HYDRAULIC CONDUCTIVITY, BULK DENSITY, MOISTURE CONTENT, AND ELECTRICAL CONDUCTIVITY OF A NEW SANDY LOAM FEEDLOT SURFACE

M. C. McCullough, D. B. Parker, C. A. Robinson, B. W. Auvermann

ABSTRACT. *Infiltration of nutrients and salts into earthen feedlot surfaces is of concern because of possible groundwater contamination. An experiment was conducted at a new feedlot to quantify changes in hydraulic conductivity and bulk density in the upper 15 cm of the feedlot surface. Moisture content and electrical conductivity were also monitored in the upper 210 cm of the soil profile. Soil samples were obtained immediately after construction of the feedlot (initial samples) and again nine months after introducing animals to the pens (nine–month samples). Soil samples were collected from three areas (apron, water trough, bottom) within each of four pens and also from a control plot located just outside the pens. Undisturbed soil cores from the upper 15 cm were tested for saturated hydraulic conductivity (K_S) and bulk density. Soil samples were collected from 210–cm deep borings in 15–cm increments for moisture content and electrical conductivity. The geometric mean K_S of initial samples ranged from 9.3E–6 to 1.8E–5 cm/s, while nine–month samples ranged from 5.3E–7 to 1.9E–6 cm/s. Over the nine–month period, geometric mean K_S values decreased by 23 times for the apron area, 5 times for the water trough area, and 34 times for the bottom area. There were no significant differences observed in bulk density over the same time period. The amount of water stored in the upper 210 cm of the soil profile increased during the nine–month period within the pens and the control area, ranging from 14.2 to 20.3 cm. Electrical conductivity in the pen areas increased considerably in the surface 5 cm. This research shows that K_S values of sandy loam surfaced beef cattle feedlots can be expected to decrease by one to two orders of magnitude during the first nine months of stocking, and that some infiltration of water and salts can be expected during this time period.*

Keywords. *Seepage, Infiltration, Feedlot, Beef cattle, Hydraulic Conductivity, Density, Manure.*

More than 7 million beef cattle are fed each year in feedlots in the Texas High Plains (SPS, 1999). There are 70 feedlots with capacities greater than 20,000 cattle, with several yards as large as 85,000 head capacity. Beef cattle feedlots in the Texas High Plains are constructed as open lots with earthen pen surfaces. Animals deposit manure (feces and urine) directly on the open lot surface, and the manure is scraped and removed every 180 to 365 days. Front–end loaders are used most often for removing manure from pens.

The Texas High Plains is a semiarid environment with an average annual precipitation of 46 cm. Precipitation falling on the pen surfaces makes direct contact with manure, creating a nutrient and salt rich effluent. Runoff from feedlots is produced at the rate of about 10 cm/year from the pen areas, which corresponds to 22% of the total precipitation (Sweeten, 1996). The remaining 36 cm is absorbed by the manure pack and either evaporates or infiltrates. There are about 4,900 ha of pen surface in Texas High Plains feedlots, producing about 4.9E+6 m^3 of runoff from the pen areas per year with 1.76E+7 m^3 lost to evaporation or infiltration.

The profile of a beef cattle feedlot surface varies from most natural soil profiles. Feedlots do not sustain vegetation, therefore plant roots play no role in soil water extraction. Feedlot profiles generally have more uniform moisture content than cropped land profiles (Mielke et al., 1974). Distinct layers form on the earthen feedlot surface over time. Variable in depth, the layers consist of a loose manure layer on the surface overlaying a compacted manure layer, and a transition layer consisting of mixed soil and manure (Mielke et al., 1974).

When examining soil profile conditions of cattle feedlots, Elliott et al. (1973) reported feedlot surfaces have negligible seepage or chemical transport through the profile after a compacted manure layer has formed. Mielke et al. (1974) reported the feedlot surface seals due to a combination of compaction and plugging from soil particle dispersion caused by manure. Mielke also stated texture of the soil profiles under the feedlots appeared to have little effect on the water movement into the profile or runoff characteristics for a mature feedlot. Mielke attempted infiltration measurements in a feedlot using the concentric cylinder technique. He stated infiltration was so slow that the infiltration rate could not be measured, and expansion of the

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soil caused problems with inaccurate measurements. In Australia, Southcott and Lott (1996) had similar problems when using a disc permeameter to measure saturated hydraulic conductivity of feedlot surfaces. They found the feedlot surface was too hard to drive the rings in without significant disturbance of the surface, so they placed the rings directly on the surface and sealed the edges with plasticine. Southcott and Lott compared saturated hydraulic conductivities of a new feedlot before stocking and six months after stocking. In a clayey gravel soil, hydraulic conductivities decreased from 3.1E–5 cm/s before stocking to 2.3E–6 cm/s after six months, a reduction of 13 times. In a silty sand soil, hydraulic conductivities decreased from 2.5E–4 cm/s before stocking to 1.4E–6 cm/s after six months, a reduction of 178 times. They credited the reduction of hydraulic conductivity of a feedlot surface to the thin transition layer between the manure and the original soil surface.

In Canada, Rowsell et al. (1985) found organic solids lodged between soil particles when examining soil that had been exposed to beef manure infiltration. In addition to physical blockage, biochemical mechanisms can develop that destroy the macrostructure of the soil (Barrington and Jutras, 1983; Barrington and Madramootoo, 1989). In research unrelated to feedlots, Meerdink et al. (1996) found that unsaturated hydraulic conductivities were strongly affected by compactive effort.

Technologies available for measuring saturated hydraulic conductivities have improved significantly in the past 10 years. Flexible wall permeameters equipped with precise electronics are now capable of measuring saturated hydraulic conductivities of less than 1E–7 cm/s (ASTM, 1996c). Using a flexible wall permeameter, hydraulic conductivities of feedlot surfaces can be accurately measured, making it possible to quantify the extent of sealing that occurs on the feedlot surface.

Most of the previous research on soil sealing by manure has been done on swine and dairy manure and under continuously saturated conditions, significantly different from most cattle feedlots (Barrington and Jutras, 1983; Barrington and Madramootoo, 1989; Chang et al., 1974; Culley and Phillips, 1982; DeTar, 1979; Hills, 1976; Parker et al., 1999). Researchers have taken different approaches to assessing solute infiltration. Some researchers have chosen to measure specific nutrients while others have used indicators of solute movement (such as salinity or electrical conductivity). One of the benefits of using electrical conductivity (EC) is that many observations can be made in a rapid and inexpensive manner. Maule and Fonstad (1996) used EC to monitor seepage beneath hog manure storages. Smith et al. (1993) used EC and other parameters to assess infiltration of feedlot wastes into natural shallow lakes, while Westerman et al. (1993) used EC to assess seepage of swine lagoon effluent in sandy soils. Nonintrusive techniques have also been used to measure groundwater contamination by measuring the apparent electrical conductivities surrounding animal waste lagoons (Brune and Doolittle, 1990; Huffman and Westerman, 1993).

Infiltration into earthen feedlot surfaces is a concern as some nutrients and pathogens can cause groundwater contamination. Water balance, infiltration, and solute fate and transport models are often used in the risk assessment and permitting process for existing and proposed feedlots. Modelers need representative hydraulic conductivity and bulk density values to be used in these models. The primary objective of this research was to quantify the extent of sealing that occurs on a sandy loam feedlot surface by monitoring changes in saturated hydraulic conductivity in the surface 15 cm. A secondary objective was to determine if infiltration of water and solutes could be detected during the first nine months of feedlot operation.

MATERIALS AND METHODS

The research was performed at West Texas A&M University's new beef cattle research feedlot located 10 km east of Canyon, Texas. The feedlot has 30 identical pens, 6 × 26 m, each with a concrete apron below the feed bunk and a concrete pad surrounding the water trough (fig. 1). Each pen has a capacity of 10 cattle, for a stocking rate of 15.6 m^2 per animal.

Four identical pens in orientation, layout, and drainage features (2% slope) were selected. A control area located just outside the pen area was sampled and kept free of animal traffic and plant growth (fig. 1). A berm was constructed between the pens and the control area to prevent runoff entering the control area.

The soil covering the original feedlot area and all soil imported from nearby for grading during construction of the feedlot was Amarillo fine sandy loam (fine–loamy, mixed, thermic Aridic Paleustalfs) (NRCS, 1970). The soil was characterized for particle size distribution (ASTM, 1996a), compaction characteristics (ASTM, 1996d), and plasticity (ASTM, 1996b). The sandy loam extended from the surface to a depth of 156 cm. From the surface to 30 cm depth, the soil was composed of 59.1% sand (2 to 0.05 mm), 36.9% silt (0.002 to 0.05 mm) and 4.0% clay (<0.002 mm), with 47.2% passing the no. 200 sieve. The soil was relatively uniform down to 156 cm, with 55.2 and 52.9% passing the no. 200

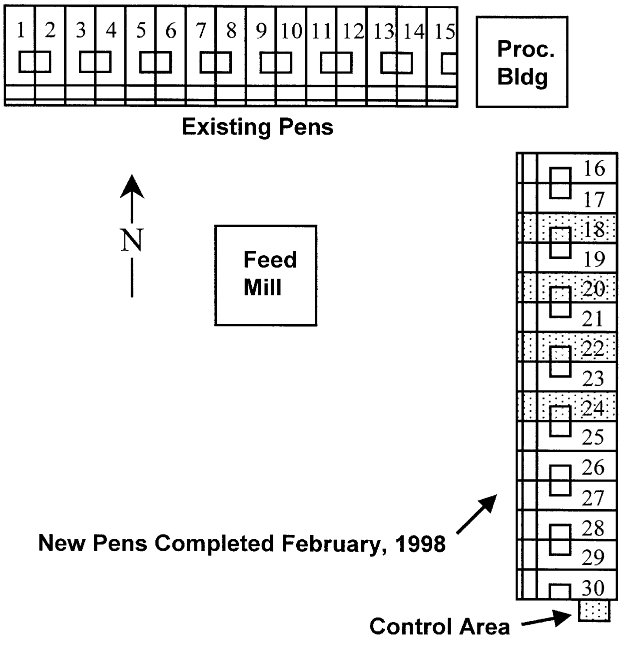

Figure 1. Layout of the research feedlot. The research was performed in pens 18, 20, 22, and 24.

sieve at depths of 30–60 and 60–156 cm, respectively. From 156 to 210 cm, the soil graded coarser and was classified as loamy sand per the USDA classification (86.2% sand, 12.4% silt, 1.4% clay).

The soil was nonplastic and was classified as SM per the Unified Soil Classification System (USCS). The maximum dry density was 1.83 g/cm^3 per the "Standard Proctor" compaction test, ASTM Method D 698 (ASTM, 1996d). Construction specifications required the soil in the pens and control area be compacted to no less than 95% of maximum dry density. Actual dry densities immediately after construction were 99 to 102% of the maximum dry density.

Soil samples were collected from three distinct areas in each of the four pens: (1) the apron, (2) the water trough, and (3) the bottom (fig. 2). Initial soil samples were collected in late March 1998, two weeks prior to initial stocking. In mid–January 1999, after nine months of stocking, a second set of samples was collected using the same sampling techniques.

Undisturbed soil cores were obtained from the first 15 cm for analysis of K_S and bulk density. Three soil cores were collected at each location in the pen as shown in figure 2. The cores were obtained by driving a 7.3–cm diameter thin–wall sampler into the ground with a slide hammer. A metal holder was placed over the top to prevent damaging the tube. One additional core from each of the apron, water trough, and bottom areas was collected and analyzed for volatile solids (organic matter) content in 1–cm increments in the upper 15 cm. Additional soil samples for moisture content and electrical conductivity analysis were collected in 15–cm increments to a depth of 210 cm from one boring at each location within the pen (fig. 2). These samples were collected using either a tractor–mounted hydraulic probe or a hand auger.

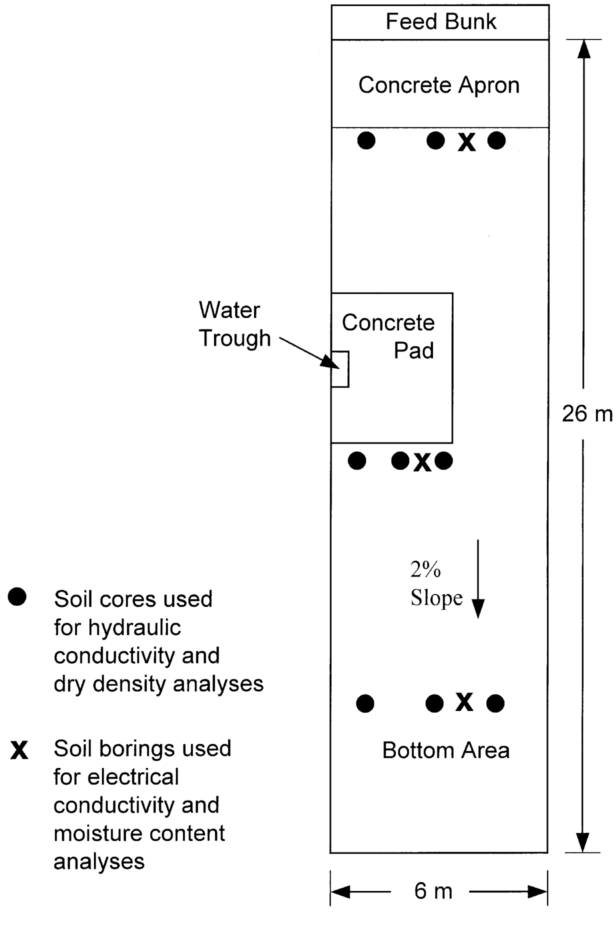

Figure 2. Pen layout and soil sampling locations.

Gravimetric moisture content was determined after oven drying at 105° C for 24 h (Gardner, 1986). Volatile solids content was determined by combustion at 550°C for 1 h (ASAE, 1999). Electrical conductivity was measured using an electrical conductivity meter and a saturated soil solution. The soil solution was made from one part soil to two parts water by weight as recommended by Sonnevelt and van den Ende (Rhoades, 1996). The electrical conductivity probe was rinsed with distilled water after each reading and was checked against standard solutions after every fifth reading and between treatments.

Bulk density (Blake and Hartge, 1986) was determined using the cores from the hydraulic conductivity tests. The height and weight of each core were noted prior to and after hydraulic conductivity testing. Cores were oven dried at 105°C for 48 hours.

The same sampling procedures were used to collect soil cores and boring samples in the 1.8– × 1.8–m control area. During construction, the control area was compacted to the same specifications as the pens. Cattle had no access to the control area, so it was not affected by hoof action or manure accumulation. The control area was covered with a weed barrier fabric to prevent vegetation from growing.

The saturated hydraulic conductivity of each soil core was measured using a flexible wall permeameter (SoilTest Tri–Flex 2 One–Cell Permeability Test System, ELE International, Lake Bluff, Ill.) following ASTM Method D 5084 (ASTM, 1996c). The soil cores were extruded from the thin wall sampler using a hydraulic ram and trimmed to a length of 15 cm. A latex membrane was placed around the core, and saturated filter paper and porous stones were placed on each end of the core. Two rubber o–rings affixed the membrane around each plastic end piece.

The soil sample was placed within a Plexiglas test cell and the cell was filled with water. A small pressure was applied to the test cell, providing a lateral pressure of about 34.5 kPa (5.0 psi) to the soil sample. The core was saturated from bottom to top, allowing soil air to escape more easily. A small gradient was applied to the core during saturation by applying a pressure of 20.7 kPa (3.0 psi) to the bottom and 13.8 kPa (2.0 psi) to the top of the core. When no air bubbles were observed at the top, the pressures were increased in 13.8– to 34.5–kPa (2.0– to 5.0–psi) increments, pausing at each increase until air bubbles were no longer observed. Pressures were increased to a maximum of 206.9–kPa (30.0–psi) lateral pressure, 172.4–kPa (25.0–psi) head pressure, and 124.1–kPa (18.0–psi) tail pressure. The entire saturation process took about 8 h per sample for initial samples and two days per sample for nine–month samples. Based on ASTM guidelines, the soil cores reached nearly 97% saturation using this method.

Typical confining, head, and tail pressures during K_S measurement for initial samples were 137.9, 124.1, and 103.4 kPa (20.0, 18.0, and 15.0 psi), respectively. Because of the lower K_S in the nine–month samples, a larger hydraulic gradient was used to increase flow where it could be measured in a timely manner. For the nine–month samples, typical confining, head, and tail pressures were 137.9, 124.1, and 82.8 kPa (20.0, 18.0 and 12.0 psi), respectively.

Leakage from the latex membrane was evaluated by monitoring the volume of water in the test cell surrounding the soil core. Lateral movement indicated a leak in the latex membrane surrounding the soil core. Following ASTM guidelines, the test was redone if leakage exceeded 10% of the volume of water passing through the soil core. Per ASTM guidelines, three K_S values were measured for each core, and the geometric mean of the three readings was used as the representative K_S value for that core (ASTM, 1996c).

Statistical analyses were performed using a spreadsheet and SPSS Version 7.0. Hydraulic conductivity data were log–transformed (geometric means were compared) prior to running ANOVA and LSD comparisons because hydraulic conductivity data has been shown to be lognormally distributed (Freeze and Cherry, 1979).

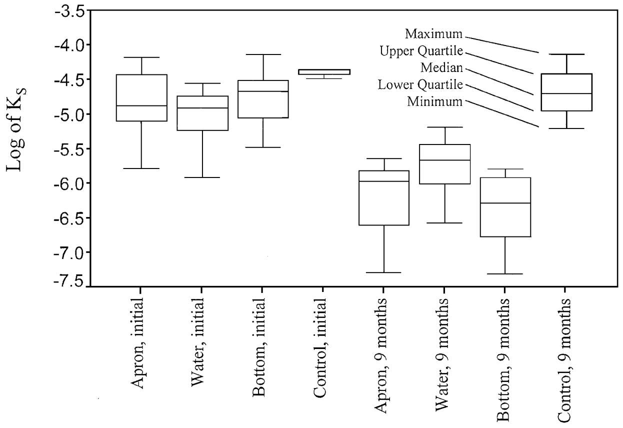

Figure 4. Boxplots of log K_S values for the control and three locations within the pen comparing values prior to stocking (initial) and after nine months of stocking. Units of original K_S values were cm/s.

RESULTS AND DISCUSSION

Nine–month core samples for K_S measurement exhibited a compacted manure–soil mixture in the upper 5 to 7 cm. This surface layer had a dry basis volatile solids (VS) content of 12 to 20% (fig. 3), which compares to a volatile solids content (dry basis) of about 47% for fresh beef cattle manure (NRCS, 1992). Immediately below the compacted manure/soil layer was a 2– to 3–cm thick transition layer (VS = 2 to 10%). Below the transition layer was native soil with VS ranging from 0.3 to 2%. In comparison, Southcott and Lott (1996) found a 2.0– to 4.0–cm accumulation of compact manure, but only a 0.1– to 0.5–cm thick, poorly defined transition layer. Mielke et al. (1974) reported a 7– to 10–cm compacted manure layer and a transition layer of about 5 cm.

Boxplots providing a visual representation of the log10 K_S values are shown in figure 4. The boxplots show the medians and ranges of all four sampling locations for the two sampling periods. For the initial sampling period, similar medians and ranges are observed for all locations within the pen and the control (fig. 4). The apron, water trough, and bottom nine–month data had lower log K_S values, an indication that sealing had occurred in these locations.

There were no statistically significant differences initially between geometric mean K_S values at different locations within the pen and the control area, an indication that compaction during construction was relatively uniform (table 1). Initial geometric mean K_S values ranged from 9.3E–6 to 1.8E–5 cm/s after construction, while nine months later they ranged from 5.3E–7 to 1.9E–6 cm/s (table 1). Geometric mean K_S decreased significantly after nine months for the apron, water trough, and bottom areas, but not for the control area. Geometric mean K_S values decreased by 23 times for the apron area, 5 times for the water trough area, and 34 times for the bottom area.

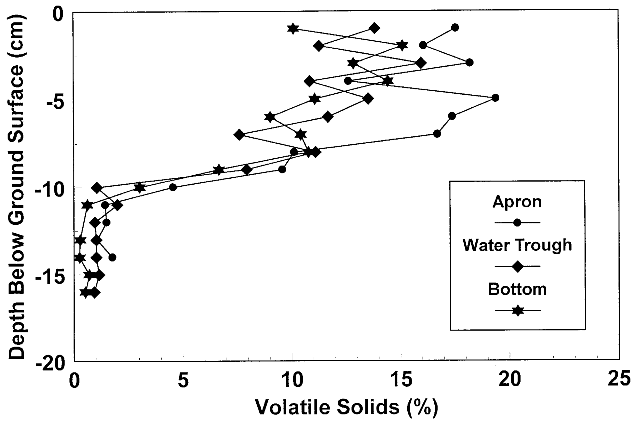

Figure 3. Volatile solids contents in three soil cores nine months after placing cattle in pens.

Moisture contents increased over the nine–month period throughout the profile for all pen areas and the control area (figs. 5 and 6) and were highest near the soil surface. The total precipitation over the nine–month period was 29.1 cm, of which October accounted for 19.5 cm. In the control area, 18.6 cm of water was stored in the upper 210 cm of the soil profile during the nine–month period. Thus, at least 64% of the nine–month precipitation can be accounted for based on this increase in water stored in the soil profile. The remainder of precipitation was either lost to evaporation, deep infiltration, or runoff. In the pen areas, manure (feces plus urine) deposited on the feedlot surface added an additional 35 cm of water, while urine alone added about 13 cm of water. During the nine–month period, 20.2, 14.2, and 20.3 cm of water was stored in the upper 210 cm in the apron, water trough, and bottom areas, respectively, which corresponds to

Table 1. Summary of saturated hydraulic conductivity measurements initially and after nine months.

Sampling Date	Sampling Location	No. of Samples Analyzed	Geometric Mean Hydraulic Conductivity (cm/s)[a]	Mean Dry Density (g/cm^3)	Std. Dev. Dry Density
Initial					
	Apron	12	1.4E–05 a	1.84 a	0.18
	Water Trough	12	9.3E–06 a	1.81 a	0.20
	Bottom	12	1.8E–05 a	1.84 a	0.18
	Control	3	4.0E–05 a	1.87 a	0.10
9 months					
	Apron	12	6.2E–07 c	1.74 a	0.13
	Water Trough	12	1.9E–06 b	1.73 a	0.07
	Bottom	12	5.3E–07 c	1.75 a	0.15
	Control	3	2.2E–05 a	1.84 a	0.06

[a] Using LSD comparisons, means within a column with different letters are significantly different at α = 0.05.

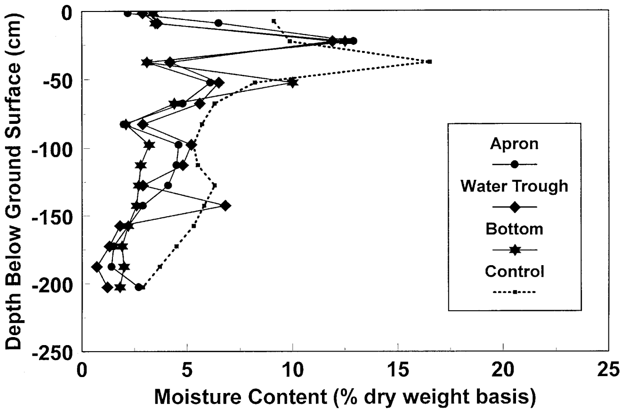

Figure 5. Moisture content of soil profiles immediately after construction of the feedlot and prior to placing cattle in the pens. Each data point is the average of four observations.

22–32% of the total water (precipitation and manure) deposited on the feedlot surface. The exact amount of water infiltrated into the feedlot surface cannot be determined because the amount of infiltration deeper than 210 cm is unknown.

There were no statistically significant differences in mean bulk densities of the top 15 cm of the feedlot surface between the initial and nine–month samples (table 1). Given that the soil surface was compacted to more than 99% of maximum dry density during construction of the feedlot, this is not surprising. In contrast, Mielke et al. (1974) showed that the bulk density of the top manure layer was less than half of the original soil surface. Mielke also showed that the bulk density of the bottom of the transition layer was greater than the underlying soil. Both Mielke et al. (1974) and Southcott and Lott (1996) have indicated that it is the transition layer that causes the reduction in saturated hydraulic conductivities of the feedlot surface. Given the significant decrease in hydraulic conductivities with little change in bulk densities in the upper 15 cm, a similar conclusion was determined for the sandy loam soil in this research.

The bottom area was more difficult to sample than the apron, water trough, and control areas, an indication of higher soil strength in the bottom area. There are several possibilities for why the soil strength might be greater, including higher bulk density, lower moisture content, or greater cohesion resulting from mixing of manure and soil. Because the moisture content of the bottom area was only slightly lower than the apron and water trough areas, it is unlikely that moisture content alone was the cause of the increased near–surface soil strength. The control area was considerably easier to sample after nine months than the three pen areas, though the mean dry density of the upper 15 cm was not significantly different. This is another indication that, although not evident from the bulk density of the entire upper 15 cm, the transition layer was compacted or otherwise modified resulting in higher soil strength as compared to the control area.

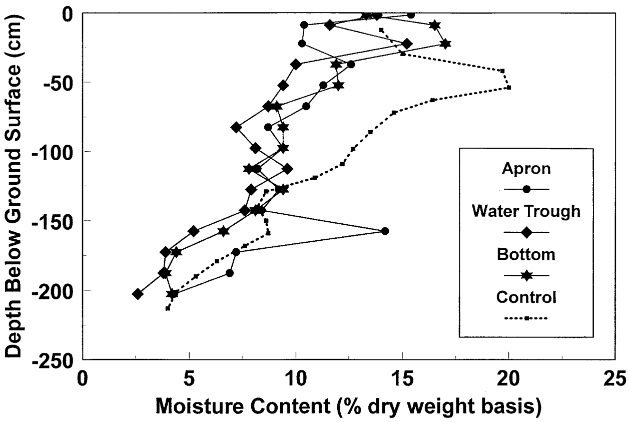

Figure 6. Moisture content of soil profiles nine months after placing cattle in the pens. Each data point is the average of four observations.

After nine months, electrical conductivity increased near the surface of the apron, water trough, and bottom areas, corresponding with the layer of organic matter accumulation near the surface of the pens (figs. 7 and 8). No increase of electrical conductivity was observed near the surface of the control area. There was evidence of solute movement based on elevated electrical conductivity values to the maximum soil sampling depth of 210 cm in all of the samples within the feedlot pens. There were few differences in electrical conductivities among the three pen locations. Electrical conductivity changed little during the nine–month period for the control area (figs. 7 and 8).

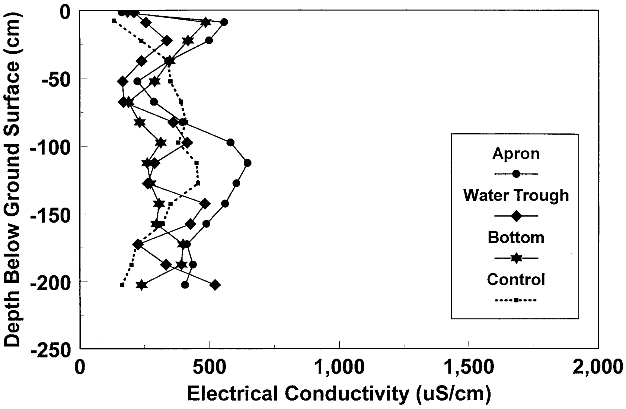

Figure 7. Electrical conductivity of soil profiles immediately after construction of the feedlot and prior to placing cattle in the pens. Each data point is the average of four observations.

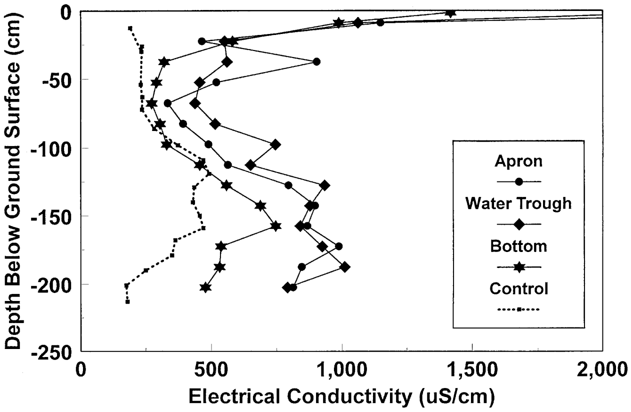

Figure 8. Electrical conductivity of soil profiles nine months after placing cattle in the pens. Each data point is the average of four observations.

CONCLUSIONS

The saturated hydraulic conductivity of the feedlot surface decreased significantly during the nine–month stocking period. The geometric mean K_S of initial samples ranged from 9.3E–6 to 1.8E–5 cm/s, while nine–month samples ranged from 5.3E–7 to 1.9E–6 cm/s. Geometric mean K_S decreased by 23 times for the apron area, 5 times for the water trough area, and 34 times for the bottom area. Final K_S values were lowest in the bottom area, which is the area that cattle frequent most often. Contrary to previous research projects, the dry density of the upper 15 cm of the feedlot surface did not change significantly over the nine–month period, probably because the feedlot surface had been compacted prior to stocking. Of the 64 cm of water (29 cm from precipitation and 35 cm from manure) deposited on the feedlot surface during the nine–month period, 14 to 20 cm was accounted for in storage in the upper 210 cm of the soil profile in the feedlot. Most of this water was likely infiltrated before formation of the surface seal. This research shows that K_S values of sandy loam surfaced beef cattle feedlots can be expected to decrease by one to two orders of magnitude during the first nine months of stocking. While some infiltration of water and salts can be expected during this time period, it is likely that limited infiltration will take place after the feedlot surface has sealed.

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