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ABSTRACT. *Air quality is becoming a pressing issue for beef feedlot producers. Feeding practices influence the excretion of starch, fiber, nitrogen (N), and sulfur (S) in manure, thereby affecting nutrient content and the production of ammonia (NH_3) and odorous compounds. Wet distillers grains with solubles (WDGS) are a common and economical ingredient in feedlot diets. WDGS are high in protein, fiber, phosphorus (P), and S but low in starch. The objective of this study was to compare NH_3 concentration in the air and nutrients and volatile organic compounds (VOC) concentration in manure between two dietary treatments fed to feedlot cattle. Five pens of feedlot cattle were fed diets containing 14% to 35% WDGS and five pens were fed a corn-based diet with no ethanol byproducts (Control). Each pen had twelve sampling locations (N = 120) where air and manure samples were collected from the feedlot surface. Air samples were analyzed for NH_3 concentration. Manure samples were analyzed for dry matter, pH, volatile solids, VOC, and nutrient composition (N, P, and S). Concentrations of P and S in manure and NH_3 in the air were higher in pens fed WDGS compared to pens fed the control diet. Concentrations of VOC were similar across both treatments.*

Keywords. *Ammonia, Beef, Nitrogen, Phosphorus, Volatile organic compounds, Wet distillers grains with solubles, WDGS.*

Air quality in and around livestock operations is a growing concern for feedlot producers because it can affect the health and well-being of humans and livestock. Four primary sources of emissions exist on livestock operations: silage production, the manure storage facility, animal housing, and land application of manure. Three sources of emissions are associated with livestock waste. Cattle excreta is composed of undigested organic compounds including starch, protein, nonprotein nitrogen, lipids, and nonstarch polysaccharides. Volatile organic compounds (VOC) such as volatile fatty acids (VFA), sulfur (S) compounds, and aromatic compounds are produced by the aerobic and anaerobic digestion of organic residues by bacteria (Mackie et al., 1998). Some VOC present in livestock manure correlate strongly to odor perception by humans (Zahn et al., 1997, 2001; Powers et al., 1999). Therefore, eliminating or reducing the production of VOC may reduce perceived odors from cattle feedlots. Feeding practices that influence the excretion of starch, nitrogen (N), and S by livestock may significantly affect the production of odor-causing VOC from livestock facilities (Shurson et al., 1998; Miller and Varel, 2001; Archibeque et al., 2006).

Corn wet distillers grains with solubles (WDGS) are a byproduct of the ethanol industry and a common feed ingredient used in cattle finishing diets. Relative to corn, distillers grains are high in protein, fiber, fat, P, and S but low in starch (Spiehs et al., 2002). Optimal inclusion rate of WDGS in beef feedlot diets for growth performance is 20% to 40% of the diet on a dry matter basis (Erickson et al., 2007). Use of WDGS at these inclusion rates has negative environmental implications including elevated concentration of nutrients (N, P, S) in manure (Benson et al., 2006; Varel et al., 2008; Spiehs and Varel, 2009) and on the pen surface of cattle feedlots (Benson et al., 2005) and the production of odorous compounds (Varel et al., 2008; Spiehs and Varel, 2009). Previous research at the U.S. Meat Animal Research Center has demonstrated that feeding WDGS to feedlot cattle increases odorous compounds (branched chain fatty acids, NH_3, and phenol) in manure compared to cattle fed a dry rolled corn diet (Varel et al., 2008; Spiehs and Varel, 2009), indicating that NH_3 and odor emissions from the feedlot may increase when WDGS is fed. Woodbury et al. (2010) demonstrated that incubated manure samples from the feedlot surface where cattle were fed diets containing WDGS had significantly greater branched-chain fatty acids (BCFA) than manure from pens with cattle fed a corn-based diet. Manure collected from pens with cattle fed a corn-based diet had greater average straight-chain fatty acids (SCFA) and total VFA generation than pens where WDGS were fed. Because many BCFA

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have a lower odor detection threshold than SCFA (Parker et al., 2010) the authors concluded that odors emitted from WDGS manure would likely be more offensive. Phosphorus concentrations in the cattle manure were also higher when WDGS were fed, which increases the amount of land necessary to utilize manure P (Spiehs and Varel, 2009). The objectives of this study were as follows:

- Determine the effect of feeding diets containing WDGS to feedlot cattle on NH_3 concentration in the air and nutrients and VOC concentration in manure on the feedlot surface.
- Determine if the temperature, pH, volatile solids, nutrients, or dry matter content of the feedlot surface affects NH_3 concentration in the air.
- Evaluate spatial distribution of NH_3, nutrients, and VOC on the feedlot surface.

Table 1. Ingredient and nutrient composition (dry matter basis) of feedlot diets containing 0%, 14%, or 35% corn wet distillers grains with solubles (WDGS) fed during the grower and finishing period.

Ingredient (%)	Starter[a] Control/ WDGS	Grower Control	Grower WDGS	Finisher Control	Finisher WDGS
Corn, dry rolled	34.0	29.5	0.0	82.7	50.4
Corn, high moisture	0.0	0.0	75.9	0.0	0.0
Corn WDGS[b]	0.0	0.0	13.8	0.0	35.0
Corn silage	20.0	66.0	9.4	12.8	13.5
Urea	2.4	4.5	0.0	4.5	0.0
Alfalfa Hay	43.6	0.0	0.0	0.0	0.0
Mineral supplement[c]	0.0	0.0	0.9	0.0	1.1
Composition-Analyzed[d]					
Dry matter, %	61.7	50.2	55.9	70.9	47.5
Crude protein, %	14.3	11.6	13.8	12.8	16.8
Metabolizable energy, Mcal/kg	2.55	2.70	3.23	3.03	3.11
Phosphorus, %	0.30	0.3	0.39	0.36	0.52
Calcium, %	0.95	0.68	0.35	0.56	1.01

[a] Common starter diet fed to cattle on both dietary treatments.
[b] Corn WDGS obtained from Abengoa Bioenergy Corp., York, Neb. Nutrient analysis was 31.3% DM, 31.6% CP, 13.7% oil, 0.83% P, and 0.73% S (DM basis).
[c] The supplement contained 94.45% limestone, 0.73% vitamins A, D, and E, and 2.742% Rumensin 80 (Elanco Animal Health, Indianapolis, Ind.), and 2.073% thiamine.
[d] Random samples were analyzed for nutrient composition throughout the study and were found to be within 5% of the calculated nutrient analysis.

Materials and Methods

Ten open-lot, soil-surfaced pens (15.2 × 61.0 m) at the U.S. MARC feedlot were monitored for 14 months. When the study began in June 2009, each pen contained approximately 32 mixed-breed finishing steers with an average body weight (BW) of 318 kg. Cattle in these pens had not been fed WDGS prior to the initiation of the study. These cattle were marketed on 10 September 2009 (453 kg BW). A new group of 32 cattle (193 kg BW) were added to each pen between 18 and 22 September 2009 and remained in their respective pens until being marketed between 10 June and 27 July 2010 (558 kg BW). Control diets and WDGS diets were randomly assigned to pens and remained constant throughout the 14-month study period. Pens were not cleaned between groups of cattle or at any time during the study.

Five pens were fed diets containing 14% to 35% WDGS on a dry matter-basis and five pens were fed a corn-based diet with no ethanol byproducts which served as the control diet. Inclusion rate of WDGS in the diet increased with increasing body weight of the cattle, with each treatment having a five-step diet to accommodate animal growth over the finishing period. The first diet fed to newly weaned calves in both treatment groups did not contain WDGS and was fed for approximately 30 days from 18 September to 20 October 2009. Over the course of the study, crude protein content of the WDGS diets ranged from 13.8% to 16.8%, while crude protein content of the control diets ranged from 11.6% to 14.3%. Nutrient composition of diets fed during the starter, grower, and finishing phases are shown in table 1.

Air and manure samples from the feedlot surface were collected in June, August, September, and December 2009 and May, July, and August 2010. The initial samples were collected in June 2009 before the cattle were placed on dietary treatments. For each sampling period, data were collected over one day, beginning at 0700 and ending at 1500. However, due to extreme heat during the August 2009 sampling period, five pens were sampled between 0730 and 1130 on 12 August 2009 and five pens were sampled between 0730 and 1130 on 13 August 2009. Cattle were removed from the pens immediately before samples were collected and promptly returned to their pens afterward. On each sampling date, the pens were surveyed using electromagnetic induction (EMI; Woodbury et al., 2009, 2010; Eigenberg et al., 2010). From this survey, 12 locations per pen were selected for sampling (N = 120 total) using the Electrical conductivity Spatial Analysis Program (ESAP; Eigenberg et al., 2010). The ESAP method selects sampling sites based on electrical conductivity in an iterative, nonrandom manner to optimize the estimation of a regression model and simultaneously maximize the average separation distance between adjacent sampling locations. Each sampling location was identified as being on the mound (M) or on the edge of the mound (E) by visual determination. Within a pen, all samples were collected within a 45-min period. Of the 840 samples collected from the pens over the course of the 14 month project, 512 samples (61%) were collected from the E and 328 (39%) were collected from the M.

To determine relative differences in steady-state NH_3 concentrations in the air in each pen, air samples were collected from 12 locations on the pen surface using stainless steel hemispherical flux chambers (Miller and Woodbury, 2006; Woodbury et al., 2006) with acid traps containing 0.5N sulfuric acid. The flux chambers had an internal volume of 7 L with a surface area of 0.064 m^2. Inside the headspace of the chamber was a 40-mm, 12-V axial-flow suspended in the center of the headspace approximately 70 mm above the pen surface. Fan airflow direction was from the surface up to the chamber top. The air within the flux chamber was recycled through the acid traps at a flow rate of 1 L min^{-1} for 20 min using the procedure described by Woodbury et al. (2006). The NH_3 content in the acid trap was analyzed using a modification of the Sigma urea N kit (Procedure No. 640, Sigma-Aldrich Chemicals, St. Louis, Mo.). Five microliters of each standard and sample were transferred to a well in a 96-well microtiter plate. This was followed by additions of 50-µL phenol nitroprusside, 50-µL alkaline hypochlorite, and 250-µL distilled water. Color was allowed to develop for 20 min at room temperature. Absorbance at 620 nm was measured using a microplate reader (Ceres UV900C, BioTek Instruments, Inc., Winooski, Vt.). The concentration of each 96-well plate was determined from a standard curve run with the plate. The coefficient of variation of each duplicate sample in the plate was less than 3%.

Soil temperature of the pen surface was measured approximately 7.6 cm below the surface using a pH/mV/temperature meter (IQ150, Spectrum Technologies, Inc., Plainsfield, Ill.) Surface temperature was measured using a ST ProPlus noncontact infrared thermometer (Rayteck, Santa Cruz, Calif.). Additionally, a sample of surface material was collected from each location and analyzed for dry matter (DM), pH, volatile solids (VS), volatile organic compounds (VOC), and nutrient composition (N, P, and S). Grab samples of the manure/soil mixture to be used for DM, VS, N, P, and S analysis were collected from the surface of the pen, placed in 3.8-L plastic bags, and held on ice during transport to the laboratory. Samples were collected from no deeper than the top 10 cm of the soil surface. A 15-g subsample of the manure/soil material from each plastic bag was transferred to a 50-mL conical tube to be analyzed for total VFA, total SCFA, total BCFA, and total aromatic compounds (phenol, indole, skatole, 4-ethylphenol, and *p*-cresol). Analysis of SCFA included acetate, butyrate, propionate, valerate, caproate, and heptanoate while BCFA included isobutyrate, isovalerate, and isocaproate. To each 50-mL conical tube, 1-*N* sulfuric acid was added to prevent fermentation during transport. All samples were held at 4°C in the laboratory until analyzed. Dry matter was determined by weighing samples before and after drying at 100°C in a forced-air oven for 24 h. To determine VS, samples were dried at 60°C for 24 h and weighed before and after ashing in a muffle furnace at 550°C for 15 h. The following formula was used to determine percent VS:

$$VS = (1 - M_{Ash}/M_{Dry}) \times 100 \quad (1)$$

where M_{Ash} is the mass of the ashed sample, and M_{Dry} is the mass of the dry sample. Samples collected from the pen surface were dried, ground through a 1-mm screen, and sent to a commercial laboratory (Ward Laboratory, Inc., Kearney, Neb.) for N (Watson et al., 2003), P, and S analysis (Wolf et al., 2003). A Hewlett-Packard 6890 gas chromatograph (Agilent Technologies, Palo Alto, Calif.) equipped with flame-ionization and mass-selective detectors was used to determine concentrations of VFA, SCFA, BCFA, and aromatic compounds, as previously described by Miller and Varel (2001). Data were analyzed as repeated measures in time using the mixed procedure of SAS. The model included the effects of diet and date. To determine differences between the M and E locations within a pen, data were analyzed using the mixed procedure of SAS with the effect of pen location and diet. Covariate structure was modeled to get lowest Akaike Information Criteria value. Pen was the experimental unit.

Results and Discussion

Ammonia

Overall average concentration of NH_3 in the air samples collected from pens of cattle fed the diets containing WDGS (4.7 mmol L^{-1}) was higher than in the air samples collected from the pens of cattle fed control diets (3.6 mmol L^{-1}; $P = 0.0017$). Significant differences in NH_3 concentration between treatments were observed during August 2009, and July and August 2010, when cattle were fed the highest inclusion rates of WDGS in their diets (fig. 1). Initial measurements collected during June 2009 showed no differences between pens assigned to control diets and those assigned to WDGS diets. No treatment differences were observed in September 2009 when the newly weaned calves in both treatment groups were fed a common diet containing no ethanol by-products. Ammonia concentration was also similar between pens fed the two dietary treatments during December 2009 and May 2010 when the WDGS diet contained only 14% WDGS.

Diets with 35% WDGS contained 2% to 4% higher crude protein content than the control diet fed during the same period. Previous research has clearly demonstrated that when cattle consume dietary N in excess of their nutrient needs, urinary and fecal N excretion increase (Cole et al., 2005; Archibeque et al., 2007; Spiehs and Varel, 2009). The N excreted in urine and feces is water soluble and can be transported in runoff, leached to groundwater, volatilized to the atmosphere, or metabolized by microbes to produce odorous compounds which negatively affect air

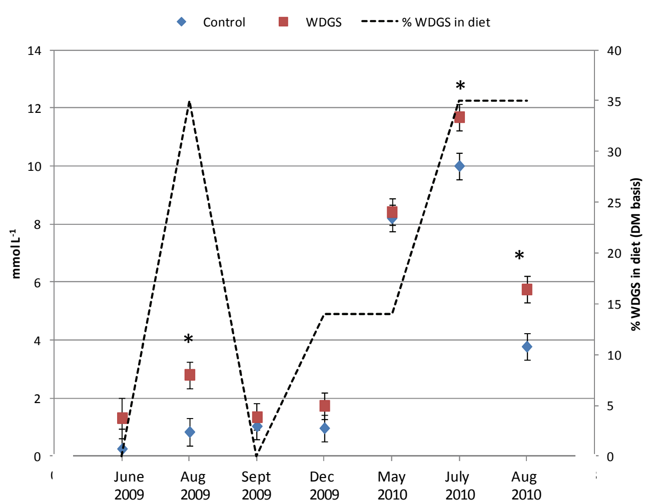

Figure 1. NH_3 concentration in air samples collected from surface of feedlot pens with cattle fed diets containing corn wet distillers grains with solubles (WDGS) or a dry-rolled corn diet with no WDGS (Control). Asterisks represent a significant difference in ammonia concentration due to dietary treatment, on a given date. The line represents dietary inclusion rate of WDGS. Each sampling period consists of 60 samples collected from pens with cattle fed WDGS and 60 samples from pens with cattle fed Control diets (N = 840).

quality. Urine is the primary route of nitrogen excretion. Nitrogen in urine is primarily in the form of urea, while fecal N contains undigested feed protein and metabolic fecal N (de Boer et al., 2002). Urea is rapidly converted to NH_3 and volatized into the air when it is exposed to the enzyme urease, which is present in feces and soil microbes. Therefore, an increase in N excretion due to high dietary N intake can lead to increased NH_3 emissions from the feedlot surface. Cole et al. (2005) reported that in vitro NH_3 emissions increased 60% to 200% when CP concentration of the diet increased from 11.5% to 13%, which demonstrated that NH_3 losses were highly correlated to urinary N excretion. Todd et al. (2006) also reported a 44% increase in daily NH_3 emissions from a simulated feedlot surface when crude protein in beef diets was increased from 11.5% to 13%. In vitro NH_3 emissions were increased when dietary crude protein concentration increased from 9.1% to 13.9% (Archibeque et al., 2007). This same pattern was evident by this study with higher concentrations of NH_3 in air samples collected from the feedlot surface of pens where cattle were fed diets containing 35% WDGS compared to pens with cattle fed corn-based diets that did not contain ethanol byproducts. However, at the lower inclusion rate, no differences in NH_3 concentration were detected between pens of cattle fed the two dietary treatments.

The substantial increase in NH_3 concentration in air samples collected in May 2010 compared to the samples collected from pens of cattle fed an equal concentration of WDGS in December 2009 is likely an effect of temperature. Seasonal variation in NH_3 volatilization from livestock facilities is well documented in the literature. Whitehead and Raistrick (1991) reported an increase in NH_3 volatilization from 25% to 38% as temperature increased from 4°C to 20°C when simulated livestock urine was applied to soil. Todd et al. (2008) reported summer and winter NH_3 emissions of 7810 and 5800 kg d^{-1}, respectively, in cattle feedlots. Similarly, Misselbrook et al. (1998) reported NH_3 emissions of 8.0 g N m^2 d^{-1} during the summer and 1.1 g N m^2 d^{-1} during the winter from concrete yards used to house dairy cattle. Under pasture field conditions, NH_3 nitrogen losses from cattle defecation and urination were reported as 1.8% in winter and 20.9% during summer months (Mulvaney et al., 2008).

The decrease in overall NH_3 concentration in air samples collected in August 2010 compared to July 2010 was due to the density of cattle in the pen at that time. Following the July 2010 sampling date, the heavier cattle in each pen were removed and marketed, leaving fewer animals in each pen to excrete urine which was volatilized into NH_3.

Physical Characteristics and Nutrient Concentration of Feedlot Manure

There were no significant differences in dry matter content, surface temperature, soil temperature, soil pH, or VS content when the two dietary treatments were fed and these factors were not found to correlate to ammonia concentration (table 2). As expected, surface and soil temperatures were highest during the summer collection dates and lowest on the December 2009 collection date (table 3).

Table 2. Concentration of nutrients and volatile organic compounds in manure/soil samples collected from the surface of feedlot pens containing cattle fed diets with or without corn wet distillers grains with solubles (WDGS) [a]

	Control	WDGS	P-Value	Std. Error
Dry matter, %	81.1	80.2	0.1968	0.48
Surface temp., °C	28.9	29.9	0.5529	1.2
Soil temp., °C	23.0	22.9	0.7844	0.39
Soil pH	7.56	7.60	0.5062	0.05
Volatile solids, %	17.4	17.5	0.9037	0.41
Total N, g/kg DM	6.69	7.09	0.1156	0.17
Total P, g/kg DM	2.87	3.21	0.0031	0.08
Total K, g/kg DM	9.0	9.29	0.2320	0.17
Total S, g/kg DM	1.9	2.25	< 0.001	0.05
Total VFA[b], mmol/kg DM	10.74	10.22	0.7750	1.3
Total SCFA[c], mmol/kg DM	10.34	9.85	0.7731	1.2
Total BCFA[d], mmol/kg DM	0.39	0.37	0.8480	0.07
Total Aromatics[e], mmol/kg DM	0.29	0.34	0.4353	0.05

[a] N = 840

[b] VFA = total volatile fatty acids.

[c] SCFA = total straight-chain fatty acids, which included acetate, butyrate, propionate, valerate, caproate, heptanoate, and caprylate.

[d] BCFA = total branch-chain fatty acids, which included isobutyrate, isovalerate, and isocaproate.

[e] Aromatics included *p*-cresol, phenol, 4-ethylphenol, skatole, and indole.

Dry matter content, soil pH, and VS content also varied across the sampling dates.

Total N and K content were similar in soil samples collected from pens with cattle fed both dietary treatments. There was a weak tendency for pens with cattle fed the WDGS diets to have a higher concentration of N in the soil, which may reflect increased N excretion. However, it is likely a majority of the additional N excreted by cattle fed the WDGS diets was excreted in the urine and quickly volatilized into NH_3, rather than accumulating on the feedlot surface. Regardless of treatment, concentration of N in the feedlot soil was highest in May, July, and August 2010 (table 3) which corresponds to the highest NH_3 concentrations measured during the study. This may reflect the higher inclusion rates of WDGS in the diet during these months coupled with the fact that these cattle were nearing their finishing weight and excreting more total N than newly weaned calves.

Consistent with previous studies, the addition of WDGS to feedlot diets resulted in an 11.8% increased P concentration in feedlot manure. The concentration of P in the feedlot soil increased over time, with the highest concentrations measured during the last three sampling periods. The dietary requirement for a feedlot steer is about 0.30% of the diet dry matter (NRC, 1996) but dietary P is often fed in excess of daily requirements. In this study, dietary P was fed 30% to 73% above the recommended requirements when WDGS was included in the diet. As a result, total P excretion increased when WDGS was added to the diet. Previous studies have also reported a higher total P excretion for feedlot cattle fed diets containing distillers co-products compared to cattle fed corn-based diets (Benson et al., 2006; Luebbe et al., 2008; Spiehs and Varel, 2009). Higher excretion of dietary P will increase P concentration in manure, thereby increasing the amount of land necessary for manure application in order to sustainably

Table 3. Concentration of ammonia, nutrients and volatile organic compounds in manure/soil samples collected from the surface of feedlot pens between June 2009 and August 2010.[a]

	June 2009	Aug 2009	Sept 2009	Dec 2009	May 2010	July 2010	Aug 2010
Ammonia, mmol L^{-1}	0.79 d	1.82 d	1.19 d	1.35 d	8.31 b	10.84 a	4.76 c
Dry matter, %	83.7 b	86.6 a	86.2 a	71.9 e	78.6 c	75.8 d	81.6 b
Surface temp, °C	43.1 a	34.7 b	26.4 c,d	2.5 e	24.6 d	31.7 b,c	42.8 a
Soil temp, °C	30.0 b	28.1 b,c	23.5 d	2.6 f	17.2 e	26.1 c	33.2 a
Soil pH	7.68 a,b	7.80 a	6.98 d	7.87 a	7.52 b,c	7.82 a	7.40 c
Volatile Solids, %	17.2 b,c,d	17.9 a,b,c	16.1 c,d	19.0 a,b	19.6 a	17.3 b,c,e	15.3 d,e
Total N, g/kg DM	5.9 d	6.9 b,c	6.5 c,d	5.6 d	7.8 a	8.0 a	7.4 a,b
Total P, g/kg DM	2.8 b	2.8 b	2.9 b	2.9 b	3.1 a,b	3.4 a	3.4 a
Total K, g/kg DM	9.4	9.1	9.4	9.9	9.0	8.6	8.7
Total S, g/kg DM	2.1	2.0	2.0	2.0	2.0	2.3	2.2
Total VFA[b]	1.90 d	3.26 c,d	5.09 cd	13.59 b	25.42 a	15.27 b	8.81 b,c
Total SCFA[c]	1.86 d	3.21 c,d	4.98 c,d	13.30 b	24.47 a	14.13 b	8.70 b,c
Total BCFA[d]	0.02 b	0.05 b	0.11 b	0.29 b	0.96 a	1.13 a	0.12 b
Total Aromatics[e]	0.10 b	0.14 b	0.17 b	0.64 a	0.54 a	0.52 a	0.12 a

[a] N = 840. Different lowercase letters within a row indicate a significant difference ($p < 0.05$).
[b] VFA = total volatile fatty acids, measured in mmol/kg DM.
[c] SCFA = total straight-chain fatty acids, which included acetate, butyrate, propionate, valerate, caproate, heptanoate, and caprylate, measured in mmol/kg DM.
[d] BCFA = total branch-chain fatty acids, which included isobutyrate, isovalerate, and isocaproate, measured in mmol/kg DM.
[e] Aromatics included *p*-cresol, phenol, 4-ethylphenol, skatole, and indole, measured in mmol/kg DM.

manage P soil concentrations. Increasing dietary P concentration in diets of lactating dairy cows from 0.35% to 0.55% increased the land area needed to manage manure P by 83% (Satter et al., 2002). Similarly, Bremer et al. (2008) reported that nearly twice as much land was needed to properly manage P contained in feedlot manure when cattle were fed diets containing 40% WDGS compared to 0% WDGS (4480 vs. 2339 ha, respectively). Producers feeding high levels of WDGS to their feedlot cattle may need to secure additional land area for manure application in order to meet P requirements contained in nutrient management plans for amending soils with manure.

Sulfur concentration in the feedlot surface material increased significantly when WDGS were fed to the cattle. The increased concentration of sulfur-containing amino acids in WDGS compared to corn results in a higher dietary concentration of S in diets containing WDGS (NRC, 1998). This may contribute to sulfide emissions (Mackie et al., 1998). Previous research in the swine industry has shown that dietary S concentrations are a significant contributor to odor and H_2S in confinement swine nursery facilities (Shurson et al., 1998). When cattle were fed diets containing 35% dried distillers grain with soluble (DDGS), H_2S concentrations from the feedlot surface were significantly greater (2.22 ppb) than when cattle were fed 0%, 15%, and 25% DDGS (0.67, 0.56, and 0.81 ppb, respectively) (Benson et al., 2005).

Concentration of Volatile Organic Compounds in Feedlot Manure

There were no differences in the concentration of VOC in surface material collected from feedlot pens with cattle fed either dietary treatment. This contrasts a previous study by Woodbury et al. (2010) who reported an increase in the concentration of BCFA in incubated manure samples from the feedlot surface where cattle were fed diets containing WDGS compared to samples from pens with cattle fed corn-based diets. One explanation for this could be that the size of the pens used during this study was much smaller (i.e. 35 head) than the pens used by Woodbury et al. (2010). It has been observed that smaller pens tend to have substantially less range in spatial variability of manure accumulation than larger pens (i.e. 75 head). Another possible explanation for this difference is that in this study, fresh samples were evaluated. Woodbury et al. (2010) incubated the soil samples at room temperature for 3 days which would facilitate fermentation and would likely increase the concentration of BCFA compared to fresh samples. Spiehs and Varel (2009) also reported a linear increase in the concentration of BCFA in cattle feces as the level of WDGS increased in the diet from 0 to 40%, but those samples were collected directly from the cattle and not diluted with soil. In the current study, the samples were collected from the feedlot surface and included manure as well as soil. However, the results of this study are consistent with Woodbury et al. (2010) and Spiehs and Varel (2009) in that the concentration of the aromatic compounds (indole, skatole, phenol, and *p*-cresol) were not affected by the addition of WDGS to the feedlot diets. This indicates that while some volatile organic compounds may increase when WDGS are fed to livestock, the highly odorous aromatic compounds will not increase when WDGS are included in the feedlot diet.

Malodorous volatile fatty acids (VFA) are the dominant beef cattle manure fermentation products (Miller and Varel, 2001, 2002). Starch is the preferred substrate for microbial fermentation of manure, yielding SCFA such as acetate, propionate, and butyrate in feces (Miller and Varel, 2002). When starch is not present, fecal microbes use protein as a substrate which produces BCFA, sulfur compounds, amines, phenols, and indoles (Spoelstra, 1980). The products of protein metabolism have a very low odor threshold (Zhu et al., 1999; Zahn et al., 2001) and BCFA have a greater odor potential than SCFA (Mackie et al., 1998; Zhu, 2000). Numerous studies have demonstrated that BCFA, H_2S, NH_3, and aromatic compounds (*p*-cresol, indole, and skatole) seem to be important odorous compounds either by virtue of their relatively high concentrations or their low detection thresholds (O'Neill and Phillips, 1992; Zahn et al., 1997; Mackie et al., 1998; Zhu, 2000; Rappert and Muller, 2005), and therefore, can serve as indicators of relative differences in odor potential when various diets are fed to feedlot cattle.

Spatial Distribution of Ammonia and Nutrients

Higher concentrations of VS, N, P, K, and S were found in soil/manure samples collected from the edge of the pen compared to samples collected on the mound (table 4). The mounds in these pens were constructed of soil. Eigenberg et al. (2010) reported higher concentration of VS in manure/soil samples collected near the feed bunk and water troughs compared to the soil-constructed mound. In another study, lower concentrations of total N, total P, and VS were found on the mound and higher concentrations of manure nutrients found around the edge of the feedlot (Woodbury et al., 2009), which is consistent with the findings of the current study. Therefore, harvesting accumulated manure around the perimeter of the central mound should yield material that is higher in VS and nutrients than material that is scraped from the entire feedlot surface. Producers who are feeding WDGS may need to be particularly concerned with the P content in the manure from the edges of the pens and ensure adequate land availability to fully utilize this valuable nutrient.

Ammonia concentrations and VOC were also higher for samples collected from the edge compared to the mound of the pen. Previous research has demonstrated that NH_3 emissions from feedlot pens appear to occur primarily where cattle recently urinated (Cole et al., 2007) and are difficult to correlate with a particular location in the pen (Spiehs et al., 2011). However, it could be that NH_3 concentrations are higher in air samples collected from the edges of the pen due to greater total N concentration in the soil/manure on the edges compared to the mound. Because of the higher concentration of VOC and NH_3, feedlot producers may want to consider mitigations to reduce potential malodorous emissions from the edges of the pen. Producers could clean the area surrounding the mound more frequently to remove organic material and reduce potential VOC and NH_3 emissions. Additionally, feedlot managers could use surface application of odor-reducing plant-derived oils (i.e. thymol and carvacrol) or urease inhibitors to control odor and NH_3 emissions (Varel, 1997; Varel and Miller, 2001; Varel et al., 2006) from the area surrounding the mound during wet periods when manure removal may not be possible.

Table 4. Concentration of ammonia in air samples, and nutrients and volatile organic compounds in manure/soil samples collected from various locations on the surface of feedlot pens.[a]

	Edge	Mound	P-value	Std. Error
Ammonia, mmol L^{-1}	4.4	3.8	0.0147	0.25
Dry matter, %	77.9	85.3	< 0.001	0.55
Surface temp, °C	29.3	29.6	0.1721	0.21
Soil temp, °C	22.7	23.3	0.1030	0.13
Soil pH	7.7	7.50	< 0.001	0.02
Volatile Solids, %	20.3	13.0	< 0.001	0.50
Total N, g/kg DM	8.0	5.1	< 0.001	0.18
Total P, g/kg DM	3.5	2.3	< 0.001	0.07
Total K, g/kg DM	9.7	8.2	< 0.001	0.11
Total S, g/kg DM	2.5	1.5	< 0.001	0.07
Total VFA[b], mmol/kg DM	12.5	7.1	0.0002	1.34
Total SCFA[c], mmol/kg DM	12.0	6.9	0.0002	1.27
Total BCFA[d], mmol/kg DM	0.52	0.18	0.0001	0.08
Total Aromatics[e], mmol/kg DM	0.41	0.24	0.0022	0.05

[a] N = 840.
[b] VFA = total volatile fatty acids, measured in mmol/kg DM.
[c] SCFA = total straight-chain fatty acids, which included acetate, butyrate, propionate, valerate, caproate, heptanoate, and caprylate, measured in mmol/kg DM.
[d] BCFA = total branch-chain fatty acids, which included isobutyrate, isovalerate, and isocaproate, measured in mmol/kg DM.
[e] Aromatics included *p*-cresol, phenol, 4-ethylphenol, skatole, and indole, measured in mmol/kg DM.

Conclusions

Use of WDGS in beef cattle diets increases ammonia concentration in the air when fed at 35% inclusion rate, but does not appear to significantly increase the highly odorous compounds *p*-cresol, phenol, indole, or skatole. Manure from the surface of feedlots with cattle fed diets containing WDGS had a higher concentration of P and S than pens with cattle fed corn-based diets containing no ethanol byproducts. Producers feeding WDGS to growing-finishing cattle may need to increase the amount of land available for manure application in order to properly utilize manure P from the feedlot, particularly the manure scraped from the edges of the pens as this contains significantly higher concentrations of N, P, K, and S compared to the material scraped from the mound. Ammonia and odorous volatile organic compounds are in higher concentration in air and surface material collected from the edge of the pens. Therefore, producers may want to consider mitigations to reduce potential malodorous emissions from the edges of the pen.

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