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NUTRIENT CONCENTRATIONS OF RUNOFF AS AFFECTED BY THE DIAMETER OF UNCONSOLIDATED MATERIAL FROM FEEDLOT SURFACES

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ABSTRACT. *Beef cattle feedlots contain unconsolidated material that accumulates on the feedlot surface during a feeding cycle. This study was conducted to measure the effects of varying diameters of unconsolidated surface material and varying flow rates on nutrient concentrations in runoff. Unconsolidated surface material with an average diameter of 4.76, 9.53, 19.1, or 47.5 mm and a composite sample with a 15.2 mm mean diameter were placed within 0.75 m wide × 4.0 m long plot areas. Flow was then introduced at the top of the plots in successive increments, and runoff samples for water quality analyses were obtained. Particle diameter significantly influenced runoff concentrations of dissolved phosphorus (DP), particulate phosphorus (PP), total phosphorus (TP), NH_4-N, and solids transport. Concentrations of DP, PP, TP, and NH_4-N for the composite material were 1.90, 1.28, 3.18, and 3.81 mg L^{-1}, respectively, and solids transport was 19.8 g min^{-1}. Runoff rate significantly affected concentrations of DP, PP, TP, NH_4-N, and solids transport for each of the particle size classes except the 4.76 mm diameter material. For the composite material, concentrations of DP, PP, TP, and NH_4-N decreased from 4.30 to 0.34 mg L^{-1}, from 5.52 to 0.41 mg L^{-1}, from 9.82 to 0.75 mg L^{-1}, and from 25.8 to 0.49 mg L^{-1}, respectively, as runoff rate increased from 0.02 to 1.10 L s^{-1}. Nutrient concentrations of runoff from feedlot surfaces are affected by both varying diameters of unconsolidated surface material and varying flow rates.*

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

Beef cattle feedlots contain unconsolidated surface material (loose manure pack) and consolidated subsurface material (compacted manure and underlying layers) (Woodbury et al., 2001). A standard feedlot management objective is to maintain a black interface layer of compacted manure above the mineral soil to enhance surface runoff, limit infiltration, and reduce wet feedlot conditions (Mielke et al., 1974; Mielke and Mazurak, 1976). Manure is usually removed from the feedlot once or twice each year between cattle production cycles.

The chemical properties of animal manure may be influenced by animal size and species, housing and rearing management, ration, manure storage, and climate (Eghball and Power, 1994). Manure enrichment, compaction, and moisture content may vary across the pen surface during the production cycle. The location of feed and water sources has been shown to significantly influence feedlot soil characteristics (Gilley et al., 2008).

Feedlot pen surfaces become muddy during high moisture conditions, and the health and performance of cattle may be affected. The stirring action of cattle's hooves mixes the soil and manure, creating a feedlot management problem (Clanton et al., 2005). The quantity of unconsolidated material on the feedlot surface usually increases following a significant rainfall event and is reduced as the feedlot dries and cattle compact the surface.

Bedding and within-pen location effects on feedlot runoff quality in southern Alberta, Canada, were examined by Miller et al. (2006). Pen location had a significant effect on electrical conductivity (EC) and concentrations of chloride, potassium, sodium, and total nitrogen (TN). 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.

Gilley et al. (2008) measured nutrient losses in runoff from selected feedlot locations and compared the effects of consolidated and unconsolidated surface material on nutrient transport. No significant differences in nutrient losses were found between unconsolidated surface materials and consolidated subsurface materials. However, pen location significantly affected runoff measurements of dissolved phosphorus (DP), NH_4-N, and EC.

Nutrient losses in runoff from pond ash amended feedlot surfaces and soil surfaces were compared by Gilley et al.

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(2009). Runoff losses of NH_4-N were significantly greater on the pond ash amended surfaces, while losses of total phosphorus (TP) were significantly greater on soil surfaces. The feedlot surfaces containing consolidated subsurface material produced significantly greater losses of NO_3-N and TN.

DeLaune et al. (2012) evaluated the impact of feeding corn-based wet distillers grain and the type of pen surface material on runoff water quality. Feeding wet distillers grain increased soluble reactive P concentrations in runoff water by 38% and total P concentrations by 27% compared to steam-flaked corn. Pen surfaces with fly ash resulted in increased total P and NH_4-N concentrations in runoff water.

If the important factors influencing nutrient transport from feedlot surfaces can be identified and quantified, appropriate practices for managing feedlot runoff can be adopted. Little attention has been focused on the effects of particle diameter and runoff rate on nutrient transport. The objectives of this study were to measure the effects of varying diameters of unconsolidated surface material and varying flow rates on nutrient concentrations of runoff.

Materials and Methods

Manure Characteristics

Beef cattle manure was collected from feedlot pens located at the U.S. Meat Animal Research Center near Clay Center, Nebraska. Calves born during the spring of 2009 were placed in the pens in October 2009, and the cattle were fed a corn-based diet. Soil was placed on the feedlot surface following each pen cleaning cycle, which usually occurred twice a year. The feedlot pens on which manure was collected did not contain mounds.

The soil was excavated at an off-site location from the 122 to 200 cm depth (C-horizon) of a Hastings soil (fine, smectitic, mesic Pachic Argiustolls). The Hastings series consists of very deep well drained soils located on interfluves and hill-slopes that formed in loess. The neutral to moderately alkaline C-horizon of this series has a silt loam or silty clay loam texture, a sand content of 5% to 12%, and a clay content of 20% to 30%.

A rake was used to form small piles of unconsolidated surface material from two feedlot pens that were occupied by cattle. All of the unconsolidated material within the collection area was collected, except any recently deposited manure. The unconsolidated material on the feedlot surface was constantly mixed by the stirring action of cattle hooves as they moved across the feedlot surface. Therefore, material from the feedlot pens on which samples were collected was not mixed prior to sieving. It was not necessary to place the surface material in an oven prior to sieving since it was dry at the time of collection.

The material contained in the individual piles was transported to a set of nested sieves located above a 19 L bucket and then sieved by hand through successively smaller sieves. The width of commercially available material to be used in the sieves helped dictate the number and size of sieves that were constructed. Screens were fabricated to separate the unconsolidated surface material into 4.76, 9.53, 19.1, and 47.5 mm size classes.

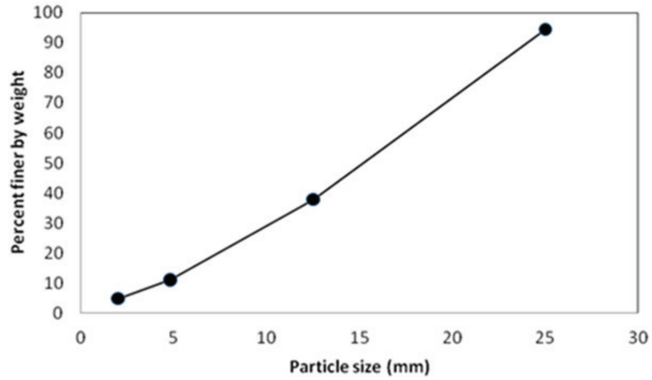

Figure 1. Size distribution of a composite sample of the unconsolidated surface material.

The material that remained on a particular sieve was placed in a 19 L bucket reserved for a given size class. A micrometer was used to measure the diameter of selected particles remaining on the largest sieve. The diameter of each of the other size classes was reported as the average of the size through which the material passed and the size of the sieve on which it was retained. The size distribution of the composite material, which had a mean diameter of 15.2 mm, is shown in figure 1.

A sample of the composite material was sent to a commercial laboratory for analyses. The concentrations of NO_3-N and NH_4-N (measured with a flow injection analyzer using spectrophotometry), TN (Bremner and Mulvaney, 1982), TP (Olsen and Sommers, 1982), water content (Gardner, 1986), EC, and pH of the composite sample were determined to be 0.01 g kg^{-1}, 0.26 g kg^{-1}, 15 g kg^{-1}, 4.1 g kg^{-1}, 83 g kg^{-1}, 19 dS m^{-1}, and 8.2, respectively. A mean particle density of 1.63 g cm^{-3} was obtained using the laboratory procedure of Blake and Hartge (1986).

Study Site Characteristics

The manure was transported from the feedlot for field testing at the University of Nebraska Rogers Memorial Farm located 18 km east of Lincoln, Nebraska. The Aksarben silty clay loam soil (fine, smectitic, mesic Typic Argiudoll) on which the manure was placed is moderately well drained, and its permeability is moderately slow. The study site had been cropped using a grain sorghum (*Sorghum bicolor* (L.) Moench), soybean (*Glycine max* (L.) Merr.), and winter wheat (*Triticum aestivum* L. cv. Pastiche) rotation. A long-term continuous no-till management system with controlled wheel traffic was used on the farm. The study area was planted to winter wheat during the 2009-2010 cropping season. The winter wheat was clipped by hand near the soil surface at the time of plot establishment.

Clark et al. (1975b) reported that the mean slope of selected feedlots in the southern Great Plains ranged from 1.3% near Pratt, Kansas, to 9.0% near Mead, Nebraska. Gilley et al. (2009) conducted tests on a feedlot near Clay Center, Nebraska, that had a mean slope of 4.8%. The mean slope of the study site used in this investigation was 5.1%.

PLOT PREPARATION

Twelve 0.75 m wide × 4 m long test sections were established with the longer plot dimension parallel to the slope in the direction of overland flow. Two replicated field tests were conducted on surface material obtained from each of four size classes and a composite sample that had not been sieved. The surface material was placed on the plots to a depth of approximately 6 cm. The top few centimeters of depth, where overland flow comes in contact with manure, are thought to most significantly influence surface water quality. A manure depth of 6 cm was thought to adequately represent this critical zone of interaction. The total mass of manure on a dry weight basis that was applied to each plot was approximately 293 kg. It is recognized that separating the unconsolidated surface material into individual size classes and conducting field tests at varying flow rates at a cropland site with different infiltration characteristics is an idealized situation that may not fully replicate existing feedlot conditions.

RUNOFF COLLECTION PROCEDURES

Water used during the field tests was obtained from an irrigation well located near the experimental site. Replicated samples for water quality characterization were obtained at the beginning and end of the study. The characteristics of the water used in the simulation tests may influence phosphorus release (Bormann et al., 2010). Measured mean concentrations of DP, TP, NO_3-N, NH_4-N, and TN in the irrigation water were 0.17, 0.17, 14.9, 0.00, and 14.9 mg L^{-1}, respectively. The irrigation water had a mean EC of 0.79 dS m^{-1} and a pH of 7.4.

Following manure application, to provide more uniform antecedent soil water conditions among treatments, water was added to the plots with a hose until runoff began. Plot borders channeled the runoff into a sheet metal lip that emptied into a collection trough that extended across the bottom of each plot. Runoff was then diverted into a 0.18 m HS flume on which a stage recorder was mounted to measure discharge rate (USDA, 1979). A grab sample for water quality analyses was collected at the outlet of the flume at one point in time after steady-state runoff conditions were established.

A sample of water from the irrigation well was collected each day that field tests were conducted. Duplicate laboratory measurements of DP, NO_3-N, and NH_4-N were made on each of these "blank" samples. Nutrient values reported in this study were obtained by subtracting nutrient concentrations in the irrigation well water that were obtained each day from measured runoff concentrations.

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 EC, pH, TN (Tate, 1994), and TP (Johnson and Ulrich, 1959). The difference between measurements of TP and DP was reported as PP. The additional runoff samples that were obtained for sediment analyses were dried in an oven at 105°C and then weighed to determine solids concentrations.

INFLOW TEST PROCEDURES

Simulated rainfall was not used during the study. The runoff rate from feedlot surfaces is directly proportional to the length of the overland flow plane. Inflow was introduced in successive increments at the upstream end of the 0.75 m × 4.0 m overland flow plane. The inflow device was a 2.5 cm diameter plastic tube that extended across the top of the plot. Only one plastic tube was used at a time, but several separate tubes were employed during the testing procedure. Several holes were drilled into the plastic tubes to allow water to be introduced uniformly across the plot surface. A gate valve and pressure gauge located on the inlet to the plastic tubes was adjusted to provide the desired flow rate. A narrow mat was placed on the soil surface beneath the inflow device to prevent scouring and distribute flow more uniformly across the plot surface.

Flow addition for each inflow increment occurred only after steady-state runoff conditions for the previous inflow increment became established and runoff samples for water quality analyses had been collected. Steady-state runoff conditions were determined using the stage recorder and flume. Once the flow rate was large enough to cause the unconsolidated surface material to move, a channel was formed and broad sheet flow conditions were no longer present. Therefore, runoff sample collection for a given size class was completed when the runoff rate became large enough to cause movement of the unconsolidated surface material. The number and range of flow increments varied among size classes since the flow rates required to cause movement of the unconsolidated surface material varied among size classes.

The ten-year, one-hour rainfall for southeast Nebraska is approximately 6.4 cm (Weather Bureau, 1963). The feedlot pens on which the manure was collected were 60 m long. If the rainfall intensity for this design storm was uniform and infiltration did not occur, the flow rate at the bottom of a 0.75 m wide section of pen (the same width as the experimental test plot) would be approximately 0.80 L s^{-1}. Runoff rates in this study ranged from 0.02 to 1.10 L s^{-1}. Uniform flow as represented in this idealized situation would not be expected in feedlots because of convergence and divergence of flow resulting from uneven surfaces.

STATISTICAL ANALYSES

Analysis of variance (SAS, 2011) was performed to determine the effects of particle diameter on selected water quality characteristics. Measurements obtained at varying flow rates from the replicated plots used for each particle size class and the composite sample were included in the analyses and were treated as repeated measures. A probability level of <0.05 was considered significant. If a significant difference was identified, the least significant difference (LSD) test (SAS, 2011) was used to identify differences among individual particle size classes and the composite material.

Analysis of variance (SAS, 2011) was also performed to determine the effects of runoff rate on selected water quality characteristics. Measurements obtained from the replicated plots used for each particle size class were included in the analyses and were treated as repeated measures. A probability level of <0.05 was considered significant.

RESULTS AND DISCUSSION

WATER QUALITY CHARACTERISTICS AS AFFECTED BY PARTICLE DIAMETER

Phosphorus Measurements

Runoff concentrations of DP, PP, and TP, when averaged across flow rates, decreased significantly as particle diameter increased from 4.76 to 47.5 mm (table 1; figs. 2 through 4). Concentrations of DP, PP, and TP for the composite material were larger than values predicted for the regression equations derived for the individual particle size classes (figs. 2 through 4). The composite material contained particle size classes that were much smaller than the mean diameter of 15.2 mm (fig. 1). The smaller diameter materials produced the largest P concentrations of runoff. As a result, the smaller size fractions caused P concentrations for the composite material to be larger than values estimated by the regression equations obtained for the individual size classes.

Concentrations of DP, PP, and TP in runoff for both the 4.76 and 9.53 mm diameter materials were significantly larger than measurements obtained for the other particle size classes (table 1). No significant differences in concentrations of DP, PP, or TP were found between the 19.1 and 47.5 mm diameter fractions. Runoff concentrations of DP, PP, and TP for the composite material were 1.90, 1.28, and 3.18 mg L^{-1}, respectively.

Nitrogen Measurements

Particle diameter did not significantly influence runoff concentrations of NO_3-N and TN when averaged across all flow rates (table 1). However, concentrations of NH_4-N in runoff were significantly affected by particle diameter (table 1; fig. 5). Runoff concentrations of NH_4-N decreased from 5.18 to 0.51 mg L^{-1} as particle diameter increased from 4.76 to 47.5 mm. The NH_4-N concentration of 5.18 mg L^{-1} obtained for the 4.76 mm diameter size class was significantly larger than the values obtained for the other size fractions. No significant differences in runoff concentrations of NH_4-N were found among the 9.53, 19.1, and 47.5 mm size classes. Runoff concentrations of NO_3-N, NH_4-N, and TN for the composite material were 0.09, 3.81, and 20.4 mg L^{-1}, respectively.

EC, pH, and Solids Transport Measurements

Particle diameter significantly affected EC measurements when averaged across all flow rates, with values decreasing from 2.33 to 0.87 dS m^{-1} as particle diameter increased from 4.76 to 47.5 mm (table 1; fig. 6). The EC value of 2.33 dS m^{-1} measured for the 4.76 mm diameter material was significantly larger than the values obtained for the other size classes. No significant differences in EC measurements were found among particle size classes varying from 9.53 to 47.5 mm. The composite material had an EC value of 1.33 dS m^{-1}. Measurements of pH were not significantly affected by particle diameter (table 1). A pH

Table 1. Effects of particle diameter on selected water quality characteristics.[a]

Particle Diameter (mm)	DP (mg L^{-1})	PP (mg L^{-1})	TP (mg L^{-1})	NO_3-N (mg L^{-1})	NH_4-N (mg L^{-1})	TN (mg L^{-1})	EC (dS m^{-1})	pH	Solids Transport (g min^{-1})
4.76	4.33 a	3.97 a	8.29 a	0.03	5.18 a	16.9	2.33 a	7.64	12.9 b
9.53	1.77 b	1.23 b	3.00 b	0.35	1.39 b	20.9	1.15 bc	7.57	42.6 a
19.1	0.46 c	0.94 bc	1.40 c	0.10	1.12 b	18.9	1.02 bc	7.55	20.7 b
47.5	0.40 c	0.45 c	0.85 c	0.35	0.51 b	16.0	0.87 c	7.58	19.5 b
15.2 (composite)	1.90 b	1.28 b	3.18 b	0.09	3.81 a	20.4	1.33 b	7.67	19.8 b
Pr > F	0.01	0.01	0.01	0.56	0.04	0.62	0.01	0.59	0.02

[a] Values followed by different letter are significantly different at the 0.05 probability level based on Student's t-test.

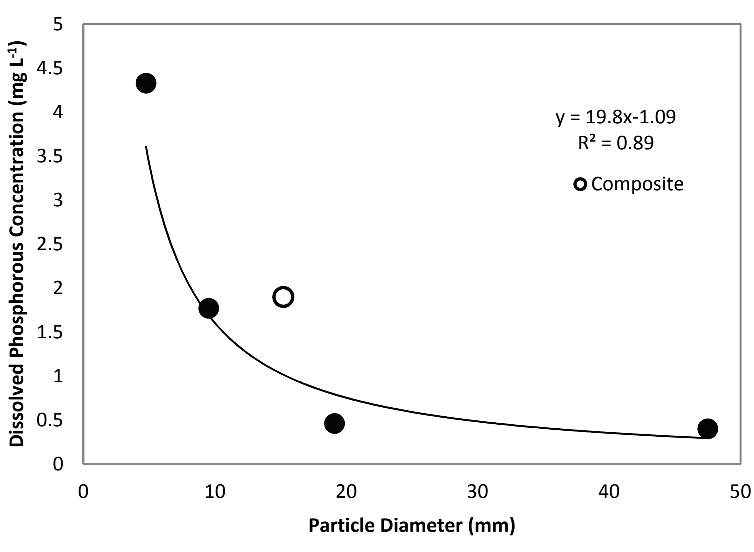

Figure 2. Dissolved phosphorous concentration of runoff as affected by the diameter of the unconsolidated surface material. The value for the composite sample was not included in the derivation of the regression equation.

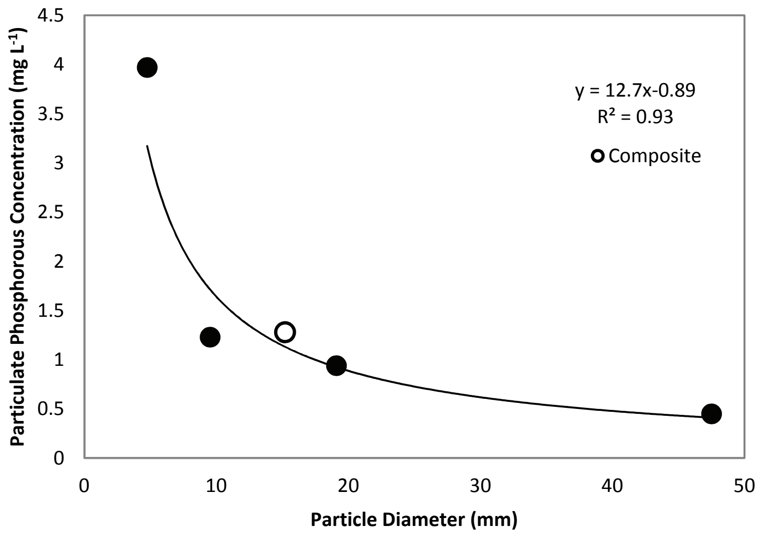

Figure 3. Particulate phosphorous concentration of runoff as affected by the diameter of the unconsolidated surface material. The value for the composite sample was not included in the derivation of the regression equation.

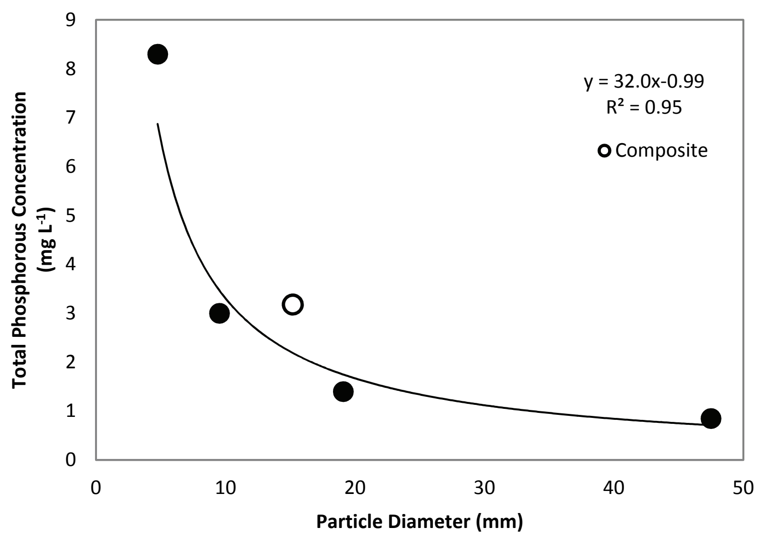

Figure 4. Total phosphorous concentration of runoff as affected by the diameter of the unconsolidated surface material. The value for the composite sample was not included in the derivation of the regression equation.

value of 7.67 was measured for the composite material.

Since a rainfall simulator was not used in this investigation, overland flow served as the mechanism responsible for detaching and transporting solids in runoff. The solids transported in runoff contained manure and soil materials that had been mixed together by the stirring action of cattle hooves. Solids transport rates were significantly affected by particle diameter (table 1). The solids transport rate of 42.6 g min^{-1} measured for the 9.53 mm diameter material was significantly larger than the values obtained for the other particle size classes. No significant differences in solids transport rates were found among the 4.76, 19.1, 47.5, and 15.2 (composite) mm size fractions. A solids transport rate of 19.8 kg min^{-1} was measured for the composite material.

Water Quality Characteristics as Affected By Runoff Rate

Phosphorus Measurements

Runoff rate significantly influenced concentrations of DP and TP for each of the particle size classes and the composite material (table 2; figs. 7 and 8). The concentrations of DP and TP in runoff for the composite material decreased from 4.30 to 0.34 mg L^{-1} and from 9.82 to 0.75 mg L^{-1} as runoff rate increased from 0.02 to 1.10 L s^{-1}. Runoff concentrations of DP and TP for the composite material were similar at flow rates greater than 0.4 L s^{-1}. Concentrations of PP in runoff were influenced by each of the particle size classes except the 4.76 mm diameter material (table 2).

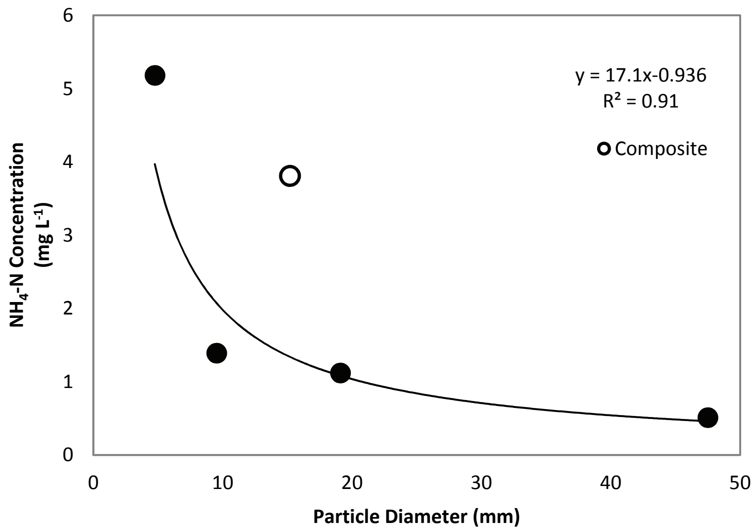

Figure 5. NH_4-N concentration of runoff as affected by the diameter of the unconsolidated surface material. The value for the composite sample was not included in the derivation of the regression equation.

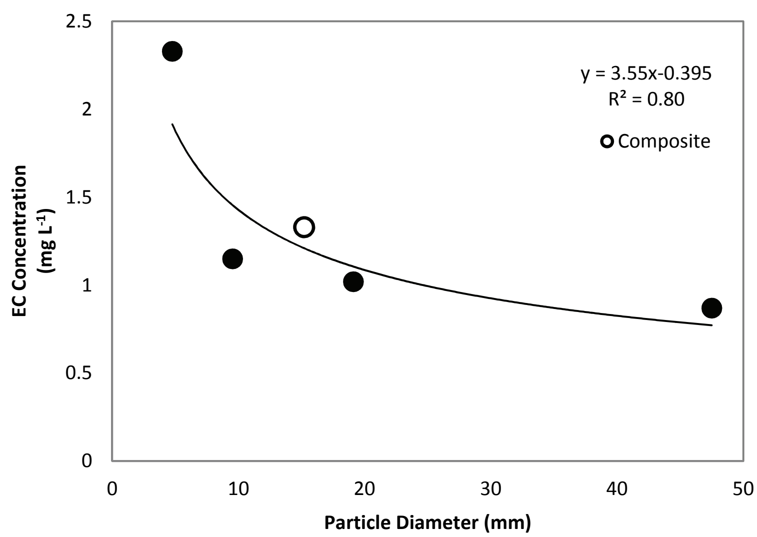

Figure 6. Electrical conductivity (EC) of runoff as affected by the diameter of the unconsolidated surface material. The value for the composite sample was not included in the derivation of the regression equation.

Table 2. Analysis of variance showing the effects of runoff rate on selected water quality characteristics for individual particle size classes.

Particle Diameter	Pr > F								
(mm)	DP	PP	TP	NO_3-N	NH_4-N	TN	EC	pH	Solids Transport
4.76	0.03	0.07	0.02	0.69	0.19	0.72	0.31	0.18	0.27
9.53	0.01	0.03	0.01	0.53	0.02	0.06	0.04	0.27	0.01
19.1	0.01	0.01	0.01	0.33	0.01	0.01	0.01	0.01	0.01
47.5	0.01	0.01	0.01	0.24	0.01	0.83	0.01	0.57	0.01
15.2 (composite)	0.01	0.02	0.01	0.01	0.03	0.45	0.01	0.10	0.01

Nitrogen Measurements

The concentration of NO_3-N in runoff was not significantly affected by runoff rate except for the composite material (table 2). Runoff rate did not significantly affect runoff concentrations of TN except for the 19.1 mm size class. In comparison, the concentration of NH_4-N in runoff was significantly affected by runoff rate for each of the particle size classes except the 4.76 diameter material. The concentration of NH_4-N in runoff for the composite material decreased from 25.8 to 0.49 mg L^{-1} as runoff rate increased from 0.02 to 1.10 L s^{-1} (fig. 9). Runoff concentrations of NH_4-N for the composite material were similar at flow rates greater than 0.4 L s^{-1}.

EC, pH, and Solids Transport Measurements

EC measurements were significantly affected by runoff

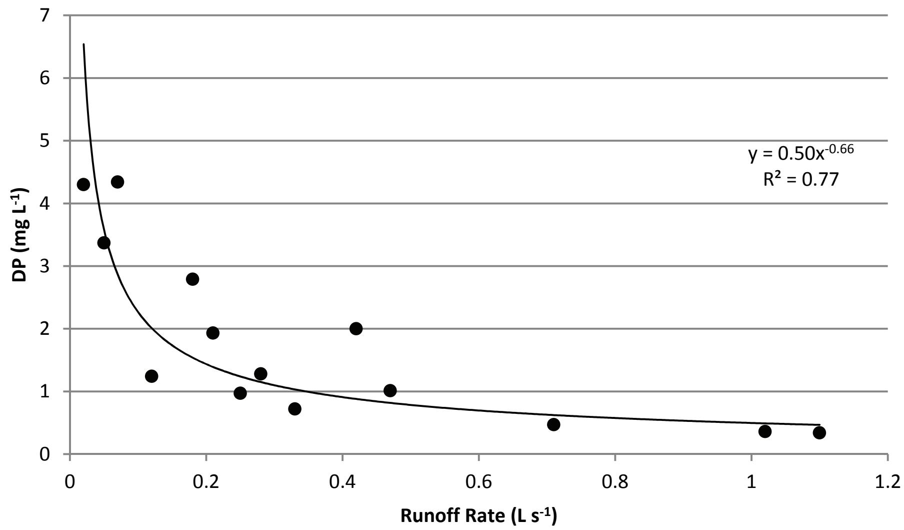

Figure 7. Concentration of dissolved phosphorus (DP) in runoff as affected by runoff rate for the composite unconsolidated surface material having a mean diameter of 15.2 mm.

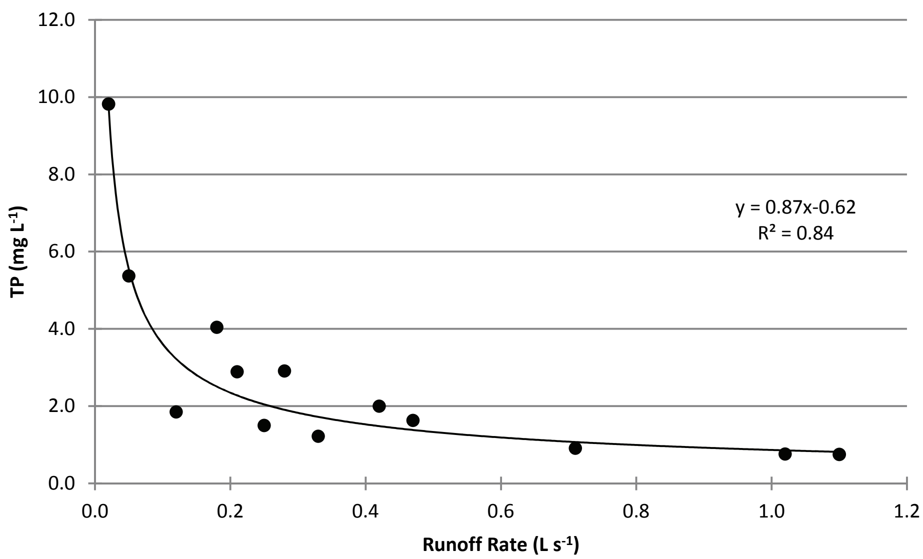

Figure 8. Concentration of total phosphorus (TP) in runoff as affected by runoff rate for the composite unconsolidated surface material having a mean diameter of 15.2 mm.

rate for each of the particle size classes except the 4.76 diameter material (table 2). EC values for the composite material decreased from 3.69 to 0.79 dS m^{-1} as runoff rate increased from 0.02 to 1.10 L s^{-1} (fig. 10). However, EC values for the composite material were similar at flow rates greater than 0.4 L s^{-1}. Values for pH were not significantly affected by runoff rate except for the 19.1 mm particle size class (table 2). Runoff rate significantly affected solids transport measurements for each of the particle size classes except the 4.76 diameter material.

Comparison of Results with Previous Studies

Clark et al. (1975a) described the water quality characteristics of runoff from eight unpaved Great Plains feedlots located in five states. Water quality measurements was found to be quite variable at each location and depended on rainfall intensity and duration, time since last runoff, and stocking rate. Mean total phosphorus concentrations ranged from 47 mg L^{-1} at Sioux Falls, South Dakota, to 300 mg L^{-1} at Mead, Nebraska, with a mean value of 121 mg L^{-1} reported for the eight locations.

Chemical constituents in runoff from an unpaved beef cattle feedlot near Bushland, Texas, were measured over a three-year period by Clark et al. (1975b). The concentrations of the chemical constituents varied substantially both within storms and among storms. The mean concentration of TP was 205 mg L^{-1}, and approximately 75% of the runoff samples had concentrations ranging from 101 to 300 mg L^{-1}. The mean concentration of TN was 1083 mg L^{-1}, and approximately 56% of the runoff samples had concentra-

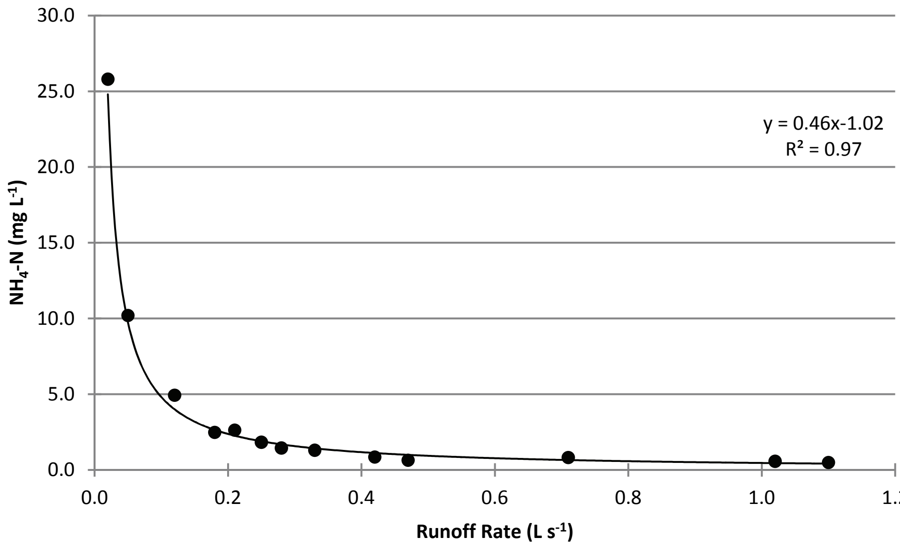

Figure 9. Concentration of ammonium nitrogen in runoff as affected by runoff rate for the composite unconsolidated surface material having a mean diameter of 15.2 mm.

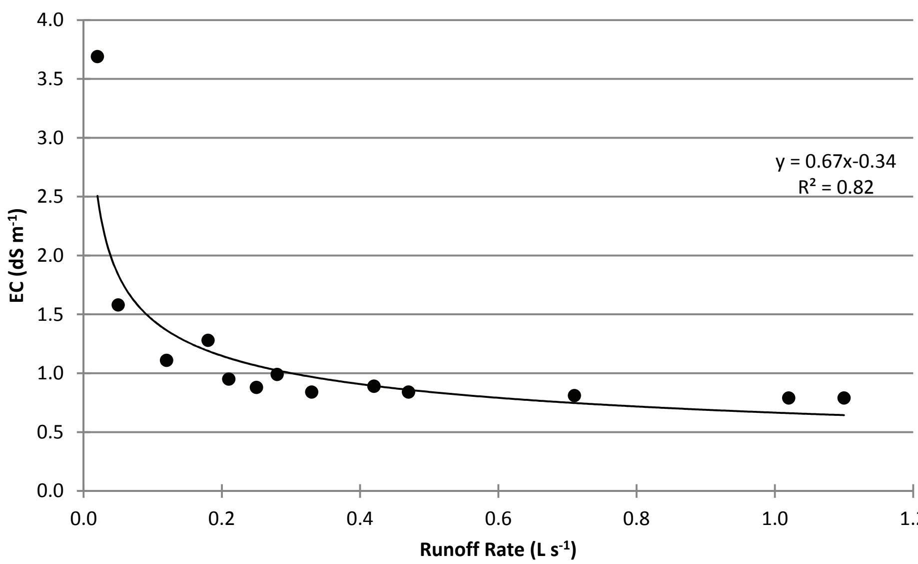

Figure 10. Electrical conductivity (EC) of runoff as affected by runoff rate for the composite unconsolidated surface material having a mean diameter of 15.2 mm.

tions greater than 1000 mg L^{-1}.

Edwards et al. (1983) measured water quality characteristics of runoff from a paved beef cattle feedlot in east-central Ohio. Water quality measurements were made for 98 runoff events occurring over a three-year period. The concentration of TP varied from 15 to 770 mg L^{-1}, and the mean value was 218 mg L^{-1}. Approximately 70% of the runoff events resulted in TP transport of <1 kg from the 243 m^3 feedlot, while transport quantities of 1 to 2 kg and >2 kg were measured for 17% and 13% of the runoff events, respectively. The concentration of TN varied from 186 to 2640 mg L^{-1}, and the mean value was 905 mg L^{-1}.

The quantity and quality of runoff from an unpaved beef cattle feedlot in southern Alberta were measured by Miller et al. (2004). The eleven runoff events occurring over the five-year study period resulted from rainfall durations ranging from 5 to 59 h and rainfall amounts varying from 12 to 137 mm. The mean concentration of TP was 35.3 mg L^{-1} (coefficient of variation of 43%), and the mean concentration of TN was 85.7 mg L^{-1} (coefficient of variation of 38%).

Andersen et al. (2013) measured the water quality characteristics of runoff from settling basins located below six open lot feedlots located throughout Iowa. The mean annual concentrations of TP measured over three- or four-year study periods varied from 53 to 179 mg L^{-1}, and the mean value for the six feedlots was 87 mg L^{-1}. The mean annual concentrations of TN ranged from 124 to 1307 mg L^{-1}, and the mean value for the six feedlots was 415 mg L^{-1}.

The effects of varying runoff rate on nutrient transport

from feedlot surfaces as affected by corn-based and wet distiller's grain diets was examined by Gilley et al. (2010). Field tests were conducted on 0.75 m wide × 2.0 m long plots, and inflow was added to the top of the plots to produce varying runoff rates. No significant differences in measured water quality parameters were found between the corn-based and wet distillers grain treatments. However, measurements of DP, PP, TP, NO_3-N, NH_4-N, TN, EC, pH, and solids transport were each significantly influenced by runoff rate, with nutrient concentration values generally decreasing as runoff rate increased. Concentrations of DP, TP, and NH_4-N varied from 2.2 to 0.69 mg L^{-1}, from 2.9 to 1.1 mg L^{-1}, and from 2.5 to 0.71 mg L^{-1}, respectively, as flow rate ranged from 0.07 to 0.29 L s^{-1}.

Gilley et al. (2012) conducted a field investigation to measure the effects of varying runoff rates on nutrient transport rates from feedlot surfaces containing varying amounts of unconsolidated surface material. The 0.75 m wide × 2.0 m long plots used in the study contained 0, 6.7, 13.5, or 26.9 kg m^{-2} of unconsolidated surface material. Inflow was added to the top of the plots to produce runoff rates ranging from 0.01 to 0.26 L s^{-1}. Runoff rate significantly influenced measurements of DP, PP, TP, NO_3-N, NH_4-N, TN, EC, pH, and solids transport, with nutrient concentration values generally decreasing as runoff rate increased. As flow rate ranged from 0.08 to 0.26 L s^{-1}, concentrations of DP, TP, and NH_4-N varied from 3.4 to 1.0 mg L^{-1}, from 3.8 to 1.3 mg L^{-1}, and from 2.5 to 0.80 mg L^{-1}, respectively.

In the present study, varying flow rate on the composite material also significantly affected runoff measurements of DP, PP, TP, NO_3-N, NH_4-N, EC, and solids transport on the composite material. However, flow rates as large as 1.10 L s^{-1} were used in the present study, which is substantially larger than those employed by Gilley et al. (2010, 2012).

Clark et al. (1975a, 1975b), Edwards et al. (1983), and Miller et al. (2004) each reported that nutrient concentrations of runoff from feedlot surfaces were highly variable. Substantial variations in mean annual concentrations of TN and TP in runoff from settling basins located below feedlots were reported by Andersen et al. (2013). Gilley et al. (2010, 2012) reported that nutrient concentrations were significantly influenced by flow rate and that concentrations usually decreased as flow rate increased. The variations in nutrient concentrations occurring during natural precipitation events could be influenced by large differences in flow rate among runoff events.

Most of the runoff events on feedlots are relatively small, and the corresponding nutrient concentration values would be expected to be relatively large. As a result, mean concentration values would also be expected to be relatively large. The total annual load of nutrients from a feedlot is significantly influenced by the largest runoff events, even though the concentration values from larger storms may be much less than the values from smaller precipitation events.

The nutrient concentration measurements obtained in the present study were similar to values reported by Gilley et al. (2010, 2012) for similar flow rates. However, the nutrient concentration measurements obtained in the present investigation were at flow rates much larger than those expected under typical natural rainfall conditions. Many of the nutrient concentration measurements reported in the literature for feedlots are mean values obtained for all runoff events. Flow rates for most runoff events occurring from natural precipitation are relatively small, while the nutrient concentration values are relatively large. As a result, the nutrient concentration measurements reported in this study should be representative of values expected from feedlots under similar flow conditions but not representative of annual mean concentration values obtained from a large number of events with relatively small runoff rates.

Feedlot Runoff Management Considerations

Runoff from animal feeding operations is stored within settling basins or holding ponds and then land applied for pasture or crop production. Settling basins are established at the bottom of feedlot pens, allowing deposition to occur before runoff reaches a holding pond. Settling basins can be very effective in reducing sediment delivery to holding ponds. Since feedlot runoff does not directly enter an off-site water course, it does not immediately impact the aquatic environment. As a result, even though feedlot runoff concentrations may exceed established water quality standards, there is no immediate water quality threat.

Sediment transport may be reduced by using a mildly concave pen design that enhances sediment deposition at the bottom of a hillslope. However, depositional areas may sometimes remain wet for extended periods, which would require a larger feedlot area since cattle usually avoid areas that are very wet. Mounds may be constructed within feedlot pens to provide an unsaturated surface for cattle to reside. In order to maintain proper drainage, mounds are usually constructed in the center of a pen.

Dickey and Vanderholm (1977) reported that the water quality characteristics of runoff from feedlots is often substantially different from that within holding ponds due to the chemical, physical, and biological activities occurring during storage. The large decrease in N concentration occurring during the summer months was attributed to the increased volatilization of NH_3 due to higher temperatures. Dewatering of holding ponds in the spring was recommended to provide maximum nutrient benefits.

Linderman and Ellis (1978) reported that the composition of effluent within holding ponds located below two feedlots in eastern Nebraska changed substantially with time. Concentrations of N were generally larger at the beginning of the irrigation season. An analysis of effluent quality to identify nutrient status prior to land application was recommended.

Chemical constituents in a holding pond located below an unpaved beef cattle feedlot near Papillion, Nebraska, were measured over a three-year period by Gilbertson et al. (1979). The mean concentration of TP within the holding pond was 45 mg L^{-1}, and concentrations ranged from 20 to 106 mg L^{-1}. Concentrations of TN varied from 70 to 624 mg L^{-1}, and the mean concentration was 300 mg L^{-1}.

In the present study, water quality measurements were obtained at flow rates less that those required to cause in-

cipient motion of the feedlot surface material. Sediment loading within settling basins or holding ponds would be expected to increase substantially once flow rates become large enough to transport surface materials. As a result, settling basins and holding ponds must be cleaned at more frequent intervals because of reductions in storage capacity. Proper management practices should be employed to reduce environmental impacts following land application of materials contained in holding ponds.

An important feedlot management practice would be to reduce excess runoff and maintain flow rates that are less that those required to cause incipient motion of the feedlot surface material. Feedlot surface materials detached by overland flow are transported to settling basins or holding ponds. Following deposition, the unconsolidated material breaks down into smaller particle sizes, including non-aggregated materials. The surface area on which adsorption and desorption occur would be much larger for the non-aggregated materials found within settling basins or holding ponds. In the present study, the nutrient concentration of runoff was found to significantly increase as the diameter of unconsolidated surface materials decreased.

The length of time that feedlot surface materials and water are in contact increases substantially once the surface materials are deposited within a settling basin or holding pond. The nutrient concentrations and loads within a settling basin or holding pond would be expected to be larger than those occurring in runoff as a result of the increased solid/liquid contact time. It is much easier to manage the nutrients contained within feedlot pens if they remain on the feedlot surface and are not transported into a settling basin or holding pond.

Runoff from areas outside the feedlot pens should not be allowed to enter individual pens. In addition, runoff draining from one pen should not be permitted to enter additional pens. Runoff discharge rates occurring with pen-to-pen drainage may become large enough to cause incipient motion of the feedlot surface materials and result in excessive sediment transport.

Feedlots should be designed to reduce the slope length before runoff enters a settling basin or holding pond. When successive rows of pens with shorter slope lengths are established along a hillslope, separate bunk areas and drainage areas are required for each successive row of pens. Reducing pen length and increasing the total number of pens requires a larger feedlot area.

Conclusions

The diameter of unconsolidated material from feedlot surfaces significantly influenced runoff concentrations of DP, PP, TP, and NH_4-N, with nutrient concentration consistently decreasing as particle diameter increased. Concentrations of DP, PP, TP, and NH_4-N in runoff for the particle size classes 9.53 mm and larger were significantly influenced by runoff rate, with the largest concentrations measured at the smallest runoff rates. Concentrations of DP, TP, and NH_4-N in runoff for the composite material were similar at flow rates greater than 0.4 L min^{-1}. Both the diameter of unconsolidated surface material and the flow rate significantly influence nutrient concentrations in runoff.

References

Andersen, D. S., Burns, R. T., Moody, L. B., Helmers, M. J., Bond, B., Khanijo, I., & Pederson, C. (2013). Impact of system management on vegetative treatment system effluent concentrations. *J. Environ. Mgmt., 125*, 55-67. http://dx.doi.org/10.1016/j.jenvman.2013.03.046.

Blake, G. R., & Hartge, K. H. (1986). Particle density. In A. Klute (Ed.), *Methods of Soil Analysis: Part 1. Physical and Mineralogical Methods* (pp. 377-382). Madison, Wisc.: ASA.

Bormann, N. L., Baxter, C. A., Andraski, T. W., Good, L. W., & Bundy, L. G. (2010). Source water effects on runoff amount and phosphorus concentration under simulated rainfall. *SSSA J., 74*(2), 612-618. http://dx.doi.org/10.2136/sssaj2009.0156.

Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen-total. In *Methods of Soil Analysis: Part 2. Chemical and Microbiological Properties*. (pp. 595-624). Agronomy Monograph No. 9. Madison, Wisc.: ASA.

Clanton, C. J., Endres, M. I., Bey, R. F., Farnsworth, R. J., Janni, K. A., & Schmidt, D. R. (2005). Dolomitic limestone bedding effects on microbial counts and cow comfort. *Appl. Eng. Agric., 21*(6), 1073-1077.

Clark, R. N., Gilbertson, C. B., & Duke, H. R. (1975a). Quantity and quality of beef feedyard runoff in the Great Plains. In *Proc. 3rd Intl. Symp. on Livestock Wastes* (pp. 289-296). St. Joseph, Mich.: ASAE.

Clark, R. N., Schneider, A. D., & Stewart, B. A. (1975b). Analysis of runoff from southern Great Plains feedlots. *Trans. ASAE, 18*(2), 319-322. http://dx.doi.org/10.13031/2013.36579.

DeLaune, P. B., MacDonald, J. C., & Auvermann, B. W. (2012). Manure and runoff water quality from feedlots as affected by diet and pen surface. *Trans. ASABE, 55*(6), 2319-2324. http://dx.doi.org/10.13031/2013.42500.

Dickey, E. C., & Vanderholm, D. H. (1977). Feedlot runoff holding ponds: Nutrient levels and related management aspects. *Trans. ASAE, 6*(3), 307-312.

Edwards, W. M., Owens, L. B., & White, R. K. (1983). Managing runoff from a small, paved, beef feedlot. *J. Environ. Qual., 12*(2), 281-286. http://dx.doi.org/10.2134/jeq1983.00472425001200020026x.

Eghball, B., & Power, J. F. (1994). Beef cattle feedlot manure management. *J. Soil Water Cons., 49*(2), 113-122.

Gardner, W. H. (1986). Water content. In *Methods of Soil Analysis: Part 1. Physical and Mineralogical Methods* (pp. 493-544). Agronomy Monograph No. 9. Madison, Wisc.: ASA.

Gilbertson, C. B., Nienaber, J. A., Gartung, J. L., Ellis, J. R., & Splinter, W. E. (1979). Runoff control comparisons for commercial beef cattle feedlots. *Trans. ASAE, 22*(4), 842-846. http://dx.doi.org/10.13031/2013.35111.

Gilley, J. E., Berry, E. D., Eigenberg, R. A., Marx, D. B., & Woodbury, B. L. (2008). Spatial variations in nutrient and microbial transport from feedlot surfaces. *Trans. ASABE, 51*(2), 675-684. http://dx.doi.org/10.13031/2013.24380.

Gilley, J. E., Vogel, J. R., Berry, E. D., Eigenberg, R. A., Marx, D. B., & Woodbury, B. L. (2009). Nutrient and bacterial transport in runoff from soil and pond ash amended feedlot surfaces. *Trans. ASABE, 52*(6), 2077-2085. http://dx.doi.org/10.13031/2013.29210.

Gilley, J. E., Vogel, J. R., Eigenberg, R. A., Marx, D. B., & Woodbury, B. L. (2010). Nutrient transport in runoff from feedlots as affected by wet distillers grain diet. *Trans. ASABE, 53*(2), 545-552. http://dx.doi.org/10.13031/2013.29569.

Gilley, J. E., Vogel, J. R., Eigenberg, R. A., Marx, D. B., & Woodbury, B. L. (2012). Nutrient losses in runoff from feedlot surfaces as affected by unconsolidated surface materials. *J. Soil Water Cons., 67*(3), 211-217. http://dx.doi.org/10.2489/jswc.67.3.211.

Johnson, C. M., & Ulrich, A. (1959). Analytical methods for use in plant analysis. Bulletin 766. Berkeley, Cal.: University of California, Agricultural Experiment Station.

Linderman, C. L., & Ellis, J. R. (1978). Quality variation of stored feedlot runoff. *Trans. ASAE, 21*(2), 337-341. http://dx.doi.org/10.13031/2013.35300.

Mielke, L. N., & Mazurak, A. P. (1976). Infiltration of water on a cattle feedlot. *Trans. ASAE, 19*(2), 341-344. http://dx.doi.org/10.13031/2013.36024.

Mielke, L. N., Swanson, N. P., & McCalla, T. M. (1974). Soil profile conditions of cattle feedlots. *J. Environ. Qual., 3*(1), 14-17. http://dx.doi.org/10.2134/jeq1974.00472425000300010004x.

Miller, J. J., Handerek, B. P., Beasley, B. W., Olson, E. C. S., Yanke, L. J., Larney, F. J., McAllister, T. A., Olson, B. M., Selinger, L. B., Chanasyk, D. S., & Hasselback, P. (2004). Quantity and quality of runoff from a beef cattle feedlot in southern Alberta. *J. Environ. Qual., 33*(3), 1008-1097. http://dx.doi.org/10.2134/jeq2004.1088.

Miller, J. J., Olson, E. C. S., Chanasyk, D. S., Beasley, B. W., Yanke, L. J., Larney, F. J., McAllister, T. A., Olson, B. M., & Selinger, L. B. (2006). Bedding and within-pen location effects on feedlot pen runoff quality using a rainfall simulator. *J. Environ. Qual., 35*(2), 505-515. http://dx.doi.org/10.2134/jeq2005.0205.

Murphy, J., & Riley, J. P. (1962). A modified single-solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta, 27*, 31-36. http://dx.doi.org/10.1016/S0003-2670(00)88444-5.

Olsen, S. R., & Sommers, L. E. (1982). Phosphorus. In *Methods of Soil Analysis: Part 2. Chemical and Microbiological Properties* (pp. 403-430). Agronomy Monograph No. 9. Madison, Wisc.: ASA.

SAS. (2011). *SAS/STAT User's Guide*. Version 9.3. (4th ed., Vol. 1). Cary, N.C.: SAS Institute, Inc.

Tate, D. F. (1994). Determination of nitrogen in fertilizer by combustion: Collaborative study. *J. Assoc. Anal. Comm. Intl., 77*(4), 829-839.

USDA. (1979). Field manual for research in agricultural hydrology. Agriculture Handbook No. 224. Washington, D.C.: USDA.

Weather Bureau. (1963). Rainfall frequency atlas of the United States. Technical Paper No. 40. Washington, D.C.: U.S. Department of Commerce, Weather Bureau.

Woodbury, B. L., Miller, D. N., Nienaber, J. A., & Eigenberg, R. A. (2001). Seasonal and spatial variations of denitrifying enzyme activity in feedlot soil. *Trans. ASAE, 44*(6), 1635-1642. http://dx.doi.org/10.13031/2013.7050.