0.01	0.09	-0.03	-0.01	0.01	0.31	0.12	0.08	-0.01	-0.12	0.13	0.11
	(0.54)	(0.99)	(0.68)	(0.89)	(0.95)	(0.95)	(0.14)	(0.59)	(0.73)	(0.99)	(0.58)	(0.55)	(0.62)
TP	0.23	0.06	0.18	0.03	0.06	0.09	0.39	0.22	0.04	0.05	-0.14	0.21	0.20
	(0.28)	(0.79)	(0.40)	(0.89)	(0.79)	(0.69)	(0.06)	(0.31)	(0.86)	(0.81)	(0.53)	(0.33)	(0.36)
NH_4-N	0.55	0.60	0.48	0.43	0.56	0.52	0.53	0.58	-0.23	0.55	-0.21	0.76	0.50
	(0.01)	(0.01)	(0.02)	(0.04)	(0.01)	(0.01)	(0.01)	(0.01)	(0.27)	(0.01)	(0.32)	(0.01)	(0.01)
Total N	0.38	0.30	0.29	0.17	0.32	0.29	0.38	0.41	-0.14	0.33	-0.23	0.51	0.30
	(0.07)	(0.16)	(0.16)	(0.43)	(0.12)	(0.17)	(0.07)	(0.04)	(0.53)	(0.11)	(0.27)	(0.01)	(0.15)
CL	0.45	0.27	0.34	0.16	0.22	0.21	0.25	0.44	0.07	0.44	-0.26	0.31	0.36
	(0.03)	(0.21)	(0.10)	(0.46)	(0.30)	(0.33)	(0.23)	(0.03)	(0.74)	(0.03)	(0.22)	(0.14)	(0.08)
EC	0.79	0.44	0.69	0.40	0.59	0.60	0.58	0.80	-0.29	0.54	-0.26	0.58	0.71
	(0.01)	(0.03)	(0.01)	(0.05)	(0.01)	(0.01)	(0.01)	(0.01)	(0.17)	(0.01)	(0.23)	(0.01)	(0.01)
pH	-0.20	0.25	-0.30	-0.42	-0.35	0.39	-0.46	-0.20	0.17	0.14	-0.15	0.44	-0.32
	(0.35)	(0.23)	(0.16)	(0.04)	(0.09)	(0.06)	(0.02)	(0.36)	(0.44)	(0.51)	(0.48)	(0.03)	(0.13)
E coli	0.34	0.08	0.32	0.15	0.20	0.25	0.21	0.33	-0.39	0.27	0.01	0.25	0.30
	(0.11)	(0.70)	(0.13)	(0.49)	(0.35)	(0.23)	(0.32)	(0.11)	(0.06)	(0.20)	(0.98)	(0.25)	(0.15)

[a] A correlation coefficient is significant at the 95% level if |correlation| > 0.40 for $n = 24$.

[b] The value in parentheses represents the Pr > |r|.

were significantly correlated to 18 feedlot soil parameters. In contrast, TN concentrations of runoff were significantly correlated to only total N and water-soluble P content of the feedlot soil. Electrical conductivity of runoff was significantly correlated to 19 feedlot soil characteristics. Thus, it may be possible to estimate DP, EC, and NH_4–N concentrations of runoff from selected feedlot soil characteristics.

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. The long-term sustainability of VTA will be influenced by the quantity of soluble salts transported in runoff from feedlot areas.

Runoff values of DP, EC, and NH_4–N were all highly correlated to easily obtained feedlot soil measurements of EC. As a result, it may be possible to predict DP, EC, and NH_4–N content of runoff from on-site measurements of feedlot soil EC.

The quantity of *E. coli* in runoff was significantly correlated to calcium and manganese content of the feedlot soil. As mentioned previously, calcium carbonate ($CaCO_3$) is commonly added to cattle diets as a source of calcium. Excessive quantities of *E. coli*, calcium, or manganese at a particular feedlot location may indicate that relatively large amounts of manure were recently deposited at that site.

Several of the same parameters were measured in runoff and feedlot soil. It was found that runoff and feedlot soil values for EC, *E. coli*, NH_4–N, and total N were significantly correlated. Therefore, it may also be possible to estimate concentrations of selected runoff constituents from measurements of corresponding feedlot soil characteristics.

CONCLUSIONS

Surface condition (USM vs. CSM) did not significantly affect any of the measured feedlot soil characteristics except the concentration of *E. coli*. The 1,380,000 CFU g^{-1} of *E. coli* measured in the USM was significantly greater than the 263,000 CFU g^{-1} found in the CSM. Pen location (upper, middle, and lower slope position) was found to significantly influence several feedlot soil characteristics, with concentrations found to be significantly greater at the upper than the lower slope positions.

Only the EC of runoff was significantly affected by surface condition. Pen location was found to significantly affect runoff measurements of DP, EC, and NH_4–N. The mean concentration of *E. coli* in runoff from the USM was 1.0×10^{14} CFU ha^{-1}. Thus, it is important that feedlot runoff be initially retained in holding ponds or VTA.

Concentrations of DP and NH_4–N in runoff were significantly correlated to several soil parameters. Runoff measurements of EC, *E. coli*, NH_4–N, and total N were significantly correlated to corresponding feedlot soil characteristics. Therefore, it may be possible to estimate concentrations of selected runoff constituents from measurements of feedlot soil characteristics. Additional field tests will be required before statistically significant regression equations can be obtained.

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