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NUTRIENT TRANSPORT IN RUNOFF FROM FEEDLOTS AS AFFECTED BY WET DISTILLERS GRAIN DIET

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NUTRIENT TRANSPORT IN RUNOFF FROM FEEDLOTS AS AFFECTED BY WET DISTILLERS GRAIN DIET

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

ABSTRACT. *Distillers byproducts can serve as valuable sources of protein and energy for beef cattle. However, the water quality effects of the use of distillers byproducts in cattle rations are not well understood. The objectives of this study were to: (1) measure soil properties and nutrient transport in runoff from feedlot surfaces as affected by corn-based and wet distillers grain diets, (2) compare the effects of unconsolidated surface materials and consolidated subsurface materials on feedlot soil characteristics and runoff nutrient transport, (3) determine if runoff nutrient transport from feedlot surfaces is correlated to selected feedlot soil properties, and (4) identify the effects of varying runoff rate on nutrient transport. Simulated rainfall events were applied to 0.75 m wide by 2 m long plots. Concentrations of calcium, copper, loss on ignition, magnesium, organic-N, potassium, total N (TN), and zinc in the feedlot soil materials were significantly greater within the pens where cattle were fed a corn-based diet rather than a diet with distillers grain. The pens where cattle were fed distillers grain contained significantly greater amounts of Bray-1 P. Surface condition did not significantly affect any of the measured feedlot soil properties except potassium content. No significant differences in measured runoff water quality parameters were found between the corn-based and wet distillers grain treatments. Runoff measurements of NH_4-N, TN, NO_3-N, total dissolved solids, and electrical conductivity were each significantly correlated to seven or more feedlot soil parameters. Each of the measured water quality parameters were significantly influenced by runoff rate.*

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

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). To meet this objective, manure may be removed from the feedlot between cattle production cycles, usually once or twice a year. Beef cattle feedlots contain unconsolidated surface materials (USM, i.e., loose manure pack) and consolidated subsurface materials (CSM, i.e., compacted manure and underlying layers) (Woodbury et al., 2001). After removal of both the USM and CSM, fill material may be required to return the pen to original grade and elevation. However, even with this type of feedlot management, manure enrichment, compaction, and water content may vary across the pen surface with time during the production cycle.

The relative contributions of USM and CSM to nutrient transport in runoff from feedlots are not well defined. The source of potential contaminants must be identified before acceptable practices for managing feedlot runoff can be adopted. One management alternative that has been proposed is the frequent removal of USM from feedlot surfaces.

Unconsolidated surface materials are thought to be the source of feedlot dust (Miller and Woodbury, 2003). Maximum dust potential and airborne residence time vary among pen locations. The removal of USM has 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 examined.

FEEDLOT SOIL PROPERTIES

Feedlot soil properties may vary both spatially and temporally within a feedlot. McCullough et al. (2001) examined soil properties of a feedlot 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 nine-month stocking period. 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. A transect extending along the length of a feedlot pen was established initially. Measured denitrification enzyme activity of USM was found to vary significantly among feedlot locations.

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Gilley et al. (2008b) found that pen location significantly influenced several feedlot soil characteristics, with concentrations significantly greater in the upper than the lower slope positions. The feed and water source were located in the upper portion of the pen, so the cattle were thought to spend more time in the upper section of the feedlot. Pen location was also found to significantly affect selected water quality parameters. Concentrations of *E. coli* were found to be significantly greater in USM than CSM.

Gilley et al. (2009) compared nutrient and bacterial transport in runoff from pond ash amended surfaces and soil surfaces. 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. 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.

Use of Distillers Byproducts

Distillers byproducts can serve as valuable sources of protein and energy for beef cattle (Klopfenstein et al., 2007). Research has shown that feedlots may increase profitability by including distillers grains in feedlot finishing diets (Vander Pol et al., 2005). However, the manure nutrient composition changes when distillers grains are used in feedlot diets.

When corn is fermented to produce alcohol, the starch contained in corn is converted to alcohol and carbon dioxide. Since corn is about two-thirds starch, the nutrients remaining in the fermented corn byproduct are concentrated about three times (Aines et al., 1997). Therefore, inclusion of distillers grain in cattle diets results in greater nutrient excretion. Wet distillers grains are usually added to corn-based rations in feedlots at levels ranging from 10% to 40% of total ration dry matter. Cattle readily consume wet distillers grains, and the quality and yield grades of carcasses are similar to those fed corn-based diets.

An increase in dietary P level was found to result in greater manure P concentration and P water solubility of manure (Bremer et al., 2007b). The water solubility of P in feedlot manure is an indicator of the potential for P transport in runoff from feedlots (Bremer et al., 2007a). Little information is currently available concerning nutrient transport in runoff from feedlots where distillers grains are included in the diet.

The objectives of this study were to: (1) measure soil properties and nutrient transport in runoff from feedlot surfaces as affected by corn-based and wet distillers grain diets, (2) compare the effects of USM and CSM on feedlot soil characteristics and runoff nutrient transport, (3) determine if runoff nutrient transport from feedlot surfaces is correlated to selected feedlot soil properties, and (4) identify the effects of varying runoff rate on nutrient transport.

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. Average long-term annual precipitation at the study site is approximately 728 mm. Eight 30 m × 60 m pens were used for this study. The pens were constructed on a Hastings silt loam soil (fine, smectitic, mesic Pachic Argiustolls). The central mound was built with soil excavated from the C-horizon of the same soil series located off-site. The C-horizon usually has a silt loam texture and contains free carbonates.

Steer calves born during the spring of 2007 were placed in the feedlot in September 2007 at a rate of 36 head per pen (50 m^2 per head). Cattle in four of the pens were fed a corn-based diet (fig. 1). Wet distillers grain was fed in place of corn (40% on a dry matter basis) to the cattle in the other four pens.

The study sites were located in upslope pen locations within areas with a mean slope gradient of 10.5%, which 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 pens after the cattle had been removed. Unconsolidated surface material was removed from one of the two adjoining plots. Thus, a total of 16 plots were examined (8 pens × 1 location per pen × 2 surface conditions per location). The surface condition of eight of the plots was USM, while the other eight plots was CSM.

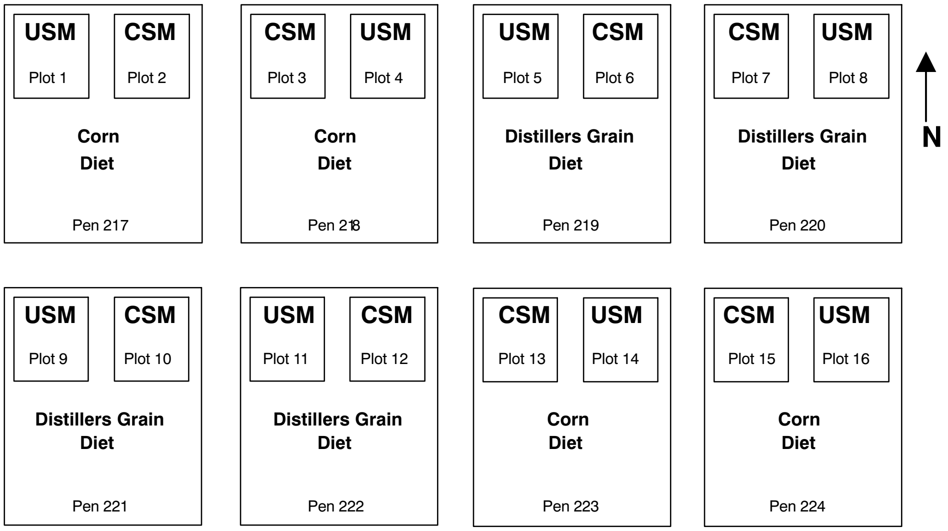

Figure 1. Schematic showing the plot layout and locations of the feedlot pens where cattle were fed a corn-based or distillers grain diet (CSM = consolidated subsurface material, USM = unconsolidated surface material).

Livestock from an individual pen 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.

COLLECTION AND ANALYSES OF FEEDLOT SOIL MATERIALS

The mass of USM collected 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 obtain the feedlot soil samples from a depth of approximately 0 to 1.5 cm (after the USM had been removed). Composite samples of USM or CSM were sent to a commercial laboratory and analyzed for calcium, chloride, copper, electrical conductivity (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) (Bray and Kurtz, 1945), 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, Wisc.). The Bray-1 P test is an indicator of the availability of soil P for the growth of plants and has also been shown to correlate with runoff P (Gilley et al., 2008a). Water-soluble P in solution was measured by shaking 2 g of soil for 5 min with 20 mL of deionized water using the Murphy and Riley (1962) procedure.

RAINFALL SIMULATION PROCEDURES

Water used in the rainfall simulation tests was obtained from a hydrant near the feedlot complex and was 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 hydrant water were 0.13, 3.20, and 0.04 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 sheet metal was coated with metallic-free paint prior to the study. The trough extended across the plot and diverted runoff into plastic drums. The collection trough was lined with clear plastic sheeting prior to each rainfall simulation test. 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 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.

The plastic drums were weighed to determine total runoff volume after completion of each of the three rainfall simulation runs. The runoff was then placed in a sterile Teflon churn to ensure a well mixed representative sample. Runoff samples were obtained from the churn for suspended sediment analysis and water quality measurements. All tubing and churns were cleaned and sterilized between each simulation run. Runoff that was collected within the plastic drums was discarded after each rainfall event.

The samples obtained for sediment analysis were dried in an oven at 105°C and then weighed to determine sediment concentration. 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 (Cl), EC, pH, total dissolved solids (TDS), total nitrogen (TN) (Tate, 1994), and TP (Johnson and Ulrich, 1959).

The rainfall simulation protocols established by the National Phosphorus Research Project were followed during each of the three rainfall simulation runs (Sharpley and Kleinman, 2003). Additional testing was conducted to identify the effects of varying flow rate on nutrient transport. After the first 30 min of the third simulation run, runoff from selected plots was diverted into a 0.18 m HS flume on which a stage recorder was mounted to measure runoff rate (fig. 2). The flume was located in an area excavated within the USM. To reduce the number of runoff samples that had to be processed and analyzed, inflow tests were only performed in those pens where cattle had been fed a corn-based diet.

A 2.5 cm diameter plastic tube that extended across the top of the plot served as an inflow device. Several holes were drilled into the plastic tube to allow water to be introduced uniformly across the plot surface. A gate valve and associated pressure gauge located on the inflow device were adjusted to provide the desired flow rate. Inflow was added in four successive increments to produce average runoff rates of 4.4, 9.1, 12.7, and 17.2 L min^{-1}. A narrow mat was placed on the soil surface beneath the inflow device to prevent scouring and

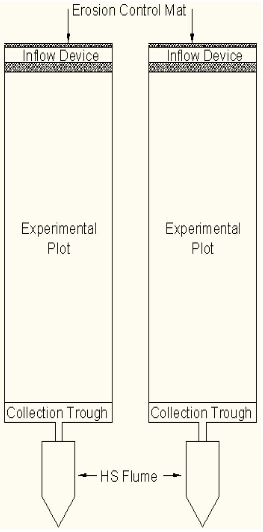

Figure 2. Schematic showing a pair of experimental plots, inflow devices, collection troughs, and HS flumes.

distribute flow more uniformly across the plot. Flow addition for each inflow increment usually occurred for approximately 8 min. This was the period of time typically required for steady-state flow conditions to become established and samples for nutrient and sediment analyses to be collected.

Overland flow discharge rate within individual feedlot pens increases with downslope distance. If the flow rate from a plot of a given length is known, then the effective plot length for other discharge rates can be estimated. The effective plot lengths for the tests conducted under inflow conditions were approximately 3.3, 6.7, 9.4, and 12.7 m.

Statistical Analyses

Statistical analyses were conducted using the Mixed Procedures of SAS (SAS, 2003) (ANOVA) to determine the effects of diet (corn-based or distillers grain) and surface condition (USM or CSM) on feedlot soil and runoff characteristics. The effects of surface condition and runoff rate on runoff characteristics were also identified using ANOVA. Differences among treatment means were determined using the least significant difference (LSD) test. A probability level < 0.05 was considered significant. Correlation analysis was used to test the relationship between runoff nutrient transport and chemical and physical characteristics of the feedlot soil materials.

Results and Discussion

Feedlot Soil Properties

There was no significant diet × surface condition interaction for any of the measured feedlot surface characteristics (table 1). Soil potassium content was significantly greater for surfaces with CSM than USM ($P = 0.04$). The reason for increased concentrations of potassium in the CSM is not known. Surface condition did not significantly affect any of the other measured feedlot soil characteristics. Gilley et al. (2008b) also found that surface condition did not significantly affect feedlot soil characteristics measured in feedlot pens containing cattle that were fed a corn-based diet.

Measurements of calcium, copper, loss on ignition, magnesium, organic-N, potassium, TN, and zinc were significantly greater within the pens where cattle were fed a diet containing corn. Some of the trace minerals contained in corn may have been removed during the distillation process. As a result, manure from cattle fed distillers grains may have a lower trace mineral content.

The relatively high mean pH value of 8.3 for the feedlot surfaces is attributed to the presence of calcium carbonate in the manure. The mean sodium adsorption ratio (SAR) of 2.90 would be expected to have been larger if calcium carbonate was not present in the manure. Calcium carbonate is commonly added to cattle diets as a source of calcium at the recommended level of 7 g kg^{-1} of ration (Klemesrud et al., 1998). Much of the calcium carbonate contained in the diet is ex-

Table 1. Effects of diet 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})	Iron (mg kg^{-1})	Loss on Ignition (g kg^{-1})	Magnesium (g kg^{-1})	Manganese (mg kg^{-1})	NH$_4$-N (g kg^{-1})	NO$_3$-N (mg kg^{-1})
Diet[a]											
Corn	611 b	18.8 a	2.3	38.2a	10.8	14900	285 a	7.8 a	283	0.6	0.01
Distillers grain	943 a	12.2 b	2.0	27.8b	10.1	15600	223 b	6.9 b	269	0.4	0.02
Surface condition[b]											
USM	786	15.1	2.1	32.9	9.9	14700	259	7.2	272	0.4	0.01
CSM	769	15.8	2.2	33.1	10.9	15800	249	7.4	280	0.6	0.02
Pr > F											
Diet	0.02	0.02	0.44	0.01	0.59	0.28	0.03	0.04	0.20	0.36	0.84
Surface cond.	0.90	0.77	0.73	0.95	0.42	0.17	0.68	0.58	0.46	0.31	0.42
Diet × surface condition	0.66	0.69	0.73	0.63	0.48	0.36	0.21	0.66	0.54	0.42	0.54

[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 1 (continued). Effects of diet and surface condition on selected soil characteristics.

Variable	Organic N (g kg^{-1})	pH	Phosphorous (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})	Water Content (g kg^{-1})	Water-Soluble P (mg kg^{-1})	Zinc (mg kg^{-1})
Diet[a]											
Corn	14.6 a	8.4	12.2	15.0 a	3.06	2.0	3.0	15.2 a	256	156	131 a
Distillers grain	11.0 b	8.2	11.1	14.1 b	2.73	1.5	2.9	11.4 b	231	184	109 b
Surface condition[b]											
USM	13.6	8.2	11.7	14.1 b	2.78	1.7	2.9	14.0	245	177	124
CSM	12.0	8.4	11.6	14.9 a	3.01	1.9	3.0	12.7	242	164	115
Pr > F											
Diet	0.01	0.06	0.12	0.04	0.33	0.12	0.90	0.01	0.75	0.33	0.01
Surface cond.	0.15	0.06	0.86	0.04	0.50	0.57	0.90	0.27	0.97	0.65	0.22
Diet × surface condition	0.34	0.57	0.49	0.84	0.71	0.68	0.45	0.29	0.80	0.45	0.34

[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 2. Effects of diet 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})	NO_3-N (kg ha^{-1})	TDS (kg ha^{-1})	EC (dS m^{-1})	pH	Runoff (mm)	Erosion (Mg ha^{-1})
Diet												
Corn	1.15	0.98	2.13	2.86	4.17	68.1	0.79	424	2.14	7.66	22.3	0.61
Distillers grain	2.10	1.14	3.24	1.62	6.16	57.5	1.02	342	1.84	7.61	23.6	1.27
Surface condition[a]												
USM[b]	1.83	1.07	2.90	2.61	5.66	70.3	1.02	424	2.21 a	7.62	23.2	0.78
CSM	1.42	1.05	2.47	1.87	4.66	55.4	0.78	342	1.77 b	7.65	22.6	1.10
Pr > F												
Diet	0.24	0.80	0.41	0.30	0.28	0.54	0.74	0.52	0.43	0.19	0.66	0.06
Surface cond.	0.13	0.92	0.32	0.22	0.48	0.16	0.48	0.11	0.01	0.48	0.85	0.08
Diet × surface condition	0.80	0.29	0.70	0.56	0.65	0.70	0.86	0.68	0.78	0.70	0.73	0.19

[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.

creted in manure. The pH of manured soils can be increased (become more basic) as a result of land application (Eghball, 1999).

No significant differences in the concentration of TP or water-soluble phosphorus were found between the pens where corn and distillers grain products were fed. However, the pens in which distillers grains were part of the ration contained significantly greater amounts of Bray-1 P. Thus, the relatively large concentration of Bray-1 P on feedlot soils containing manure from cattle fed a distillers grain diet will require different land application guidelines.

FEEDLOT RUNOFF CHARACTERISTICS

There was no significant diet × surface condition interaction for any of the measured runoff characteristics (table 2). Runoff loads of DP, PP, TP, TN, and NO_3-N were numerically greater from the pens where distillers grain was part of the ration, but the differences between the corn and distillers grain treatments were not significant. Because soil concentrations of Bray-1 P and water-soluble P were higher in the pens with the distillers grain diets (table 1), we were expecting greater phosphorus transport in runoff from the distillers grain pens. This did not occur, although phosphorus transport values were larger for the distillers grain pens.

Runoff EC measurements were significantly larger for surfaces with USM than for surfaces with CSM ($P = 0.01$). Surface condition did not significantly affect any of the other measured runoff characteristics. The USM treatments had a greater surface area in contact with overland flow; therefore, there was an increased opportunity for soluble salts to be transferred into solution. Gilley et al. (2008b) also found that only the EC of runoff from pens containing cattle fed a corn-based diet was significantly influenced by surface condition.

In this study, mean values for runoff and erosion from the feedlot surfaces were 23 mm (approximately 35 mm of rainfall was applied) and 0.94 Mg ha^{-1}, respectively. Gilley et al. (2007) measured runoff and erosion from a cropland site with a mean slope gradient of 7% 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 the feedlot and the selected cropland site was similar. However, transport of particulate materials was larger from the feedlot than from the selected cropland location.

CORRELATION ANALYSES

The runoff load of TN was significantly correlated to nine feedlot soil parameters (table 3). The loads of NH_4-N, NO_3-N, and TDS in runoff were each significantly correlated to seven or more feedlot soil parameters. In comparison, runoff concentrations of PP and TP were not significantly correlated to any of the measured feedlot soil characteristics.

The DP load in runoff was significantly correlated to soil measurements of Bray-1 P and water-soluble P. The NO_3-N load in runoff was significantly correlated to soil EC measurements and NO_3-N content. Therefore, it may be possible to estimate DP and NO_3-N load in runoff from selected feedlot soil characteristics. More extensive testing will be required before reliable regression relationships can be developed.

RUNOFF CHARACTERISTICS AS AFFECTED BY INFLOW

Separate statistical analyses were performed on data collected for the experimental tests conducted with and without the addition of inflow. For the inflow tests, the surface condition (USM or CSM) × runoff rate interaction was significant for EC ($P = 0.02$) (table 4). As flow rate increased, the relative concentration of dissolved solids in solution would be expected to decrease, resulting in smaller EC values. Surface condition did not significantly affect any of the other measured water quality parameters. In contrast, all of the measured water quality parameters were significantly influenced by runoff rate ($P = 0.01$).

The transport of DP and TP in runoff ranged from 11.2 to 79.5 g ha^{-1} min^{-1} and from 17.4 to 121 g ha^{-1} min^{-1}, respectively (table 4). No significant differences in DP or TP transport were found for runoff rates 4.4 L min^{-1} and larger.

The rate of transport of NO_3-N increased significantly with each inflow increment, and ranged from 5.7 to 392 g ha^{-1} min^{-1}. The transport rates for NH_4-N and TN also varied significantly among inflow rates, ranging from 20.9 to 85.4 g ha^{-1} min^{-1} and from 75.9 to 646 g ha^{-1} min^{-1}, respectively. The transport of Cl and TDS consistently increased with each inflow increment, varying from 434 to 2990 g ha^{-1} min^{-1} and from 3840 to 62500 g ha^{-1} min^{-1}, respectively.

Measurements of EC consistently decreased with each additional inflow increment on the plot surfaces containing USM and CSM (fig. 3). On both the USM and CSM treatments, significant reductions in EC occurred when the mean runoff rate increased from 2.7 to 4.4 L min^{-1}. No significant differences in EC were found among the three largest runoff rates.

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

Runoff Constituent	Bray-1 P	Calcium	Chloride	Copper	EC	Iron	Loss on Ignition	Magnesium	Manganese	NH_4-N	NO_3-N
DP	**0.61**	-0.45	-0.22	-0.35	-0.16	0.08	-0.29	-0.39	-0.14	-0.19	-0.10
	(0.01)	(0.08)	(0.41)	(0.18)	(0.54)	(0.76)	(0.27)	(0.14)	(0.60)	(0.48)	(0.71)
PP	-0.07	0.15	0.33	0.15	0.34	0.02	-0.01	0.23	-0.42	0.29	-0.38
	(0.79)	(0.58)	(0.22)	(0.59)	(0.20)	(0.94)	(0.96)	(0.39)	(0.10)	(0.28)	(0.15)
TP	0.35	-0.21	0.01	-0.15	0.05	0.06	-0.19	-0.13	-0.29	0.02	-0.24
	(0.19)	(0.43)	(0.96)	(0.57)	(0.84)	(0.82)	(0.48)	(0.62)	(0.28)	(0.95)	(0.37)
NH_4-N	**-0.56**	**0.67**	0.48	**0.72**	0.41	-0.31	0.43	**0.65**	-0.33	0.34	-0.23
	(0.02)	**(0.01)**	(0.06)	**(0.01)**	(0.11)	(0.24)	(0.09)	**(0.01)**	(0.22)	(0.20)	(0.40)
Total N	**0.58**	**-0.61**	**-0.56**	**-0.56**	**-0.57**	0.41	**-0.61**	**-0.63**	0.33	-0.37	0.15
	(0.02)	**(0.01)**	**(0.02)**	**(0.02)**	**(0.02)**	(0.12)	**(0.01)**	**(0.01)**	(0.21)	(0.16)	(0.58)
Cl	-0.48	**0.50**	0.41	**0.52**	0.36	-0.19	0.25	0.44	-0.31	0.17	-0.12
	(0.06)	**(0.04)**	(0.11)	**(0.04)**	(0.18)	(0.48)	(0.36)	(0.09)	(0.25)	(0.52)	(0.66)
NO_3-N	0.33	-0.41	**-0.55**	-0.40	**-0.60**	0.28	-0.39	**-0.51**	**0.52**	-0.43	**0.54**
	(0.21)	(0.11)	**(0.03)**	(0.13)	**(0.01)**	(0.29)	(0.13)	**(0.04)**	**(0.04)**	(0.10)	**(0.03)**
TDS	-0.39	**0.53**	**0.51**	**0.56**	0.45	-0.31	0.33	**0.52**	-0.35	0.37	-0.14
	(0.13)	**(0.03)**	**(0.04)**	**(0.03)**	(0.08)	(0.25)	(0.22)	**(0.04)**	(0.18)	(0.15)	(0.62)
EC	**-0.56**	**0.55**	**0.52**	**0.58**	0.42	-0.25	0.40	0.48	-0.41	0.09	-0.09
	(0.03)	**(0.03)**	**(0.04)**	**(0.02)**	(0.11)	(0.35)	(0.13)	(0.06)	(0.12)	(0.75)	(0.73)
pH	**-0.61**	**0.54**	0.33	**0.54**	0.33	-0.11	0.31	**0.50**	0.09	0.21	-0.20
	(0.01)	**(0.03)**	(0.21)	**(0.03)**	(0.21)	(0.68)	(0.24)	**(0.04)**	(0.75)	(0.44)	(0.46)

[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|.

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

Runoff Constituent	Organic N	pH	Phosphorous	Potassium	SAR	Sodium	Sulfur	Total N	Water Content	Water-Soluble P	Zinc
DP	-0.29	-0.33	-0.32	-0.09	-0.06	-0.22	-0.04	-0.31	0.14	**0.67**	0.01
	(0.27)	(0.22)	(0.22)	(0.75)	(0.83)	(0.41)	(0.88)	(0.24)	(0.59)	**(0.01)**	(0.99)
PP	-0.16	0.17	-0.34	0.27	0.48	0.38	0.01	-0.12	0.42	0.11	0.14
	(0.54)	(0.52)	(0.20)	(0.32)	(0.06)	(0.15)	(0.98)	(0.66)	(0.11)	(0.70)	(0.61)
TP	-0.26	-0.13	-0.36	0.07	0.19	0.04	-0.02	-0.25	0.29	0.47	0.07
	(0.33)	(0.64)	(0.17)	(0.79)	(0.48)	(0.90)	(0.94)	(0.34)	(0.28)	(0.07)	(0.81)
NH_4-N	0.44	0.49	0.18	0.30	**0.67**	**0.70**	0.30	0.46	0.39	-0.27	**0.60**
	(0.09)	(0.06)	(0.52)	(0.25)	**(0.01)**	**(0.01)**	(0.26)	(0.07)	(0.14)	(0.31)	**(0.01)**
Total N	-0.40	-0.25	-0.38	-0.34	**-0.50**	**-0.57**	-0.27	-0.44	-0.17	0.46	-0.23
	(0.13)	(0.34)	(0.14)	(0.19)	**(0.04)**	**(0.02)**	(0.31)	(0.09)	(0.53)	(0.07)	(0.39)
Cl	0.28	0.38	-0.02	0.15	**0.55**	**0.56**	0.24	0.28	-0.03	-0.32	0.42
	(0.29)	(0.15)	(0.95)	(0.59)	**(0.03)**	**(0.02)**	(0.36)	(0.29)	(0.93)	(0.22)	(0.10)
NO_3-N	-0.09	-0.17	-0.01	-0.38	**-0.64**	**-0.57**	-0.19	-0.15	**-0.52**	0.12	-0.23
	(0.73)	(0.53)	(0.97)	(0.14)	**(0.01)**	**(0.02)**	(0.48)	(0.58)	**(0.04)**	(0.65)	(0.39)
TDS	0.33	0.35	0.05	0.35	**0.63**	**0.63**	0.24	0.36	-0.27	-0.09	**0.52**
	(0.21)	(0.18)	(0.86)	(0.19)	**(0.01)**	**(0.01)**	(0.37)	(0.17)	(0.31)	(0.75)	**(0.04)**
EC	0.35	0.27	0.01	0.27	**0.59**	**0.60**	0.15	0.34	-0.07	-0.36	0.43
	(0.18)	(0.32)	(0.98)	(0.32)	**(0.02)**	**(0.01)**	(0.58)	(0.20)	(0.79)	(0.17)	(0.09)
pH	0.30	0.47	0.27	0.28	0.42	0.48	0.32	0.31	0.02	(0.61)	0.24
	(0.27)	(0.07)	(0.31)	(0.29)	(0.11)	(0.06)	(0.22)	(0.24)	(0.96)	(0.01)	(0.36)

[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|.

Significant differences in feedlot soil loss rates were found among inflow increments. The increase in soil loss rate with flow rate is well established. Gilley et al. (1987) measured runoff rate, runoff velocity, sediment concentration, and soil loss rates at selected downslope distances on plots with varying amounts of sorghum and soybean residue. Soil loss rate was found to increase with downslope distance.

Table 4. Runoff water quality parameters as affected by surface condition and runoff rate.

Variable	DP (g ha^{-1} min^{-1})	PP (g ha^{-1} min^{-1})	TP (g ha^{-1} min^{-1})	NO_3-N (g ha^{-1} min^{-1})	NH_4-N (g ha^{-1} min^{-1})	TN (g ha^{-1} min^{-1})	Cl (g ha^{-1} min^{-1})	TDS (g ha^{-1} min^{-1})	EC (dS m^{-1})	pH	Soil Loss (kg ha^{-1} min^{-1})
Surface condition[a]											
USM[b]	72.8	24.1	96.9	202	76.4	436	2090	35600	0.90	7.72	3.49
CSM	48.5	31.2	79.7	185	62.4	366	1460	36800	0.80	7.73	7.57
Runoff rate (L min^{-1})											
2.7	11.2 a	6.3 a	17.4 a	5.7 a	20.9 a	75.9 a	434 a	3840 a	1.30 a	7.84 a	0.62 a
4.4	65.7 b	19.2 b	84.9 b	89.5 b	73.8 b	300 b	1440 b	28000 b	0.86 b	7.74 b	2.94 a
9.1	71.7 b	31.5 c	103 b	195 c	85.4 b	454 c	1740 b	38600 bc	0.74 c	7.69 c	7.62 b
12.7	75.3 b	38.8 c	114 b	285 d	85.3 b	530 cd	2250 bc	47900 c	0.69 c	7.67 c	7.54 b
17.2	79.5 b	42.3 c	121 b	392 e	81.8 b	646 d	2990 c	62500 c	0.67 c	7.68 c	8.93 b
Pr > F											
Surface condition	0.32	0.24	0.46	0.51	0.53	0.24	0.21	0.82	0.11	0.56	0.08
Runoff rate	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Surface condition × runoff rate	0.58	0.11	0.45	0.96	0.63	0.78	0.73	0.90	0.02	0.35	0.19

[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.

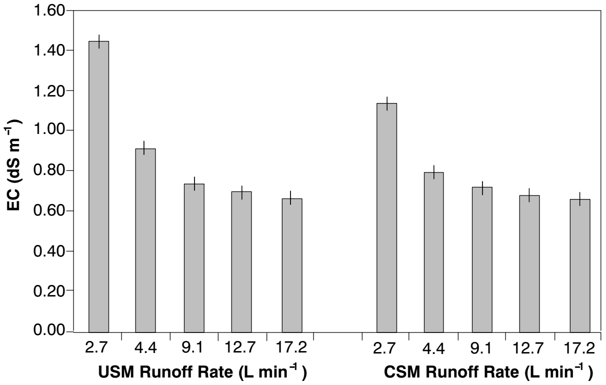

Figure 3. Electrical conductivity (EC) as affected by runoff rate for feedlot surfaces containing unconsolidated surface material (USM) and consolidated subsurface material (CSM). Vertical bars are standard errors.

CONCLUSIONS

Surface condition (USM or CSM) did not significantly affect any of the measured feedlot soil characteristics except potassium. Measurements of calcium, copper, loss on ignition, magnesium, organic-N, potassium, sulfur, TN, and zinc were significantly greater within the pens where cattle were fed a corn-based diet. The pens in which distillers grains were part of the ration contained significantly greater amounts of Bray-1 P.

Only runoff measurements of EC were significantly affected by surface condition. Runoff loads of DP, PP, TP, TN, and NO_3-N were greater from the pens where distillers grain were fed, but the differences between experimental treatments were not significant. None of the measured runoff water quality parameters were significantly affected by diet.

Runoff measurements of NH_4-N, NO_3-N, TDS, and EC were each significantly correlated to seven or more feedlot soil characteristics. The DP and NO_3-N load in runoff were significantly correlated to soil Bray-1 P and NO_3-N content, respectively. Thus, it may be possible to estimate DP and NO_3-N load in runoff from feedlot soil nutrient measurements.

Surface condition did not significantly affect any of the measured runoff water quality parameters under varying flow rates. In contrast, each of the measured water quality parameters was significantly influenced by runoff rate. Runoff rate, not diet or surface condition, was the principal variable influencing nutrient transport from feedlot surfaces.

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