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ABSTRACT. *The maintenance of feedlot pen surfaces, which includes removal of manure and replacement of fill soil, is a time-consuming and expensive process. Pond ash (PA), a by-product of coal-fired electrical generation, has been proposed as a feedlot pen surface amendment because of its foundational support characteristics. A study was conducted to compare the performance of PA-surfaced pens to traditional soil-surfaced (SS) pens. Four of eight SS pens (7.3 m × 20.7 m) were excavated to a depth of 0.5 m and resurfaced with PA. The remaining four pens were kept as SS. Eight heifers were housed in each pen (19 m^2 $head^{-1}$) for four feeding cycles that ranged from 73 to 172 days. Following each feeding cycle, the animals were removed and the pens were cleaned. A subsample of the accumulated manure was removed from each pen for analysis of total mass (TM), total solids (TS), volatile solids (VS), percent volatile solids (VS%), moisture, and ash content. Higher heating value (HHV) was estimated using the VS% and moisture content. As compared to the SS pens, surfacing pens with PA reduced TM by 34%, TS by 34%, and ash content by 46%. PA increased VS% by 70% and HHV by 75%. Restoring the PA-surfaced pens to the original grade required only 25% of the amount of fill material required for the SS pens. However, there were no differences in the total amount of VS removed. Harvested feedlot surface material (FSM) from the PA pens was more nutrient and energy dense, based on the increased VS% of the collected material. The increased density improved the economics of transport and handling, and allowed for greater energy recovery. In addition, the PA pens were less erodible than the SS pens.*

Keywords. *Animal waste, Beef cattle, Bioenergy, Biosolids, Combustion, Energy recovery, Land application, Manure, Renewable energy, Waste management.*

One of the difficulties of using soil as a surface material for feedlot pens is that soil becomes muddy during high-moisture conditions. Muddy surfaces impact the animals' health and performance, and the stirring action of their hooves mixes the manure and soil (Parker et al., 2004; Clanton et al., 2005). Mixed soil and manure that accumulates on the feedlot surface creates a management problem, since the manure/soil needs to be removed periodically and soil must be brought back in to maintain proper pen surface elevation. Typical percent volatile solids of feedlot surface material (FSM) at the USDA-ARS U.S. Meat Animal Research Center (Clay Center, Nebraska) are only 25% to 35%, which indicates that most of the material removed is soil (Woodbury et al., 2010). Replacing soil that was removed when the pens were cleaned can be a considerable expense for feedlot operators in their attempt to maintain pen surfaces at the recommended grade (Parker et al., 2004).

Fly ash is a by-product of coal-fired electrical generation (ACAA, 2006). Typical uses of fly ash include concrete production, embankments, grout, waste stabilization and solidification, mine reclamation, stabilization of soft soils, and road sub-base construction (ACAA, 2006). Its use as a feedlot pen construction material has also been investigated (Kalinski et al., 2005; Parker et al., 2004; Sweeten et al., 2006). However, high construction costs and a concern for animal leg and hoof health issues have limited the use of fly ash by the feedlot industry.

Pond ash is fly ash that has been flushed to evaporative ponds for storage. The evaporative pond is subsequently dewatered, and the pond ash is excavated for disposal. Pond ash is valuable as a structural material, but it is different from fly ash because much of its cementing properties are lost. Therefore, pond ash may be an adequate compromise between hard-surface materials, such as cement and fly ash, and a highly erodible, ductile material like soil.

The objective of this study was to evaluate the effect of pond ash (PA) feedlot pen surfaces and traditional soil-surfaced (SS) pens on unconsolidated FSM properties to determine the suitability of PA surfacing as a management practice. Unconsolidated FSM performance was measured for total mass (TM), total solids (TS), volatile solids (VS), percent volatile solids (VS%), ash content, moisture, and estimated higher heating value (HHV).

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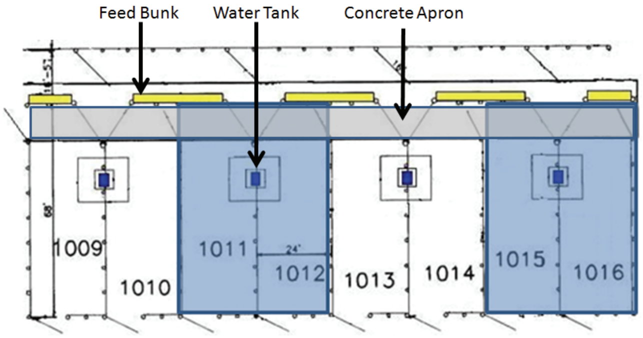

Figure 1. Diagram of feedlot pens 1009 through 1016 used during the study. The shaded pens had pond ash surfaces.

MATERIALS AND METHODS

This study was performed in conjunction with another study that was designed to determine how animals with known risk factors for heat stress (color, previous cases of pneumonia, condition score, and temperament) respond to having access to shade (Brown-Brandl et al., 2010). Feedlot heifers of two breeds (Angus and Charolais) and two crossbreeds (MARC I [1/4 Charolais, 1/4 Braunvieh, 1/4 Limousin, 1/8 Angus, and 1/8 Hereford] and MARC III [1/4 Pinzgauer, 1/4 Red Poll, 1/4 Hereford, and 1/4 Angus]) were selected and penned on the basis of weight and breed. Eight pens, each measuring 7.3 m × 20.7 m, were used during the study (fig. 1). Each pen housed eight heifers, for a total of 64 heifers per feeding cycle. Animals were removed from the pens when they achieved market weight. Data from four feeding cycles (1 through 4) were used to evaluate the pen surface materials. Dietary ingredients and percentages fed during each feeding cycle are presented in table 1. Animals were weighed approximately every 28 days to determine average daily gain during the feeding cycle (table 2). Feeding cycle start and stop dates are listed in table 3.

All eight pens were constructed on a Hastings silt loam soil (fine, smectitic, mesic Udic Argiustolls). Four of the eight pens were modified by removing the soil surface and replacing it with PA. The PA was obtained from the evaporative pond of a nearby coal-fired electrical power plant. Specifically, pens 1011, 1012, 1015, and 1016 were excavated to a depth of 0.5 m and then returned to grade with PA (fig. 1). The installation of the PA was performed in 0.15 m increments followed by compaction using a sheep-foot compactor after each increment. Water was added to each layer to facilitate compaction. The remaining four pens (1009, 1010, 1013, and 1014) were not altered. At the end of each feeding cycle, these SS pens were returned to grade using soil excavated from a soil pit that was located in the Hastings silt loam soil. This soil pit was operated by removing the upper 0.5 m of top soil, so the remaining soil used for fill in the SS pens was from the C-horizon of this soil series. The C-horizon is typified by a silt loam texture with free carbonates. Wooden barriers were installed at the bottom of the pen fences to isolate SS from PA pen treatments. Monthly precipitation amounts are presented in table 4.

Table 1. Primary dietary constituents fed during study period.

Feed Constituent	Feeding Cycle 1	2	3	4
Corn (%)	82.8	22.4	79.0	76.2
Corn silage (%)	12.7	66.0	13.0	19.2
Liquid Biegert (%)	4.5	4.5	4.5	4.6
CO 15 (%)	-	7.1	3.5	-

Table 2. Average daily gain for each pen during the study period (values are in kg; numbers in parentheses are standard deviations).

Surface Material and Pen	Feeding Cycle 1	2	3	4
Soil				
1009	1.3 (0.38)	1.3 (0.26)	0.9 (0.12)	0.9 (0.38)
1010	1.3 (0.47)	1.4 (0.47)	0.9 (0.32)	0.8 (0.33)
1013	1.6 (0.22)	1.3 (0.33)	0.9 (0.35)	0.8 (0.38)
1014	1.2 (0.38)	1.4 (0.22)	1.0 (0.31)	0.8 (0.37)
Average	1.4	1.4	0.9	0.8
Pond ash				
1011	1.3 (0.60)	1.4 (0.24)	0.9 (0.14)	0.9 (0.40)
1012	1.5 (0.45)	1.4 (0.33)	1.0 (0.30)	0.8 (0.39)
1015	1.6 (0.42)	1.4 (0.10)	0.9 (0.15)	0.9 (0.35)
1016	1.5 (0.31)	1.3 (0.31)	0.9 (0.27)	0.9 (0.27)
Average	1.5	1.4	0.9	0.9
p-value	0.221	0.510	0.885	0.134

Table 3. Feeding cycle dates and lengths for the study period.

Feeding Cycle	Date In	Date Out	No. of Days
1	15 May 2006	8 Aug. 2006	86
2	1 Feb. 2007	25 May 2007	114
3	5 June 2007	16 Aug. 2007	73
4	7 Jan. 2008	26 June 2008	172

Table 4. Monthly precipitation totals for storms greater than 13 mm during the 2006, 2007, and 2008 seasons (values are in mm).

Month	2006	2007	2008
April	18	102	55
May	79	110	129
June	46	45	57
July	91	78	128
August	78	106	81
September	63	39	39
October	0	130	135
Seasonal total	375	610	624

Following animal removal at the end of each feeding cycle, the FSM was scraped and piled in the center of each pen. This collected material was loaded into a truck and weighed using a truck scale to determine the TM. Prior to loading, approximately 12 to 15 subsamples were removed from the collected FSM. The subsamples were taken randomly from various depths and locations within the pile. These subsamples were compiled until a total volume of approximately 0.04 m^3 was obtained. A composite sample was obtained after thoroughly mixing all the subsamples. A 1 kg composite sample of FSM was removed to determine the moisture, TS, VS, VS%, and ash contents for each pen. Total mass was determined gravimetrically. Total solids were determined by removing the moisture content from the TM. The moisture content (dry basis) was measured using the direct method with oven drying, as described by Gardner (1965). Total solids were identified by adjusting the total mass by the moisture content. Volatile solids percent was determined using the "loss on ignition" procedure described by Nelson and Sommers (1996). Ash content was measured following the "loss on ignition" analysis (Nelson and Sommers, 1996). The VS was determined by multiplying the VS% by the TS to determine the mass of volatiles collected.

After the FSM was removed from each pen at the end of each feeding cycle, the pens were reconditioned by bringing fill material into each pen to return to grade. The amount of fill material added was determined by counting the number of uniformly filled skid-steer loader buckets that were required to visually return the pen surface to grade. To estimate the mass contained in each bucket, four uniformly filled buckets of fill material were placed in a truck to determine the net weight. This procedure was repeated three times for each fill material. These values were used to estimate the average mass of fill material in each bucket. The procedure was repeated after each feeding cycle to allow for the varying moisture content of the fill materials. The FSM constituent mean differences were analyzed using the TTEST procedure in SAS (SAS Institute, Inc., Cary, N.C.). Effects were considered significant at $p < 0.05$.

HHV is a measure of the energy available for combustion. An estimate of the HHV as a function of ash and moisture percent (eq. 1) was used in this study (UNL, 2008):

$$\mathrm{HHV}\left(\mathrm{kJ\ kg^{-1}}\right) = 1.98 \times \left(100 - \mathrm{ash\%}\right) \times \left(100 - \mathrm{moisture\%}\right) \tag{1}$$

Results and Discussions

The durations of the feeding cycles are presented in table 3. These durations were determined by a series of studies that was being conducted at the same time to evaluate the effect of heat stress on cattle. Average daily gains of the heifers during the four feeding cycles are listed in table 2. As indicated, there was no significant difference in the average daily gains for the animals housed on the two pen surfaces for all feeding cycles. The gross performance data suggest that neither pen surface was superior to the other. However, observations of the pen surface materials indicated that the PA pens performed differently from the SS pens, particularly during and shortly after precipitation events. It was observed that the PA pens, when wet, did not allow the animals to sink as deeply into the wet surface. The PA pens also dried more quickly than the SS pens, and the surface was less rough (fig. 2). The rougher surface of the SS pens tended to pond water rather than shed it, like the smoother PA pens.

The TM collected varied greatly among the feeding cycles due to the varying feeding cycle durations and environmental conditions. However, there were significant differences in the amount of TM collected between the SS and PA pens for each feeding cycle (fig. 3). For each feeding cycle, the SS pens had greater TM than the PA pens. The reduced TM of the PA pens is probably due to the cementing or pozzolanic properties of the PA material. These processes tended to bind the particles together and resist mixing with the manure, particularly when wet. There was a significant ($p = 0.039$) reduction in the overall average TM collected and removed from the PA pens when

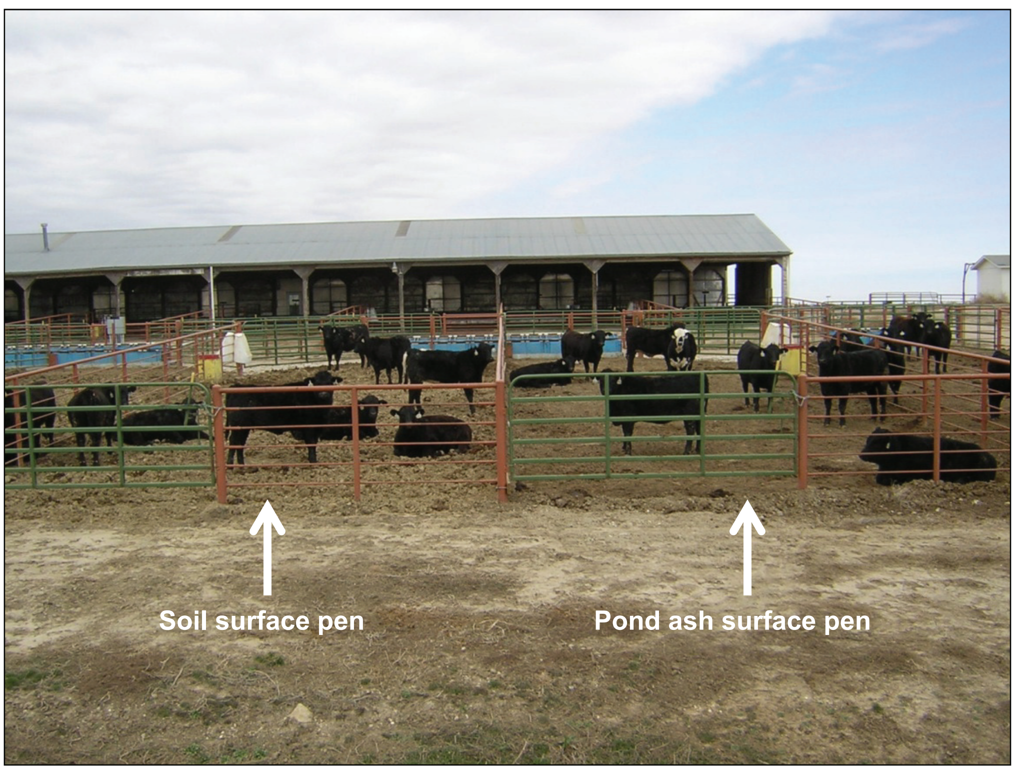

Figure 2. Photograph of a soil surface (SS) per and pond ash (PA) surface pen shortly after a precipitation event. Note the rougher surface texture of the SS pen and the smoother texture of the PA pen. The SS pens did not shed water as effectively as the PA pens.

compared to the SS pens over the four feeding cycles. Using PA as a surfacing material reduced the TM by approximately 34% (table 5). Observationally, the PA treatment pens tended to shed water more effectively and they dried faster than the SS pens. However, this observation was not reflected in the data, since there was no significant difference in the water content of the material that was collected (table 5). Additional work will have to be done to quantify the differences in drying rates of the two pen surfaces following a precipitation event.

The amount of TS collected varied significantly among the feeding cycles (fig. 3). For each feeding cycle, the SS pens had more TS than the PA pens. There were also significant ($p = 0.030$) reductions in the overall mean TS content of the FSM collected from the PA treatment pens (table 5). Using PA as a surfacing material reduced the overall TS collected by approximately 34%.

For a given feedlot surface, the VS% collected generally did not vary significantly among the feeding cycles (fig. 3). However, there were similar patterns of significant differences in the amount of VS% collected between the SS and PA pens for each feeding cycle (fig. 3). The PA pens had greater VS% than the SS pens for each feeding cycle. There were also significant increases in the overall VS% of the collected material for the PA pens when compared to the SS pens ($p = 0.001$) (table 5). Using PA as a surfacing material increased the VS% of the material that was removed by approximately 70%.

Sweeten et al. (2006) observed similar increases in VS% when they compared pens surfaced with a mixture of fly ash and bottom ash to SS pens located in the Texas Panhandle. They reported the VS% of soil surface pens as 33.8% and the VS% of fly ash pens as 64.6%. Interestingly, the VS% values of the FSM samples taken from SS treatment pens by Sweeten et al. (2006) were similar to the VS% values of the PA treatment pens in this study. Presumably, the VS% values associated with both treatments in the Sweeten et al. (2006) study were greater that the values in this study. One explanation could be that the drier climate and different chemical and physical soil properties of the southern Great Plains limited soil mixing when compared to the central Great Plains, where the feedlot used in this study is located.

The ash content (i.e., consisting primarily of soil) of the two surface materials was inversely related to the VS%. The overall average ($p = 0.001$) ash content for the SS pens was significantly greater than for the PA pens. The ash content of the PA pens was decreased by 46% when compared to the SS pens. The cementing properties of the ash material tended to bind the particles together and limited the amount of mixing with manure. This reduced the amount of non-volatile (i.e., ash) material in the FSM.

There were no measured differences in the total mass of VS collected for each feeding cycle or in overall averages (fig. 3 and table 5). This indicates that the surface treatments had no effect on the amount of VS loss due to wind or runoff. As a result, the same amount of nutrients contained in the VS could be removed from either pen surface material; however, the reduced ash content of the FSM from the PA pens would be more economical to haul for land application. The magnitude of this improved economic suitability of PA as a management practice is dependent on several variables, including fuel costs. Intrinsic in this improved hauling efficiency is the ability to cost-effectively haul the material farther from the feedlot, thereby increasing the number of acres available to include in a nutrient management plan. Increasing the available acres is especially important for feedlots that have limited local acreage due to high inherent nutrient levels (Sharpley et al., 2003). Additionally, this hauling efficiency may be very important for animals fed diets containing wet distillers grains because of the high phosphorus levels in the manure. High phosphorus levels may require land farther from the feedlot to meet the requirements of nutrient management plans.

Once the FSM has been removed, fill material must be hauled in to maintain pen integrity. There were large differences in the amount of fill material needed to restore the pens to initial study conditions. It should be noted that the PA pens during cycle 1 had no appreciable loss of soil and required no fill to be brought in to return the pen to original grade. The PA pens required significantly less fill material than the SS pens for each feeding cycle (table 6). Some of the difference can be accounted for by the amount of ash in the harvested FSM, but the remainder of the difference may be due to runoff. Although not measured, it was observed that the SS pens accumulated more sedimentary material just outside of the pen at the drainage end than the PA pens. The PA pens needed only 1/4 the amount of fill material as the SS pens to maintain pen integrity. This amount of reduction may not be fully realized by animal feeding operations, since a common practice is to scrape accumulated manure into eroded areas. However, this difference illustrates the stability of the PA

Table 5. Overall average total mass (TM), total solids (TS), volatile solids (VS), percent volatile solids (VS%), ash, and higher heating value (HHV) for the feedlot surface material obtained during this study from the soil and pond ash pens.

Surface Material	TM (kg)	TS (kg)	VS (kg)	VS (%)	Ash (kg)	H_2O (%)	HHV (kJ kg^{-1})
Soil	5269	3525	709	19.7	2816	32.0	2644
Pond ash	3467	2330	822	33.5	1511	30.0	4642
p-value	0.039	0.030	0.525	0.001	0.001	0.377	0.001

Table 6. Average surface material required to restore pens following feeding cycle (values are in kg; SD is standard deviation).

Surface Material and Pen	Feeding Cycle 1	2	3	4	
Soil					Overall
1009	10086	5627	6335	2527	
1010	9732	7255	5471	2619	
1013	4601	7609	4211	3220	
1014	8494	6936	4919	3312	
Avg.	8228	6857	5234	2920	5810
SD	2513	865	897	404	2403
Pond ash					
1011	0.0	4203	1190	851	
1012	0.0	4903	1292	1145	
1015	0.0	3152	1250	840	
1016	0.0	3178	1446	787	
Avg.	0.0	3859	1294	906	1515
SD	0.0	851	109	162	1530
t-test	0.000606	0.002597	0.000126	8.99E-05	1.28E-06

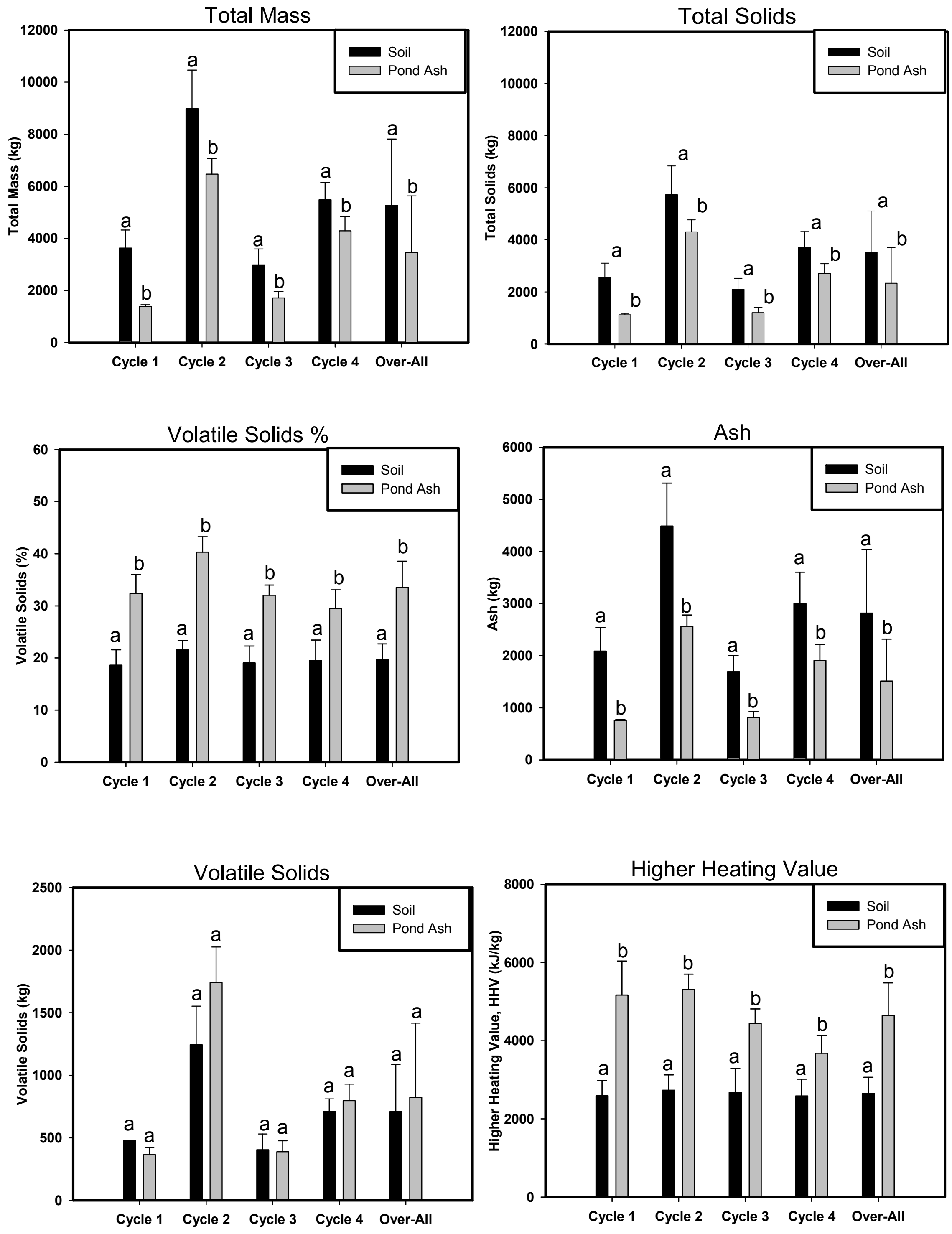

Figure 3. Properties of feedlot surface material collected from the soil and pond ash pen surface treatments. Error bars represent standard deviations. Mean differences were determined using Student's t-test with significance at p = 0.05. Differences are noted by letters above bars.

material on pen surfaces.

Energy recovery from the accumulated manure removed at the end of the feeding cycle provides an alternative to land application (Carlin et al., 2009; Eigenberg et al., 2012; Hashimoto et al., 1981; Hashimoto, 1982; Martin et al., 1983). Manure contains undigested or partially digested organic material that contains energy. The amount of energy in the manure that can be recovered is dependent on the method of recovery and the amount of moisture and volatile organic compounds contained in the manure. The higher heating values (HHV) of the accumulated manure removed at the end of each feeding cycle were statistically different (fig. 3). The PA pens had greater HHV than the SS pens for each feeding cycle. There were significant differences in the overall average HHV ($p = 0.000$) (table 5). Using PA as a pen surfacing material increased the HHV by nearly 75% when compared to the SS pens.

Feedlot surface material with sufficient VS content could yield energy recovery through direct combustion (Annamalai et al., 2003; Priyadarsan et al., 2004). Sweeten et al. (2006) found that the HHV of FSM removed from coal-ash based feedlot pen surfaces was more than twice that of FSM removed from more typical SS pens. In addition, the FSM from SS pens contained approximately 30% of the HHV per equivalent weight of coal from the Powder River basin, while the FSM from coal-ash treatment pens contained approximately 62% of the HHV per equivalent weight of coal.

According to Sweeten et al. (2006), increasing the HHV of the removed FSM could allow for more lucrative alternative uses, such as direct combustion. Sweeten et al. (2006) also stated that an added benefit of using manure for co-combustion with coal for power generation is improved quality of the flue gas from the combustion process. Carlin et al. (2009) reported that burning manure in a coal-fired power plant reduced nitrogen oxide (NO_x) emission by 60% to 90% beyond levels achieved using primary NO_x emission controllers.

Summary and Conclusions

The surfaces of four pens of an eight-pen series were excavated to a depth of approximately 0.5 m and returned to grade with PA to contrast with SS pens. A study was conducted to compare the effect of the pen surface treatments on animal performance and on the quality and quantity of the FSM removed from the pens. The study was replicated over four feeding cycles. The animals used for each feeding cycle were fed a corn-based diet. The animals were removed when they achieved market weight.

There were no significant differences in average daily gain of animals reared on either treatment. Surfacing the pens with PA reduced the TM of the FSM by 34%, TS by 34%, and ash content by 46%. There were no significant differences in the mass of VS removed from either treatment; however, the PA treatment increased the VS% by 70%. This indicates that the FSM removed from the PA pens was much more nutrient and energy dense. Nutrient-dense FSM can be economically hauled over greater distances for land application. This may be very important for animals fed diets containing distillers grains because of the high manure phosphorus levels associated with this diet. Being able to economically haul the material farther could aid in meeting the requirements of nutrient management plans. Furthermore, the PA treatment pens only required a quarter of the amount of fill material required by the SS treatment pens at the end of the feeding cycles, another economic net benefit.

The PA treatment also increased the HHV of the FSM by 75%. An additional benefit of increasing the FSM energy density is that the FSM can be used as a fuel for direct combustion or co-combustion in coal-fired power plants. This could ultimately reduce the amount of coal needed, an environmental benefit, and could also result in improved flue gas quality by reducing NO_x emissions. Conceivably, an increased energy value would create a more sustainable system, with animal feeding operations supplying manure for fuel. The ash byproduct from the combustion process could then be returned to the animal feeding operation to improve the pen surface and subsequently increase the manure energy content. Based on these findings, using PA on a feedlot surface appears to improve the efficiency of handling FSM by reducing the ash content. However, additional work needs to be done to quantify the long-term impact on the environment and on animal well-being.

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