

# MANURE AND RUNOFF WATER QUALITY FROM FEEDLOTS AS AFFECTED BY DIET AND PEN SURFACE

P. B. DeLaune, J. C. MacDonald, B. W. Auvermann

**ABSTRACT.** *Environmental management of confined animal feeding operations is closely regulated. Hence, understanding management practices that affect nutrient outputs and the potential risk of transport in the environment is of importance. The objective of this research was to evaluate the impact of feeding corn-based wet distillers grains plus solubles (WDGS) and the type of pen surface material on manure nutrient composition and runoff water quality. Rainfall simulations were conducted at an experimental feedyard that contained soil and fly ash surfaced pens. Two diets, steam-flaked corn (SFC) and 30% WDGS, were fed to cattle on each surface type. Diets containing WDGS resulted in greater manure nitrogen (N) and phosphorus (P) concentrations than SFC diets. Runoff volumes were significantly higher from soil pens where WDGS diets were fed. Runoff volumes were consistent for fly ash pens; however, there was a 3-fold difference between soil surfaced pens, indicating great variability between soil surfaced pens. Feeding WDGS increased soluble reactive P (SRP) concentrations in runoff water by 38% and total P concentrations by 27% compared to SFC. This increase in P runoff concentrations as a result of feeding WDGS was expected, as manure WEP concentrations were greater in pens where WDGS was part of the diet. Pen surfaces with fly ash resulted in increased total P and ammonium-N ( $\text{NH}_4\text{-N}$ ) concentrations in runoff water. Mass losses of SRP, total P,  $\text{NH}_4\text{-N}$ , and total Kjeldahl N (TKN) were highest from soil surfaced pens in which cattle were fed WDGS. While manure nutrient concentration can be an excellent indicator of the potential of nutrient runoff, hydrological properties can be the single most important factor in actually transporting nutrients offsite.*

**Keywords.** *Feedlots, Nitrogen, Nutrient losses, Phosphorus, Runoff, Water quality.*

Proper management of nutrients is vital to protecting water resources, especially when confined animal feeding operations are involved due the large amount of manure generated coupled with the relatively small land area on which to apply these nutrients. The U.S. Environmental Protection Agency adopted feedlot effluent guidelines requiring no discharge and a federal permit system for feedlots larger than 1,000 head (USEPA, 1973, pp. 59-64). All existing operations must contain all of the rain and processed wastewater associated with up to a 25-year, 24-hour storm event (USEPA, 2008). Thus, in theory, there is no direct connection between feedlot runoff and adjacent water bodies.

In order to achieve a no-discharge system, retention facilities in the form of runoff collection ponds or settling basins must be properly designed and managed. Irrigation with feedlot runoff is the most effective and common means of dewatering retention facilities (Sweeten, 1990). Runoff from feedlots can contain high levels of nitrogen (N), phosphorus (P), potassium (K), sediment, and salts.

Runoff water quality has been shown to be highly variable among reported research. For example, reported total N concentrations in feedlot runoff has varied from 85.7 mg N  $\text{L}^{-1}$  in Canada (Miller et al., 2004) to 1083 mg N  $\text{L}^{-1}$  in Texas (Clark et al., 1975). Gilley et al. (2008) also reported that pen location could significantly influence soil properties and selected water quality parameters.

One factor that could potentially influence runoff characteristics is the type of pen surface. Soil surfaced (unpaved) feedlots are the most common surface type for feedlots ranging from the Southern High Plains to the Canadian prairies (Parker et al., 2004; Miller et al., 2004). Mielke et al. (1974) identified three distinct layers that develop on soil surface feedlots: organic matter or a layer of loose manure, a black interface layer, and the underlying soil. Cole et al. (2009) reported four distinct layers in Texas feedlots, consisting of a compacted dry manure layer and a wetter, more compacted manure layer. These two layers existed between the surface loose manure layer and underlying soil layer. Mielke et al. (1974) indicated that the black interface layer is primarily responsible for the self-sealing of feedlot pens, which greatly affects leaching and infiltration. Physical, chemical, and biological mechanisms have all been hypothesized to control the development of this layer (Mielke et al., 1974; Mielke and Mazurak, 1976; Rowsell et al., 1985; Miller et al., 2004; Miller et al., 2008).

The use of fly ash, a by-product of coal-fired electrical generation, has been investigated as an alternative to common soil surfaced feedlots. Fly ash reacts with water and a cementing agent to form a cementitious material. Parker et

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al. (2004) noted that hard-surfaced pens drain faster and are less prone to muddy conditions. Fly ash surfaced feedlots have been reported superior with respect to vehicular operation for routine maintenance and cleaning, to increase cattle daily gain due to reduced energy exertion, and to make cattle less prone to viral hoof infection and mastitis (Amosson, 1997; Suszkiw, 1999). As the fly ash surface results in less mixing with soil compared with soil surfaced feedlots, virtually no fill is required to bring surfaces to grade, and the manure has a greater value for use in land application (Woodbury et al., 2007; Sweeten et al., 2006). Use of pond ash, i.e., fly ash that has been placed in evaporative ponds for storage and subsequently dewatered, to pave feedlot surfaces resulted in significantly less dissolved P load and total P load compared to soil surfaced pens (Gilley et al., 2009). In contrast, ammonium loads in runoff were higher from pond ash surfaces. Runoff volumes did not differ between soil surfaced pens and pond ash amended pens (Gilley et al., 2009).

Another variable that could affect runoff water quality from feedlot surfaces is diet. Corn distillers grains have become a valuable feed source in the cattle industry (Kloppenstein et al., 2007). Spiels and Varel (2009) reported that total P and N excretion increased linearly as the amount of wet distillers grains with solubles (WDGS) increased in the diet. Luebke et al. (2012) noted that total P and N removed in manure during pen cleanout increased linearly with increasing WDGS concentration. Although it has been documented that feeding WDGS increases excretion of N and P, Gilley et al. (2009) reported no significant differences in measured runoff water quality parameters from soil surfaced pens between cattle fed corn based and WDGS diets.

Bremer et al. (2007) concluded that the water solubility of manure in feedlot feces is an indicator of the potential for P runoff from feedlots and fields receiving manure. Hence, diets that increase P excretion may be expected to increase the risk of P runoff. Bremer et al. (2007) also hypothesized that the soluble P to total P ratio could be affected by the interaction of excreted P with soil ions through mixing by hoof action. Thus, the pen surface could affect this interaction and subsequent runoff characteristics. There is little research available examining the impact of feedlot surface coupled with feeding of WDGS on runoff characteristics. The objective of this research was to measure manure nutrient composition and feedlot runoff characteristics as affected by pen surface and diet.

## MATERIALS AND METHODS

This study was conducted at an experimental feedyard in Potter County, Texas, during the summer of 2011. Each pen was 6.1 m wide  $\times$  27.5 m long. Finishing cattle were stocked at a rate of 10 head per pen (16.7 m<sup>2</sup> per head). Cattle were fed various diets for approximately 180 days. Diets selected for evaluation in this study included steam-flaked corn (SFC) and 30% WDGS. The SFC diet was formulated to contain 2.16% N and 0.30% P, and the WDGS diet was formulated to contain 2.4% N and 0.47% P. Each diet was fed to cattle on two different pen surfaces: soil and

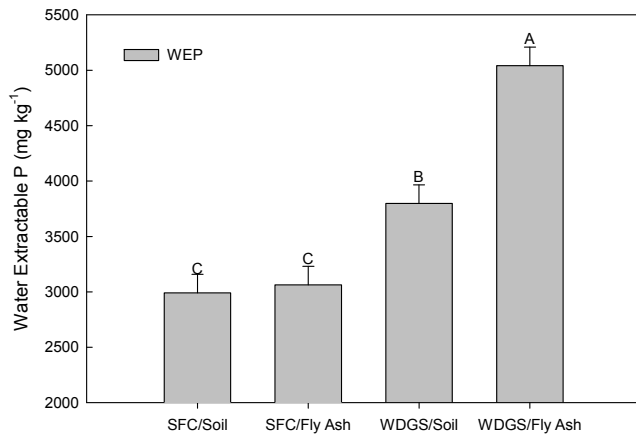
fly ash. Construction of all pens utilized in this study was completed in 1998 on a Pullman clay loam soil (fine, mixed, superactive, thermic Torrertic Paleustolls). Fly ash amended pens were paved with 15 to 20 cm of a hydrated compacted mixture of fly ash and crushed bottom ash from a nearby coal-fired power plant (Sakirkin et al., 2011). No bedding was added to any pens during the feeding trial.

At the end of the feeding trial, rainfall simulations were conducted immediately after the cattle were removed in June 2011. Four runoff plots (1.5 m  $\times$  2 m) were constructed within each pen (total of 4 pens and 16 plots). The plots were constructed uniformly in the centers of pens starting at the upslope end next to feed bunks to the downslope edge of the pens, thus encompassing all areas of the pen. Aluminum strips 15 cm in height were used to isolate runoff from surrounding areas. The aluminum strips were inserted to the fly ash base or slightly into the compacted layer of the clay surface. Once inserted, manure was scraped away from the outside plot area and caulk was used to provide a seal at the base and corners of the plot borders. A single-nozzle rainfall simulator, as described by Humphry et al. (2002), was used to provide a 70 mm h<sup>-1</sup> storm event. Runoff was directed through the lower corner of the plot and pumped into a collection barrel using a peristaltic pump. Time to runoff was recorded. Once runoff was initiated, runoff was collected for 30 min. The weight of the collection barrel was recorded to calculate total runoff volume.

Runoff water was well mixed, and subsamples were taken for chemical analysis. Samples filtered through a 0.45  $\mu$ m membrane and acidified to pH 2 using sulfuric acid were analyzed colorimetrically for soluble reactive P (SRP) using the automated ascorbic acid reduction method (APHA, 2005) and for ammonium-N (NH<sub>4</sub>-N) according to the modified Berthelot reaction (USEPA, 1983). Total P and total Kjeldahl N (TKN) were analyzed using the above procedures after digesting unfiltered, acidified samples with a copper sulfate and sulfuric acid solution (USEPA, 1993).

Manure from each pen was collected by scraping various areas of each pen surface to the compacted layer on soil surfaced pens and to the hard surface layer of fly ash pens and then mixed. Subsamples were taken for determination of water-extractable P (WEP), total P, and total N. Water-extractable P was analyzed colorimetrically using the automatic ascorbic acid reduction method after extracting 2 g manure with 200 mL water (Wolf et al., 2009). Total P was determined colorimetrically after digesting 1 g dried sample with nitric acid and hydrogen peroxide (Wolf et al., 2003). Total N was determined by combustion analysis (Wood and Hall, 1991).

Data were analyzed using Proc Mixed (SAS version 9.2, SAS Institute, Inc., Cary, N.C.). Diet, pen surface, and the interaction between diet and pen surface were considered fixed effects. Replication (nested within treatment) was considered a random effect. Least square means were calculated, and mean separation for results were considered significantly different at  $p < 0.05$ . Mean separation was produced using PDMIX800 in SAS, which is a macro for converting mean separation output to letter groupings (Saxton, 1998).



**Figure 1.** Water-extractable P (WEP) in collected manure from feedlot pens fed steam-flaked corn (SFC) and wet distillers grains with solubles (WDGS) on soil and fly ash surfaces. Bars denote one standard error. Diet × surface interaction ( $p < 0.0080$ )  $LSD_{0.05} = 545.3$ . Means followed by the same letter are not significantly different at  $p < 0.05$ .

**Table 1.** Main effects of diet and pen surface on total P and total N concentrations in manure.<sup>[a]</sup>

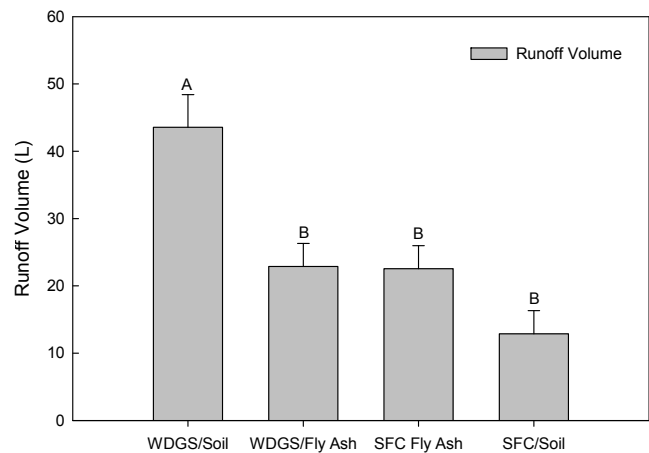
Treatment		Total P (g kg <sup>-1</sup> )	Total N (g kg <sup>-1</sup> )
Diet	WDGS	8.64 a	33.6 a
	SFC	7.84 b	31.6 b
ANOVA (Pr > F)		0.0003	0.0103
Surface	Fly ash	8.61 a	35.0 a
	Soil	7.84 b	30.2 b
ANOVA (Pr > F)		0.0006	<0.0001

<sup>[a]</sup> Treatment means followed by the same letter are not significantly different at  $p < 0.05$ .

## RESULTS AND DISCUSSION

### MANURE PROPERTIES

Water-extractable P in manure was significantly affected by the diet × surface interaction ( $p = 0.0080$ ; fig. 1). Diets containing WDGS resulted in significantly higher WEP concentrations in manure, regardless of pen surface (fig. 1). Between the WDGS diets, WEP concentrations were significantly higher from fly ash pens compared with soil surfaced pens. It is possible that a greater degree of mixing between feces and soil was achieved on soil surfaces compared with fly ash surfaces, thereby forming sparingly soluble P complexes. Total N and P manure concentrations were significantly affected by the main effects of diet and surface, but not by the diet × surface interaction (table 1). Total P and N concentrations in manure were greater from pens where cattle were fed WDGS compared to SFC. Higher total N and P concentrations in the manure from pens fed WDGS diets were expected, as the WDGS diet



**Figure 2.** Runoff volume from soil and fly ash surfaced pens containing cattle fed steam-flaked corn (SFC) and wet distillers grains with solubles (WDGS). Bars denote one standard error. Diet × surface interaction ( $p < 0.0027$ )  $LSD_{0.05} = 10.8$ . Means followed by the same letter are not significantly different at  $p < 0.05$ .

formulations contained higher percentages of N and P compared to the SFC diets. This agrees with other studies that have shown increasing total N and P manure concentrations with increasing rate of distillers grains fed (Luebke et al., 2012; Hao et al., 2009; Spiels and Varel, 2009). In addition, fly ash surfaced pens resulted in greater total N and P manure concentrations compared with soil surfaced pens. Manure scraped from hard surfaced pens has a lower ash content and higher nutrient contents, thus making the manure more valuable to farmers. Furthermore, higher nutrient content adds value to the manure, making it more affordable to haul greater distances from the feedlot for land application.

### RUNOFF VOLUME

There were no treatment effects on time to runoff (table 2). There was a significant diet × surface interaction for runoff volume ( $p = 0.0027$ ). The soil surfaced pen in which cattle were fed WDGS resulted in higher runoff volumes compared to the other three treatments (fig. 2). There were no significant differences among the other three treatments. Runoff volumes from the fly ash pens did not differ and were consistent, regardless of diet.

Runoff volumes between soil surfaced pens differed more than 3-fold (fig. 2). There are several potential reasons for this observed difference between soil surfaced pens. Mielke et al (1974) reported that as manure accumulated, the organic matter and interface layers develop and the underlying soil is

**Table 2.** Effects of diet and pen surface on runoff characteristics.<sup>[a]</sup>

Treatment		Time to Runoff (min)	Runoff Characteristics									
			Volume (L)	Nutrient Concentrations (mg L <sup>-1</sup> )				Nutrient Loads (g ha <sup>-1</sup> )				
				SRP	TP	NH <sub>4</sub> -N	TKN	SRP	TP	NH <sub>4</sub> -N	TKN	
Diet	WDGS	7.74	33.21 a	121.10 a	134.04 a	273.19	537.19	12.81 a	13.95 a	29.47 a	57.12 a	
	SFC	7.01	17.71 b	75.25 b	98.40 b	245.15	518.36	4.44 b	5.76 b	15.19 b	32.78 b	
Surface	Soil	8.43	28.21	90.69	104.39 b	224.56 b	490.01	9.34	10.06	22.90	46.73	
	Fly ash	6.32	22.71	105.66	128.06 a	293.78 a	565.54	7.90	9.65	21.75	43.16	
ANOVA		0.6748	0.0024	<0.0001	0.0009	0.2912	0.6805	0.0002	0.0010	0.0023	0.0124	
(Pr > F)		Surface	0.2466	0.1824	0.0514	0.0131	0.0185	0.1163	0.3339	0.8244	0.7506	0.6646
		Diet × Surface	0.6387	0.0027	0.7106	0.1651	0.3624	0.1270	0.0118	0.0448	0.0033	0.0031

<sup>[a]</sup> Treatment means followed by the same letter are not significantly different at  $p < 0.05$ .

protected. Miller et al. (2008) estimated that the black interface layer can develop within two months after cattle placement. Mielke et al. (1974) also indicated that self-sealing of soils in feedlot pens may be due to physical processes, such as compaction by trampling hooves and physical plugging of pores by manure. Greater manure production during the feeding cycle could potentially affect the time for development of a black interface layer, compaction, and/or physical plugging of pores and subsequent runoff characteristics. Rowsell et al. (1985) attributed the mechanism of sealing of liquid manure storage ponds to physical blocking of pores by the particulate material in manure. Hills (1976) concluded that final sealing of lagoons was caused by excretions from anaerobic microorganisms. Although not quantified in this study, dry matter removal from pens has been shown to increase with an increasing percentage of WDGS in beef cattle diets. Thus, feeding WDGS in soil surfaced pens could increase the amount of manure excreted and more rapidly develop self-sealing characteristics compared to pens where cattle were fed SFC diets.

Self-sealing of soils in feedlot pens has also been attributed to chemical processes, such as dispersion of clay by sodium (Na) and potassium (K). Batal and Dale (2003) reported that the Na content of corn-based dried distillers grains plus solubles (DDGS) was extremely variable. Benke et al. (2010) showed numerically higher Na and K content in manure from cattle fed DDGS compared to regular diets. Miller et al. (2008) found that only 2% to 36% of the layers in feedlot soil profiles had the potential to restrict infiltration of water because of high sodium adsorption ratios and low electrical conductivity. While Na and K were not measured in the diet or manure of this study, it is possible that feeding WDGS increased Na and K levels in the manure and possibly led to particle dispersion and compaction, resulting in a barrier to water infiltration.

Another plausible explanation is the removal of the black interface layer during manure cleanout. Miller et al. (2008) concluded that pen cleaning removed the black interface layer and contributed to higher field saturated hydraulic conductivity values. Parker et al. (2004) noted that manure is more easily removed from a hard surface while limiting the removal of subsoil. Woodbury et al. (2007) indicated that pond ash surfaced pens had an approximately 70% reduction in total mass of material removed compared to soil surfaced pens. Furthermore, Woodbury et al. (2007) reported that on average 11,000 kg of fill soil was required to bring soil surfaced pens back to grade, while pond ash pens did not require any fill. Over the life of the pens in our study, the soil surfaced pens have been filled back to grade multiple times. We hypothesize that this process can alter the consistency of hydrologic properties through the removal or disturbance of the black layer interface. Thus, runoff rates can be expected to be highly variable from soil surfaced pens, as seen in our study. In contrast, Gilley et al. (2009) observed no significant effect of pen surface on runoff volume within similar size pens in Nebraska. Moisture of the pen surface material differed among diet types, with WDGS diets resulting in higher moisture levels than SFC diets (data not shown). However, if moisture of the pen surface material was a driving factor in the variability

seen between soil surfaced pens, then this would have also been observed between fly ash surfaced pens.

#### NUTRIENT CONCENTRATIONS

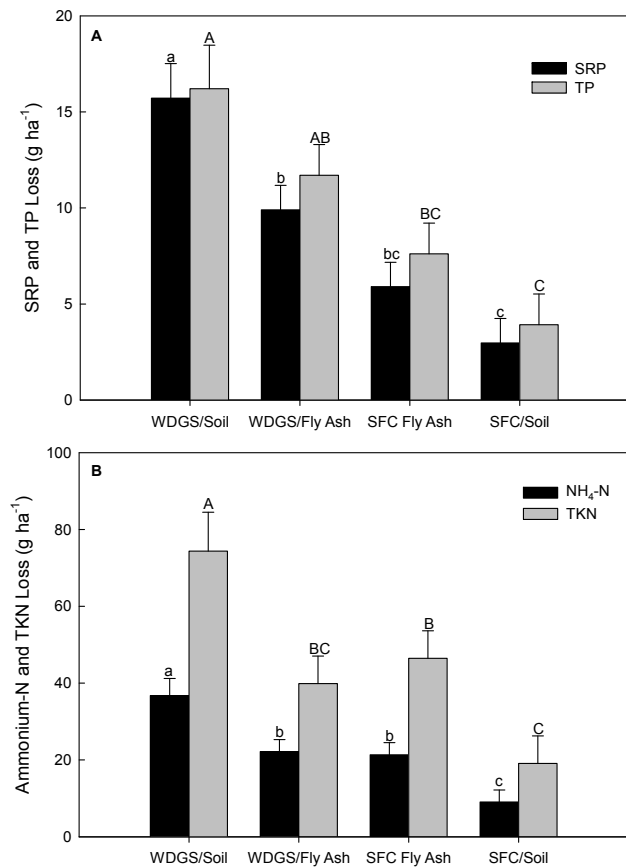
There was no significant diet  $\times$  surface interaction for SRP, TP,  $\text{NH}_4\text{-N}$ , and TKN concentrations in runoff water (table 2). The main effect of diet did have a significant effect on SRP ( $p < 0.0001$ ) and total P ( $p = 0.0009$ ) concentrations in runoff water. The WDGS diet resulted in significantly higher SRP and TP concentrations in runoff water compared to the SFC diet (table 2). Feeding WDGS increased SRP concentrations in runoff water by 38% and TP concentrations by 27% compared to SFC. Gilley et al. (2010) reported no significant differences in TP and SRP concentrations in runoff from pens where corn and WDGS diets were fed, although they observed significantly greater Bray-1 P levels in the soil of pens in which WDGS was part of the diet. We expected to see higher P concentrations in runoff water from pens fed WDGS, as manure WEP concentrations were greater in pens where WDGS was part of the diet. Seventy-six percent (SFC diet) to 90% (WDGS) of P runoff was of the dissolved form. Research has shown that runoff P concentrations are highly correlated to WEP concentrations in manure (Kleinman et al., 2002; DeLaune et al., 2004). These data agree with Bremer et al. (2007), who hypothesized that WEP in feedlot feces is an indicator for the potential for P runoff from feedlots. Thus, methods to control or reduce WEP manure concentrations could reduce P runoff from feedyards.

Total P concentrations were also significantly affected by the main effect of pen surface ( $p = 0.0131$ ; table 2). Total P concentrations in runoff water were significantly higher from fly ash surfaced pens than from soil surfaced pens. In contrast to these data, Gilley et al. (2009) found that total P loads were significantly higher from soil surfaced pens compared to pond ash surfaced pens. While Gilley et al. (2009) did not report concentration data, they did report no significant difference in runoff volume between pen surfaces. Hence, we assume that their reported differences in total P load are due to differences in total P concentrations. It should be noted that total P concentrations in manure were also greater in manure collected from fly ash pens, which subsequently affected P runoff.

Total Kjeldahl N concentration was not affected by the main effects or interaction of the main effects (table 2). Ammonium-N was significantly affected by the main effect of pen surface ( $p = 0.0185$ ; table 2). Fly ash surfaced pens increased  $\text{NH}_4\text{-N}$  concentrations in runoff water by 20% compared to soil surfaced pens. Gilley et al. (2009) observed significantly higher  $\text{NH}_4\text{-N}$  loads from pond ash surfaced pens versus soil surfaced pens. We hypothesize that  $\text{NH}_4\text{-N}$  was lower from soil pens due to mixing of manure and soil, thereby increasing adsorption sites for  $\text{NH}_4\text{-N}$ .

#### NUTRIENT LOADS

Mass losses of SRP, TP,  $\text{NH}_4\text{-N}$ , and TKN in runoff water were significantly affected by the diet  $\times$  surface interaction but not by the main effect of surface (table 2). Soluble reactive P loads were significantly higher from WDGS diets in soil pens compared with all other treatments (fig. 3a). Total P



**Figure 3.** Effect of diet  $\times$  surface interaction on (a) soluble reactive P ( $LSD_{0.05} = 4.01$ ) and total P ( $LSD_{0.05} = 5.04$ ) loads and (b)  $NH_4$ -N ( $LSD_{0.05} = 9.92$ ) and total Kjeldahl N ( $LSD_{0.05} = 22.53$ ) loads. Bars represent one standard error. Treatment means followed by the same letter are not significantly different at  $p < 0.05$ .

loads from soil pens containing cattle fed the WDGS diets were significantly higher than pens where the SFC diets were fed. Gilley et al. (2009) found significantly higher total P losses from soil surfaced pens compared with pond ash surfaces. Furthermore, Gilley et al. (2010) observed numerically higher TP loads from pens in which WDGS was part of the diet. Soil surfaced pens in which WDGS diets were fed also resulted in significantly higher  $NH_4$ -N and TKN loads than all other treatments (fig. 3b). In our study, greater total P loads from the WDGS diet by soil treatment was a function of increased runoff volumes from this treatment (fig. 2). While manure nutrient concentration can be an excellent indicator of the potential of nutrient runoff, hydrological properties can be the single most important factor in actually transporting nutrients offsite. For example, nutrient transport has been shown to occur predominantly from hydrologically active areas of a watershed (Gburek et al., 1996; Gburek and Sharpley, 1998). Management practices that can mitigate movement of nutrients should reduce subsequent mass nutrient loss from respective systems.

## CONCLUSION

Although the data set is limited to one feeding cycle, these data suggest that water-extractable P concentrations

in manure were significantly higher from diets containing WDGS in fly ash pens. In addition, SFC diets had significantly lower WEP concentrations in manure compared with WDGS diets fed in both fly ash and soil surfaced pens. Manure total P and N were greater from fly ash surfaced pens compared with soil pens and increased as a result of WDGS diets compared with SFC diets, which could be expected as a result of formulations containing higher percentages of N and P for WDGS diets compared with SFC diets. Hence, feedlot managers using WDGS diets can expect higher N and P levels in manure and could also expect higher N and P levels in manure scraped from fly ash surfaced pens as a result of no soil mixing during the feeding cycle and soil removal during pen cleanout.

Runoff volume was significantly higher from soil pens in which WDGS was part of the diet than all other treatments. While runoff volumes were almost identical between fly ash pens, runoff volumes differed 3.4-fold between soil pens. We hypothesize that removing soil during pen cleanout and replacing it with fill may have the potential to disrupt the black interface layer that influences infiltration and subsequently affect the hydrology of the system. As this is not an issue on hard surfaced pens, such as fly ash surfaces, infiltration and drainage may be more consistent.

Soluble reactive P and total P concentrations in runoff water were affected by the main effect of diet. Feeding WDGS resulted in significantly higher SRP and total P concentrations in runoff, which was expected, since WEP concentrations were greater in manure resulting from WDGS diets. Total P and  $NH_4$ -N concentrations in runoff water were significantly higher from fly ash surfaced pens compared with soil surfaced pens, potentially due to increased interaction with adsorption sites in soil surfaced pens. Generally, nutrient concentrations in the runoff water were a reflection of nutrient concentrations in the manure, particularly for P. This indicates that WEP in manure is a good indicator of the potential for P runoff from feedlots. Nutrient loads were higher from soil surfaced pens where WDGS diets were fed, which also significantly increased runoff volumes.

Reducing nutrient excretion can reduce nutrient concentrations in runoff water, but hydrological variability can significantly affect transport of nutrients offsite. Future work is warranted to quantify the chemical and physical properties of manure from cattle fed WDGS and of the surface layers on hard surface feedlots. Further research and longer-term trials consisting of multiple runoff events are warranted in this area.

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