The Professional Animal Scientist 27 (2011):302–311
©2011 American Registry of Professional Animal Scientists

Effects of concentration and source of wet distillers grains on digestibility of steam-flaked corn-based diets fed to finishing steers[1]

N. A. Cole,*[2] PAS, K. McCuistion,†[3] PAS, L. W. Greene,†[4] PAS, and F. T. McCollum,† PAS
*USDA-ARS Conservation and Production Research Laboratory, Bushland, TX 79012;
and †Texas AgriLife Research and Texas AgriLife Extension Service, Amarillo 79106

ABSTRACT

The source and dietary concentration of wet distillers grains may affect the digestibility of beef cattle finishing diets. The objectives of this experiment were to evaluate the effects of graded levels of sorghum+corn-based wet distillers grains plus solubles (NMDGS) and corn-based distillers grains plus solubles (CDGS) on digestibility of steam-flaked-corn-based diets fed to finishing beef steers and to determine potential effects on ammonia emission from feces and urine. Ten beef steers (average BW = 252 kg) were used in a replicated 5 × 5 Latin square design. Steers were fed diets containing increasing concentrations of NMDGS (0, 5, 10, or 15% of DM) or one concentration of CDGS (10% of DM), which replaced steam-flaked corn, cottonseed meal, and urea in a high-concentrate finishing diet. Apparent digestibilities of DM, OM, ash, N, P, ether extract, and NDF were quadratically affected by dietary NMDGS concentration, with lowest values for the 5 and 10% NMDGS diets and highest values for the 0 and 15% NMDGS diets. Digestibilities of DM, OM, ash, N, P, and NDF in the 10% NMDGS diet were not different ($P > 0.10$) from digestibility of the 10% CDGS diet. Digestibilities of CDGS and NMDGS, determined by difference, were not different ($P > 0.10$). In vitro ammonia losses tended ($P < 0.09$) to increase with increased NMDGS in the diet. Results of this study suggest that the digestibilities of NMDGS and CDGS are similar, and, at the concentrations used in this study, wet distillers grains plus solubles have only minor effects on total-tract digestibility of diets based on steam-flaked corn.

Key words: beef cattle, corn, distillers grains, feedlot, sorghum

INTRODUCTION

Distillers grains with solubles (**DGS**), a coproduct of the grain-based bioethanol industry, have become an important feed ingredient used as an energy and CP source in beef cattle finishing diets. To date, most of the DGS production in the United States has occurred in the northern Great Plains and Corn Belt regions; however, production is increasing in the southern Great Plains, where sorghum is frequently used as a grain source in ethanol plants.

Several studies have suggested the feeding value of wet DGS (**WDGS**) is lower in finishing diets based on steam-flaked corn (**SFC**) than in diets based on dry-rolled corn (**DRC**; Cole et al., 2006b; Corrigan et al., 2009a; May et al., 2009). Corrigan et al. (2009a) suggested the optimal level of feeding WDGS in SFC-based diets was approximately 15% of diet DM; however, Vasconcelos et al. (2007) noted a linear decrease in animal

[1] This experiment was supported, in part, by a cooperative agreement between the USDA-ARS and Texas AgriLife Research, Amarillo. The mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture.
[2] Corresponding author: andy.cole@ars.usda.gov
[3] Current address: King Ranch Institute for Ranch Management, Texas A&M University–Kingsville, Kingsville 78363.
[4] Current address: Department of Animal Science, Auburn University, Auburn, AL 36849.

performance as the concentration of WDGS increased from 5 to 15% of diet DM. The reasons for this lower feeding value are not clear but may be due to energy dilution in SFC-based diets (Cole et al., 2006b). In addition, Vasconcelos et al. (2007) noted that the feeding value of blended WDGS based on sorghum and corn (**NMDGS**) was less than that of corn-based WDGS (**CDGS**). This is possibly due to the higher fiber and lower fat content of the NMDGS compared with the CDGS (Stock et al., 2000) or differences in the quantity or quality of solubles added to the distillers grains at different ethanol plants (Corrigan et al., 2009b).

Most finishing diets in the southern Great Plains region are based on SFC, which has more digestible starch than does DRC, which is typically used in the northern Great Plains. Therefore, research is needed to delineate optimal ways to feed WDGS in SFC-based diets. In addition, gaseous emissions from agriculture are a growing environmental concern. The effects of feeding high-N ingredients, such as WDGS, on gaseous emissions need to be determined.

To that end, 2 experiments were conducted to evaluate the digestibility and ammonia production potential of 2 sources of WDGS in SFC-based diets. The objectives of the studies were to 1) evaluate increasing levels of NMDGS on digestibility of SFC-based diets when fed to feedlot cattle, 2) compare the digestibility of NMDGS and CDGS fed at similar dietary concentrations, and 3) evaluate the in vitro ammonia production potential of feces and urine from cattle fed diets containing NMDGS and CDGS.

MATERIALS AND METHODS

Digestion Study

All procedures were approved by the multi-institution (Texas AgriLife Research, Amarillo; West Texas A&M University, Canyon; and USDA-ARS, Bushland, TX) animal care and use committee. Ten mixed-breed steers (initial BW = 252 ± 15 kg) were selected from a larger group and used in a replicated 5 × 5 Latin square design with 5 dietary treatments. Steers were processed on arrival, which included receiving a uniquely numbered ear tag; vaccination for infectious bovine rhinotracheitis, bovine viral diarrhea, parainfluenza 3, bovine respiratory syncytial virus (Titanium 5, Agri-Labs, Des Moines, IA), and *Clostridium chauvoei-septicum-novyi-sordellii-perfringens* Types C and D (Vision 7 with SPUR bacterin-toxoid, Intervet Schering-Plough, Millsboro DE); and treatment for internal and external parasites (Cydectin, Ft. Dodge Animal Health, Overland Park, KS). Steers were adjusted to the facilities, handling procedures, and a 92% concentrate finishing diet for 45 d before the start of the experiment. Steers were implanted with Revalor S (120 mg of trenbolone acetate + 24 mg of estradiol; Intervet Schering-Plough) at the start of the experiment.

The 5 dietary treatments used were similar to those used by Vasconcelos et al. (2007) and consisted of a standard SFC-based, 92% concentrate (DM basis) finishing diet formulated to contain 13.5% CP (**CON**), 3 diets with 5, 10, or 15% (DM basis) NMDGS replacing SFC, cottonseed meal, and urea (**5NMDG**, **10NMDG**, **15NMDG**, respectively), and a diet with 10% (DM basis) CDGS replacing SFC, cottonseed meal, and urea (**10CDG**; Table 1). To decrease the potential for excess dietary sulfur intake, a separate premix was used in diets containing WDGS in which ground corn replaced the ammonium sulfate used in the control premix (Table 1). Diets were formulated to be isonitrogenous and to meet all nutrient requirements (NRC, 1996); however, concentrations of fat and degradable intake protein (**DIP**) were not held constant. The NMDGS was obtained from a plant in New Mexico and was a composite (DM basis) of 47.1% sorghum centrifuge cake (directly from the centrifuge), 18.4% solubles (syrup), and 34.5% corn dried distillers grains. The CDGS was obtained from a plant in Nebraska and was composed of approximately 65% centrifuge cake and 35% syrup (DM basis). Both NMDGS and CDGS were stored in sealed, plastic, 200-L drums for the duration of the experiment. Samples of each WDGS were taken weekly and immediately frozen. At the conclusion of the study, samples were composited for chemical analyses.

Each period of the Latin square was 3 wk in length. During the first 2 wk of each period calves were individually fed in pens equipped with feeding headgates (American Calan, Northwood, NH) and adapted to the experimental diet. Calves were moved to indoor individual tie stalls (1.16 × 2.38 m) for a 2-d adjustment period followed by a 5-d total urine and partial fecal collection period. Each steer was restrained in the tie stall using a halter attached to a ring that moved freely on a chain spanning the width of each stall. Feed refusals were collected daily before 0730 h and weighed, and a representative subsample was collected and composited for each steer. Steers were fed once daily (at approximately 0730 h) during the collection periods. Feed intake was adjusted daily, if necessary, to hold feed refusals to less than 200 g/d; otherwise, steers had ad libitum access to feed. Feed samples were collected daily before feeding and composited for each steer for the 2 d before and 3 d after the first day of fecal and urine collection. Total urine excretion was collected using a rubber urine pouch attached to the ventral portion of the abdomen via a harness. A constant vacuum was maintained using individual vacuum pumps to allow collection of urine from each steer into a 20-L polypropylene urine-collection reservoir (Nasco Farm & Ranch, Fort Atkinson, WI). During the first 2 d in the tie stalls, urine to be used in the in vitro ammonia emission study was collected twice daily into unacidified containers and immediately frozen for later use. During the last 5 d of collection, urine was collected into reservoirs containing 200 mL of a 30% hydrochloric acid solution to maintain a pH of less than 4.0 to preserve N. Urine mass was recorded

Table 1. Composition of experimental finishing diets fed to steers[1]

Item	Control	5NMDG	10NMDG	15NMDG	10CDG
Ingredient, % DM basis					
Steam-flaked corn	75.40	73.90	70.67	65.73	71.04
Cottonseed hulls	7.62	7.59	7.56	7.53	7.60
Cottonseed meal	5.86	1.97	—	—	—
Urea	1.01	1.01	0.77	0.25	0.81
Limestone	0.26	0.35	0.52	0.81	0.53
Yellow grease	3.06	3.05	3.04	3.02	3.06
Molasses	4.25	4.23	4.22	4.19	4.24
Supplement[2,3]	2.54	2.53	2.52	2.50	2.52
Sorghum wet distillers grains	—	5.37	10.70	15.97	—
Corn wet distillers grains	—	—	—	—	10.20
Analyzed composition					
DM, %	81.5	77.1	73.2	71.7	71.9
CP, % DM basis	14.4	15.0	14.6	13.75	13.88
NDF, % DM basis	15.8	15.3	17.0	18.4	16.7
Ash, % DM basis	3.24	3.14	3.46	4.54	3.62
Ca, % DM basis	0.60	0.62	0.70	0.81	0.69
P, % DM basis	0.32	0.34	0.38	0.38	0.37
Ether extract, % DM basis	5.18	5.18	5.68	5.96	6.06
Starch, % DM basis	58.8	58.1	56.1	51.8	54.8
N:P, %:%	6.60	6.87	6.22	5.74	6.05
DIP,[4] % DM basis	8.09	7.52	6.84	5.75	6.95

[1]Diets: Control = 92% concentrate control diet; 5NMDG = 5% (DM basis) added wet sorghum+corn distillers grains with solubles (NMDGS); 10NMDG = 10% (DM basis) added NMDGS; 15NMDG = 15% (DM basis) added NMDGS; and 10CDG = 10% (DM basis) added wet corn distillers grains with solubles.

[2]Supplement for the control diet contained (DM basis) 23.37% cottonseed meal; 0.500% Endox (antioxidant; Kemin Industries, Des Moines, IA); 42.11% limestone; 1.036% dicalcium phosphate; 8.000% potassium chloride; 3.559% magnesium oxide; 6.667% ammonium sulfate; 12.000% salt; 0.0017% cobalt carbonate; 0.157% copper sulfate; 0.133% iron sulfate; 0.0025% ethylenediamine dihydroiodide; 0.267% manganese oxide; 0.100% selenium premix (0.2% Se); 0.845% zinc sulfate; 0.0079% vitamin A (1,000,000 IU/g); 0.126% vitamin E (500 IU/g); 0.675% Rumensin (176.4 mg/kg; Elanco Animal Health, Indianapolis, IN); and 0.45% Tylan (88.2 mg/kg; Elanco Animal Health). Concentrations in parentheses are expressed on a 90% DM basis.

[3]Supplement for the distillers grains diets contained (DM basis) 30.03% ground corn; 0.500% Endox; 42.11% limestone; 1.036% dicalcium phosphate; 8.000% potassium chloride; 3.559% magnesium oxide; 12.000% salt; 0.0017% cobalt carbonate; 0.157% copper sulfate; 0.133% iron sulfate; 0.0025% ethylenediamine dihydroiodide; 0.267% manganese oxide; 0.100% selenium premix (0.2% Se); 0.845% zinc sulfate; 0.0079% vitamin A (1,000,000 IU/g); 0.126% vitamin E (500 IU/g); 0.675% Rumensin (176.4 mg/kg); and 0.45% Tylan (88.2 mg/kg). Concentrations in parentheses are expressed on a 90% DM basis.

[4]DIP = degradable intake protein. The DIP values were calculated from NRC (1996).

daily, and 10% aliquots were collected and composited for each steer for the last 5 d of each collection period. At the conclusion of each collection period, the composited urine sample for each steer was mixed thoroughly, and a subsample was obtained and stored at −20°C for later chemical analysis. Feces were scraped from the floor of the individual metabolism stalls at least twice daily (0730 and 1600 h) and mixed thoroughly. A 250-g sample was collected daily and composited for each steer for the 5-d collection period. After 5 d, two 500-g subsamples were collected and stored at −20°C. One subsample was used for laboratory analyses, and the second was used in the in vitro ammonia emission study.

Composited feed, WDGS, orts, and feces were dried at 60°C in a forced-draft oven for 48 h to determine DM. Samples were then ground in a Wiley Mill (Thomas-Wiley Laboratory Mill Model 4, Swedesboro, NJ) to pass a 1-mm screen. Composited feed, WDGS, orts, and feces were ashed at 550°C for 12 h to determine OM, and ash content (AOAC, 1995), and were analyzed for NDF using techniques developed by Goering and Van Soest (1970) as modified by Vogel et al. (1999), and for starch using the enzymatic, colorimetric procedure of MacRae and Armstrong (1968). Feed, orts, feces, and urine samples were digested using a block digester (Fisher Scientific, Pittsburgh, PA) and analyzed for N and P via colorimetric methods (QuikChem Method 10–107–06–2-E for N and Method 15–115–01–1-B for P) using a Flow Injection Analyzer (Lachat Instruments, Milwaukee, WI). Composite WDGS samples were analyzed for DM, ether extract, Ca, and S at a commercial laboratory (Servi-Tech, Amarillo, TX) using AOAC (1995) procedures.

Diet, ort, and feces samples were analyzed for indigestible NDF as an internal marker to estimate total fecal output using an ANKOM II Daisy fermentor and an ANKOM200 Fiber Analyzer (ANKOM Technology Corporation, Fairport, NY). A 0.5-g air-dried sample of diet, ort, or feces was added to a preweighed ANKOM F57 filter bag, dried at 60°C for 24 h in a forced-draft oven, and reweighed. Twenty-four filter bags and 2 L of a mixture of McDougall's buffer and strained ruminal fluid (4:1 ratio) were added to the fermentation vessel. The vessel was purged with CO_2, and samples were incubated for 96 h. Ruminal fluid for the in vitro digestion was collected from 2 ruminally cannulated steers consuming diets consisting of 75% SFC, 15% cottonseed hulls, and 10% mineral, vitamin, protein supplement. Ruminal fluid inoculum was prepared by filtering ruminal fluid through 4 layers of cheesecloth. After fermentation, inoculum in the fer-

mentation vessels was discarded, and bags were washed with hot tap water 2 times and with deionized water 4 times. Bags were dried at 60°C for 24 h and weighed, and the NDF analysis was performed as described above.

The digestibilities of NMDGS and CDGS were calculated by difference assuming the digestibility of the basal portion of the diets containing WDGS was the same as that of the control diet. For the NMDGS, digestibilities were estimated as the average of values determined using the 10NMDG and 15NMDG diets.

In Vitro Ammonia Emissions Study

The in vitro NH_3-N emission system has been described previously (Shi et al., 2001; Cole et al., 2005). Briefly, the system was composed of 48 sealed polyethylene chambers (20 cm × 20 cm × 12 cm deep) each attached to 2 NH_3-N trapping bottles containing 100 mL of 0.9 *M* sulfuric acid. A vacuum system pulled air through the chambers and NH_3-N traps at a rate of approximately 3 L/min. To each chamber 1,500 g of screened feedlot manure and 100 mL of water, followed by the feces and urine excretion of one steer (2 chambers/steer), were added. The quantity of urine and feces added to each chamber was equal to 1% of the daily excretion by the steer during the nutrient balance trial. Because a total of 3 in vitro NH_3-N runs were required, 4 chambers containing a common feces and urine sample were included in each run to correct for run-to-run variation in NH_3-N emissions. Two blank chambers containing manure but no feces or urine were included in each run to correct for atmospheric NH_3-N contamination. Acid traps were replaced with fresh traps each day for 5 d and then at 2-d intervals until d 14 of collection. The N content of the acid traps was determined colorimetrically using a Flow Injection Analyzer (Quick Chem Method 10–107–06–2-E, 2001; Lachat Instruments).

Statistical Analyses

Data from both experiments were analyzed as a replicated 5 × 5 Latin square design using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Model statements included the fixed effects of dietary treatment, animal, and period. Treatment responses were compared by the following contrasts: (1) the linear response to graded levels of NMDGS, (2) the quadratic response to graded levels of NMDGS, (3) comparison of the 10NMDG vs. 10CDG treatments, and (4) comparison of 10CDG vs. the CON diet.

RESULTS AND DISCUSSION

Digestion Experiment

The chemical composition of the experimental diets was similar to expected values (Table 1). The calculated DIP concentration of the diets decreased as NMDGS in the diet increased. The calculated DIP values for the higher NMDGS diets were lower than what is sometimes considered adequate for SFC-based diets (NRC, 1996). However, using very similar diets, Vasconcelos et al. (2007) concluded that N recycling was sufficient to prevent a ruminal DIP deficiency in these diets.

The chemical composition of the CDGS was 35.1% DM, 30.4% CP, 0.62% P, 0.88% S, 4.4% ash, 25.9% NDF, 10.4% ether extract, 6.8% starch, and 0.04% Ca (all values except DM on a DM basis). The chemical composition of the NMDGS was 40.1% DM, 38.1% CP, 0.51% P, 0.50% S, 4.4% ash, 34.3% NDF, 8.2% ether extract, 5.6% starch, and 0.04% Ca (all values except DM on a DM basis). These differences in composition are probably attributable to a combination of differences in the grain source and differences in the quantity of solubles added to the distillers grains.

Apparent DM, OM, and ash digestibilities are presented in Table 2. Dry matter and OM intake and excretion were not affected by diet, and apparent DM and OM digestion of the 10NMDG and 10CDG diets was not statistically different. Apparent DM digestion and OM digestion were higher on the control and 15NMDG diets and lower on the 5NMDG and 10NMDG diets (quadratic effect, $P < 0.04$); however, the differences were small. The cause of this quadratic effect is not clear considering the relatively small dietary changes with the addition of 5 and 10% NMDGS. May et al. (2010) also noted no effect of 15% CDGS or 15% sorghum-based DGS (**SDGS**) on total-tract digestibility of DM or OM in SFC-based diets. In contrast, Leibovich et al. (2009) reported lower in vitro DM disappearance from diets containing 15% SDGS than from control diets containing no DGS.

Vander Pol et al. (2009) and Spiehs and Varel (2009) reported that feeding 40% CDGS in diets based on DRC did not affect DMI or total-tract digestibility of DM and OM. In contrast, May et al. (2009) and Uwituze et al. (2010) noted a decrease in DM and OM digestion when 25% dried CDGS was included in an SFC-based finishing diet, and Corrigan et al. (2009a) reported that feeding 40% CDGS decreased digestibility of DM and OM in SFC-, DRC-, and high-moisture corn (**HMC**)-based diets. However, the results of Corrigan et al. (2009a) were somewhat confounded with large differences in DM and OM intake.

The reason for these somewhat inconsistent results in digestibility is unclear. The composition of WDGS is known to vary, particularly when differing proportions of distillers solubles are added (Holt and Pritchard, 2004; Kleinschmit et al., 2005). They could be due in part to differences in the quantity and form of fat in the diet (Ramirez and Zinn, 2000; Plascencia et al., 2003; Montgomery et al., 2008).

Ash intake and apparent ash absorption increased (linear and quadratic effects; $P < 0.01$) with increasing dietary NMDGS concentration. This would be expected because of the high ash content of WDGS. The percentage of ash consumed and the

Table 2. Apparent DM, OM, and ash digestion of steers fed experimental diets containing increasing concentrations of sorghum+corn-based wet distillers grains with solubles (NMDGS) or a single concentration of corn-based wet distillers grains with solubles (CDGS)[1]

Item	Control	5NMDG	10NMDG	15NMDG	10CDG	SEM	Contrast[2]
DMI, g/d	6,590	6,130	6,260	6,380	6,030	170	*P* = 0.65
DM digestion, %	86.9	85.0	85.5	86.7	86.2	0.34	Q <0.02
DM excreted, g/d	863	919	915	837	825	30.1	*P* = 0.70
OM intake, g/d	6,382	5,938	6,042	6,093	5,808	160	*P* = 0.64
OM digestion, %	88.5	87.1	87.1	88.2	88.1	0.32	Q <0.04
OM excreted, g/d	734	771	781	713	683	26.3	*P* = 0.65
OM digested, g/d	5,648	5,168	5,261	5,380	5,126	143	*P* = 0.53
Ash intake, g/d	214	192	216	290	218	8.8	L & Q <0.01
Ash absorbed, %	39.1	22.7	39.1	54.7	35.1	2.6	L & Q <0.01
Ash excreted, g/d	129	149	134	125	143	5.9	*P* = 0.47
Ash absorbed, g/d	84	44	82	164	76	8.8	L & Q <0.01

[1]Diets: 5NMDG = 5% NMDGS; 10NMDG = 10% NMDGS; 15NMDG = 15% NMDGS; and 10CDG = 10% CDGS.

[2]L = linear effect of NMDGS; Q = quadratic effect of NMDGS.

total quantity of ash apparently absorbed increased (liner and quadratic effects, $P < 0.01$) with increasing dietary NMDGS; however, the quantity of ash excreted was not affected by diet.

Nitrogen metabolism is presented in Table 3. Apparent N digestion and grams of N apparently absorbed tended to decrease linearly ($P < 0.07$) as the dietary concentration of NMDGS increased. Fecal N excretion was quadratically ($P < 0.09$) affected by NMDGS concentration and was the highest in steers fed the 5NMDG diet. Cattle fed the 10CDG diet had lower N intake ($P < 0.06$), less urine N excretion ($P < 0.04$), and less N absorbed than did steers fed the CON diet. They also tended to have lower fecal N excretion ($P < 0.10$) and less urinary N excretion ($P < 0.04$) than did steers fed the 10NMDG diet, most likely because of numerically lower N intake. Nitrogen retention was not affected by dietary treatments, although N retention tended ($P < 0.13$) to decrease with increasing dietary NMDGS concentration, possibly because of numerically lower N intakes. Urinary N excretion averaged 52.2% of N intake and 61.7% of total N excretion.

Spiehs and Varel (2009) reported that total N excretion and urinary N excretion increased as dietary CDGS

Table 3. Nitrogen metabolism of steers fed experimental diets containing increasing concentrations of sorghum+corn-based wet distillers grains with solubles (NMDGS) or a single concentration of corn-based wet distillers grains with solubles (CDGS)[1]

Item	Control	5NMDG	10NMDG	15NMDG	10CDG	SEM	Contrast[2]
N intake, g/d	152.4	147.1	146.4	140.4	133.8	3.48	CvsC <0.06
Fecal N, g/d	43.3	52.1	49.3	46.4	40.9	1.70	Q <0.09: CvsNM <0.10
Urine N, g/d	81.2	74.2	75.9	76.8	65.4	2.42	CvsC <0.01; CvsNM <0.04
Urine N, % of intake	54.4	50.5	52.0	55.4	48.9	1.46	*P* = 0.78
Urine N, % of excreted N	65.6	58.3	60.7	62.5	61.4	0.93	Q <0.02
N digestion, %	71.6	64.8	66.4	66.1	69.3	0.89	L <0.07
N absorbed, g/d	109.2	95.1	97.1	94.1	92.8	2.85	L <0.07; CvsC <0.04
N retained, g/d	28.0	20.9	21.2	17.3	27.4	2.30	L <0.13
N retained, % of intake	17.2	14.2	14.4	10.7	20.4	1.77	L <0.15
N retained, % of absorbed	23.6	22.8	21.1	14.4	28.8	2.62	L <0.12

[1]Diets: 5NMDG = 5% NMDGS; 10NMDG = 10% NMDGS; 15NMDG = 15% NMDGS; and 10CDG = 10% CDGS.

[2]L = linear effect of NMDGS; Q = quadratic effect of NMDGS; CvsNM = 10CDG vs. 10NMDG; CvsC = 10CDG vs. control diet.

Table 4. Phosphorus metabolism of steers fed experimental diets containing increasing concentrations of sorghum+corn-based wet distillers grains with solubles (NMDGS) or a single concentration of corn-based wet distillers grains with solubles (CDGS)[1]

Item	Control	5NMDG	10NMDG	15NMDG	10CDG	SEM	Contrast[2]
P intake, g/d	23.29	21.46	23.54	24.44	22.14	0.64	$P = 0.32$
Fecal P, g/d	9.82	10.52	10.45	9.04	10.15	0.58	$P = 0.78$
Urine P, g/d	4.17	5.18	4.84	5.25	4.30	0.45	$P = 0.30$
Urine P, % of intake	17.9	23.9	21.9	21.1	19.1	1.97	Q <0.12
Urine P, % of excreted P	29.2	32.4	31.8	37.0	30.4	2.93	L <0.07
P absorbed, %	53.6	44.2	48.8	52.3	44.0	2.70	L <0.01; Q <0.02
P absorbed, g/d	13.46	10.94	13.08	15.39	11.98	0.68	L <0.03; Q <0.01
P retained, g/d	9.29	5.76	8.25	10.15	7.68	0.51	Q <0.01
P retained, % of intake	39.0	26.5	34.7	40.7	34.9	1.68	Q <0.01
P retained, % of absorbed	70.2	57.1	62.7	67.9	66.8	2.71	Q <0.02
P retained / 100 g CP retained, g	4.96	5.36	3.95	5.89	5.83	1.02	$P = 0.93$

[1]Diets: 5NMDG = 5% NMDGS; 10NMDG = 10% NMDGS; 15NMDG = 15% NMDGS; and 10CDG = 10% CDGS.

[2]L = linear effect of NMDGS; Q = quadratic effect of NMDGS.

concentrations increased (0 to 20 to 40 to 60% of DM) in DRC-based diets primarily because of higher dietary N concentrations and higher N intakes. Uwituze et al. (2010) reported that feeding 25% dry CDGS in SFC-based finishing diets caused a decrease in total-tract N digestion. In contrast, May et al. (2010) noted no effect of 15% CDGS or SDGS on total-tract digestibility of N in SFC-based diets.

Phosphorus intake and fecal and urinary excretion of P were not significantly affected by diet (Table 4). However, as the dietary concentration of NMDGS increased, urinary P excretion as a percentage of P excreted tended to increase (linear effect, $P < 0.07$). Dietary NMDGS concentration also affected apparent P absorption and retention (linear and quadratic effects, $P \leq 0.03$). The quadratic effect of NMDGS concentration on P retention variables is again unclear, although it may be the result of numerical differences in P intake. Phosphorus metabolism variables were similar for steers fed the 10NMDG and 10CDG diets. The grams of P retained per 100 g of CP retained averaged 5.08, which is slightly greater than the NRC (1996) value of 3.9.

Spiehs and Varel (2009) also noted that P intake, total P excretion, and urinary P excretion increased as the concentration of CDGS increased from 0 to 60% in DRC-based diets. However, in their study, fecal P excretion was not significantly affected by dietary CDGS concentration. In nonruminants, the P in distillers grains is more available than the P in the basal grain source because of breakdown of the phytate molecule during the fermentation process (Pedersen et al., 2007). However, the results of the present trial suggest that in beef cattle, the availability of P in WDGS is similar to that of the basal grain source.

Apparent fat, NDF, and starch digestion are presented in Table 5. Fat intake increased (linear effect, $P < 0.02$) with increasing NMDGS concentration, as would be expected because of the high ether extract content of the NMDGS. Although fat digestion was quadratically affected ($P < 0.02$) by NMDGS concentration and was greater ($P < 0.02$) for 10CDG than 10NMDG, the differences were small (less than 2%).

Uwituze et al. (2010) reported that feeding 25% dry CDGS in SFC-based finishing diets did not affect fat digestion, and Corrigan et al. (2009a) noted no significant effect of 40% CDGS on fat digestion in DRC-, SFC-, or HMC-based diets, despite large differences in fat intake. In contrast, May et al. (2009) noted that 25% dried CDGS decreased fat digestion in SFC-based diets, whereas Vander Pol et al. (2009) reported that feeding 40% CDGS increased total-tract ether extract digestion in DRC-based diets.

These contradictory results may be due to differences in the quantity and source of fat in the experimental diets. California studies noted that unsaturated fats tend to be more digestible in the small intestine than saturated fats (Plascencia et al., 1999; Zinn et al., 2000). Montgomery et al. (2008) noted that the source of dietary fat (4% of dietary DM) affected the site and extent of fatty acid digestion in SFC-based finishing diets and that the 18-C unsaturated fatty acids in corn oil within full-fat corn germ were biohydrogenated less in the rumen than 18-C unsaturated fatty acids in free corn oil. This indicated there may be some protection afforded the unsaturated fatty acids in corn oil by other fractions in the germ, which might also hold true for WDGS. Vander Pol et al. (2009) reported that feeding 40% CDGS increased the proportion of dietary unsaturated fatty acids that reached the duodenum, compared with steers fed a control diet supplemented with 3.4% free corn oil. Thus, Vander

Table 5. Apparent ether extract (fat), NDF, and starch digestion of steers fed experimental diets containing increasing concentrations of sorghum+corn-based wet distillers grains with solubles (NMDGS) or a single concentration of corn-based wet distillers grains with solubles (CDGS)[1]

Item	Control	5NMDG	10NMDG	15NMDG	10CDG	SEM	Contrast[2]
Fat intake, g/d	341	321	356	383	369	11.9	L <0.02
Fat digestion, %	96.6	95.3	95.7	96.0	96.8	0.2	Q <0.02; CvsNM < 0.02
Fat excreted, g/d	12	15	15	15	11	0.7	L <0.05; CvsNM <0.05
Fat absorbed, g/d	330	306	341	368	357	11.6	L <0.03; Q <0.08
NDF intake, g/d	1,044	938	1,059	1,169	1,009	30.4	Q <0.06
NDF digestion, %	71.2	67.1	69.7	75.8	71.1	0.9	L & Q <0.02
NDF excreted, g/d	299	306	323	281	286	10.7	*P* = 0.64
NDF digested, g/d	745	632	737	888	724	25.9	L & Q <0.01
Starch intake, g/d	3,879	3,556	3,510	3,311	3,299	96.6	L <0.03; CvsC <0.02
Starch digestion, %	98.8	98.5	98.4	98.7	98.8	0.1	Q <0.07; CvsNM <0.10
Starch excreted, g/d	49	56	58	43	40	4.0	CvsNM <0.07
Starch digested, g/d	3,830	3,499	3,452	3,268	3,259	95	L <0.03: CvsC <0.02

[1]Diets: 5NMDG = 5% NMDGS; 10NMDG = 10% NMDGS; 15NMDG = 15% NMDGS; and 10CDG = 10% CDGS.

[2]L = linear effect of NMDGS; Q = quadratic effect of NMDGS; CvsNM = 10CDG vs. 10NMDG; CvsC = 10CDG vs. control diet.

Pol et al. (2009) indicated the corn oil within the CDGS was partially protected from ruminal biohydrogenation. They hypothesized that this might partially account for the higher energy value of CDGS compared with DRC noted in many feeding studies when higher concentrations of CDGS than those used in the present study were fed. However, this protection might be partially dependent on the proportion of the corn oil within the distillers grain fraction and that within the solubles fraction. In fact, with forage diets Corrigan et al. (2009b) reported that the proportion of corn condensed solubles added to dried corn distillers grains did affect fat digestion.

Neutral detergent fiber intake increased with increasing NMDGS concentration (quadratic effect, $P < 0.06$) most probably because of the high NDF concentration of the NMDGS. There were linear and quadratic effects of NMDGS concentration on percentage of NDF digestion and quantity of NDF digested ($P < 0.02$) but no dietary effects on the quantity of NDF excreted. Digestion of NDF was similar for steers fed 10NMDG and 10CDG diets.

Somewhat in contrast to our results, May et al. (2009, 2010) noted no effect of 25% dried CDGS, 15% wet CDGS, or 15% wet SDGS on total-tract digestibility of NDF. Corrigan et al. (2009a) and Vander Pol et al. (2009) reported no significant effect of 40% CDGS on NDF digestion despite significant differences in intake of NDF.

Starch intake decreased with increasing NMDGS concentration (linear effect, $P < 0.03$) and was lower for the 10CDG diet than for the CON diet ($P < 0.02$). The percentage of starch digestion was not affected by diets; however, because of the difference in starch intake, the quantity of starch digested was affected by diets, with a linear decrease ($P < 0.03$) as NMDGS concentration increased and a lower value ($P < 0.02$) for 10CDG than for the CON diet.

Similarly, May et al. (2009, 2010) noted no effect of 25% dried CDGS, 15% wet CDGS, or 15% wet SDGS on total-tract digestibility of starch. Vander Pol et al. (2009) and Corrigan et al. (2009a) reported no significant effect of 40% CDGS on starch digestion despite significant differences in starch intake. Corrigan et al. (2009a) noted that feeding 40% CDGS tended to increase the in situ ruminal digestibility of starch. However, the effect was significant only for diets based on DRC and not for diets based on more fermentable HMC or SFC. In contrast, Uwituze et al. (2010) reported that feeding 25% dried CDGS in SFC-based diets decreased the digestibility of starch.

The digestibilities of DM, OM, N, P, starch, and NDF in NMDGS and CDGS, calculated by difference, were highly variable and were not significantly different (Table 6). However, the digestibility of fat tended ($P < 0.09$) to be greater in CDGS than in NMDGS. In general, these digestibility values did not differ appreciably from values for the CON diet.

Corrigan et al. (2009a) reported 22-h in situ digestibilities of CDGS as follows: DM, 70.3%; starch, 86.6%; and NDF, 34.0%. Our estimates for DM and starch digestion were similar; however, our estimates for digestibility of NDF in the WDGS were appreciably greater. MacDonald (2011) noted that the in situ digestibilities of DM and NDF in WDGS were affected by the NDF content of the WDGS. The difference in NDF concentration was the result of a combination of differences in the original grain source (sorghum vs. corn) and differences in the quantity of solubles returned to the distillers grain. MacDonald (2011) suggested that one reason for the poor utilization of WDGS in some diets might be the low digestibility of NDF in the WDGS. In the pres-

Table 6. Apparent total-tract digestibility of DM, OM, N, P, ether extract, NDF, and starch of sorghum+corn-based wet distillers grains with solubles (NMDGS) and corn-based wet distillers grains with solubles (CDGS)

	NMDGS[1]		CDGS		
Item	% Digested	SEM	% Digested	SEM	*P*-value
DM, %	78.9	4.8	79.6	8.6	0.94
OM, %	80.3	4.3	84.5	8.1	0.62
N, %	67.9	5.2	65.3	9.0	0.78
P, %	85.8	17.5	54.2	28.7	0.33
Ether extract, %	91.6	2.0	97.4	2.6	0.09
NDF,%	75.9	5.3	71.2	8.0	0.62
Starch, %	74.6	12.3	97.3	20.5	0.32

[1]Values were determined using the 10% and 15% NMDGS diets.

ent study, the apparent digestibility of NDF in the NMDGS and CDGS exceeded 71%, which was appreciably greater than in situ values of Corrigan et al. (2009a) and MacDonald (2011). Although 71% digestibility may be considered a normal to somewhat high digestibility for NDF in most forages, it might be considered somewhat low for fiber in corn grain that is composed mostly of hemicelluloses and nonlignified cellulose. In addition, considerable hindgut fermentation of WDGS NDF could be occurring in our study that would not be measured via in situ trials. These digestibility values for DGS should be viewed as preliminary values. With the small inclusion levels, any associative effects or errors in measurements are potentially magnified and attributed solely to the DGS.

The composition of feces may be related to the future fertilizer value of manure and to gaseous emissions from the feedlot pen surface (Miller and Varel, 2001; Cole et al., 2009). Therefore, the effects of diet on composition of feces are presented in Table 7. Ether extract concentration and N:P ratio of feces increased ($P < 0.01$) with increasing NMDGS concentration. Feces of steers fed the 10CDG diet were lower ($P < 0.09$) in OM, N, ether extract, and starch concentration than were feces of steers fed the 10NMDG diet and were lower ($P < 0.07$) in OM concentrations than were feces of steers fed the CON diet. Despite differences in P intake, the concentration of P in feces was unaffected by diet.

In Vitro Ammonia Emissions Study

Dietary effects on in vitro ammonia emissions measurements are presented in Table 8. Cumulative ammonia losses after 7 and 14 d and ammonia losses as a percentage of total N added tended ($P \leq 0.11$) to increase linearly with increasing dietary NMDGS concentration. Ammonia losses from manure of steers fed the 10CDG diet were not different from losses from manure of steers fed the 10NMDG diet. The predominant source of ammonia on feedlot pen surfaces is urine spots (Cole and Todd, 2009). Thus, in general, as urinary N excretion increases, ammonia emissions increase (Cole et al., 2005, 2006a; Cole and Todd, 2009). However, in the present study, in vitro ammonia losses and urinary N additions appeared to be negatively related as NMDGS concentrations increased. In addi-

Table 7. Composition of feces from steers fed experimental diets containing increasing concentrations of sorghum+corn-based wet distillers grains with solubles (NMDGS) or a single concentration of corn-based wet distillers grains with solubles (CDGS)[1]

Item, % DM basis unless noted	Control	5NMDG	10NMDG	15NMDG	10CDG	SEM	Contrast[2]
OM	85.0	83.1	85.8	84.8	82.6	0.54	CvsNM <0.02; CvsC <0.07
N	5.02	5.70	5.48	5.59	4.96	0.10	CvsNM <0.07
P	1.17	1.19	1.14	1.08	1.25	0.06	*P* = 0.56
Ash	15.0	16.9	14.2	15.2	17.4	0.54	CvsNM <0.02; CvsC <0.07
NDF	35.1	33.0	35.8	33.6	34.9	0.52	*P* = 0.39
Ether extract	1.31	1.57	1.71	1.80	1.40	0.06	L <0.01; CvsNM <0.08
Starch	5.37	5.71	6.19	5.06	4.73	0.33	CvsNM <0.09
N:P, %:%	4.73	5.29	5.24	5.85	4.76	0.27	L <0.01

[1]Diets: 5NMDG = 5% NMDGS; 10NMDG = 10% NMDGS; 15NMDG = 15% NMDGS; and 10CDG = 10% CDGS.

[2]L = linear effect of wet NMDGS; Q = quadratic effect of NMDGS; CvsNM = 10CDG vs. 10NMDG; CvsC = 10CDG vs. control diet.

Table 8. In vitro ammonia emissions from feces and urine collected from steers fed experimental diets containing increasing concentrations of sorghum+corn-based wet distillers grains with solubles (NMDGS) or a single concentration of corn-based wet distillers grains with solubles (CDGS)[1]

Item	Control	5NMDG	10NMDG	15NMDG	10CDG	SEM	Contrast[2]
Urine pH	7.94	7.87	8.17	7.79	7.98	0.08	$P = 0.49$
Weight loss, g	159.9	164.5	166.5	160.0	165.2	2.21	$P = 0.83$
Weight loss, % of added	93.0	91.7	94.1	91.1	90.9	3.58	$P = 0.69$
Fecal N, mg	457	553	505	452	422	11	Q <0.09; CvsNM <0.10
Urine N, mg	814	798	756	737	678	15	L <0.03; CvsC <0.01; CvsNM <0.04
Total N, mg	1,270	1,352	1,261	1,188	1,100	22	Q <0.05; CvsC <0.04; CvsNM <0.06
Cumulative NH_3 loss, d 7, mg	55.3	56.8	72.1	75.3	64.9	11.6	L <0.11; Q <0.10
Cumulative NH_3 loss, d 14, mg	71.0	73.5	95.0	97.8	82.4	14.9	L <0.09; Q <0.13
14-d N loss, % of urine N added	9.9	9.2	12.6	13.3	12.2	1.22	L & Q <0.07; CvsC <0.06

[1]Diets: 5NMDG = 5% NMDGS; 10NMDG = 10% NMDGS; 15NMDG = 15% NMDGS; and 10CDG = 10% CDGS.

[2]L = linear effect of wet NMDGS; Q = quadratic effect of wet NMDGS; CvsNM = 10CDG vs. 10NMDG; CvsC = 10CDG vs. control diet.

tion, ammonia-N losses as a percentage of N input increased as urinary N additions decreased. The cause of these effects is not clear but might be related to the differences in the quantity of OM, NDF, fat, and starch added to the incubation chambers in the feces (Bierman et al., 1999; Cole et al., 2007). Erickson and Klopfenstein (2010) noted that additions of OM to pen surfaces, either as fiber in the feces or as a pen surface amendment, could decrease N volatilization losses under some circumstances. It is plausible that when sufficient readily metabolizable fiber or starch is available on the pen surface, fecal and soil microbes are capable of capturing a greater proportion of the ammonium-N produced and converting it to microbial tissue or other forms of organic-N. Although it was not measured in this trial, another possible factor might be the pH of the feces and manure. We (N. A. Cole and M. S. Brown, unpublished data) noted that feeding low (≤15%) concentrations of WDGS in isonitrogenous diets caused a decrease in fecal and manure pH. A lower manure pH could reduce the quantity of ammonium-N converted to the volatile ammonia form.

CONCLUSIONS

With essentially all digestion variables (DM, OM, ash, N, P, ether extract, and NDF) measured, there was a quadratic effect of NMDGS concentration on apparent digestion, with lowest values for the 5NMDG and 10NMDG diets and highest values for the control and 15NMDG diets. The reason for these apparent negative associative effects at the low NMDGS concentrations is not apparent. Digestion of DM, OM, ash, N, P, and NDF in diets that contained 10% NMDGS were similar to diets that contained 10% CDGS. Because the sources of the sorghum+corn-based and corn-based WDGS in this trial differed, and because the proportions of solubles and distillers grains differed, this is probably not a true comparison of the 2 grain sources used.

IMPLICATIONS

Using the same diets as in this study, Vasconcelos et al. (2007) noted that ADG and G:F decreased linearly ($P \leq 0.03$) as dietary concentration of NMDGS increased but noted no difference in ADG or G:F between steers fed the 10CDG and 10NMDG diets. However, in contrast to the results of Vasconcelos et al. (2007) and in agreement with our digestibility data, Daubert et al. (2005) noted a quadratic response in ADG and G:F when adding sorghum-based DGS to SFC-based diets, with maximum ADG and G:F ratio between 8 and 16% added DGS. The results of this study suggest that the digestibilities of NMDGS and CDGS are similar and that at the concentrations used in this study, WDGS had only minor effects on total-tract digestibility of finishing diets based on SFC.

ACKNOWLEDGMENTS

The authors thank Abengoa Bioenergy (Portales, NM) for providing distillers grains and DSM Nutritional Products (Belvidere, NJ), Elanco Animal Health (Greenfield, IN), Fort Dodge Animal Health (Overland Park, KS), Intervet (Millsboro, DE), and Kemin Industries (Des Moines, IA) for supplying various products used during the experiment.

LITERATURE CITED

AOAC. 1995. Official Methods of Analysis. 16th ed. AOAC, Arlington, VA.

Bierman, S., G. E. Erickson, T. J. Klopfenstein, R. A. Stock, and D. H. Shain. 1999.

Evaluation of nitrogen or organic matter balance in the feedlot as affected by level and source of dietary fiber. J. Anim. Sci. 77:1645.

Cole, N. A., R. N. Clark, R. W. Todd, C. R. Richardson, A. Gueye, L. W. Greene, and K. McBride. 2005. Influence of dietary crude protein concentration and source on potential ammonia emissions from beef cattle manure. J. Anim. Sci. 83:722.

Cole, N. A., P. J. Defoor, M. L. Galyean, G. C. Duff, and J. F. Gleghorn. 2006a. Effects of phase feeding of crude protein on performance, carcass characteristics, serum urea nitrogen concentrations, and manure nitrogen of finishing beef steers. J. Anim. Sci. 84:3421.

Cole, N. A., M. L. Galyean, J. MacDonald, and M. S. Brown. 2006b. Interaction of grain co-products with grain processing: Associative effects and management. Pages 193–205 in Proc. Oklahoma State Univ. Cattle Grain Proc. Symp., MP-177, Tulsa, OK.

Cole, N. A., A. M. Mason, R. W. Todd, M. Rhoades, and D. B. Parker. 2009. Chemical composition of pen surface layers of beef cattle feedyards. Prof. Anim. Sci. 25:541.

Cole, N. A., and R. W. Todd. 2009. Nitrogen and phosphorus balance of beef cattle feedyards. Pages 17–24 in Proc. Texas Anim. Manure Manage. Issues Conf., Round Rock, TX.

Cole, N. A., R. W. Todd, and D. B. Parker. 2007. Use of fat and zeolite to reduce ammonia emissions from beef cattle feedyards. Paper #41 in Proc. Int. Symp. on Air Quality and Waste Manage. for Agric., Broomfield, CO. ASABE Publication 701P0907cd.

Corrigan, M. E., G. E. Erickson, T. J. Klopfenstein, M. K. Luebbe, K. J. Vander Pol, N. F. Meyer, C. D. Buckner, S. J. Vanness, and K. J. Hanford. 2009a. Effect of corn processing method and corn wet distillers grains plus solubles inclusion level in finishing diets. J. Anim. Sci. 87:3351.

Corrigan, M. E., T. J. Klopfenstein, G. E. Erickson, N. F. Meyer, K. J. Vander Pol, M. A. Greenquist, M. K. Luebbe, K. K. Karges, and M. L. Gibson. 2009b. Effects of level of condensed distillers solubles in corn dried distillers grains on intake, daily weight gain, and digestibility in growing steers fed forage diets. J. Anim. Sci. 87:4073.

Daubert, R. W., J. S. Drouillard, E. R. Loe, J. J. Sindt, B. E. Depenbusch, J. T. Fox, M. A. Greenquist, and M. E. Corrigan. 2005. Optimizing use of wet sorghum distillers grains with solubles in flaked-corn finishing diets. Pages 15–21 in Kansas State Univ. Beef Cattle Res. 2005 Rep. of Progress 943, Kansas State Univ., Manhattan.

Erickson, G. E, and T. Klopfenstein. 2010. Nutritional and management methods to decrease nitrogen losses from beef feedlots. J. Anim. Sci. 88(E. Suppl.):E172–E180.

Goering, H. K., and P. J. Van Soest. 1970. Forage fiber analysis. USDA Agriculture Handbook No. 379. US Print. Office, Washington, DC.

Holt, S. M., and R. H. Pritchard. 2004. Composition and nutritive value of corn co-products from dry milling ethanol plants. Pages 1–7 in South Dakota State University Beef 2004–01, South Dakota State Univ., Brookings.

Kleinschmit, D. H., J. M. Ladd, D. J. Schingoethe, K. F. Kalscheur, and A. R. Hippen. 2005. Ruminal and intestinal digestibility of distillers grains with soluble varies by source. J. Anim. Sci. 83(Suppl. 1):186. (Abstr.)

Leibovich, J., J. T. Vasconcelos, and M. L. Galyean. 2009. Effects of corn processing method in diets containing sorghum wet distiller's grains plus solubles on performance and carcass characteristics of finishing beef cattle and on in vitro fermentation of diets. J. Anim. Sci. 87:2124.

MacDonald, J. C. 2011. Grain milling byproducts and fiber digestibility in grazing and finishing beef cattle. Presented at the 2011 Southwest Nutr. Manage. Conf., Tempe, AZ.

MacRae, J. C., and D. G. Armstrong. 1968. Enzyme method for determination of alpha-linked glucose polymers in biological materials. J. Sci. Food Agric. 19:578.

May, M. L., J. C. DeClerck, M. J. Quinn, N. DiLorenzo, J. Leibovich, D. R. Smith, K. E. Hales, and M. L. Galyean. 2010. Corn or sorghum wet distillers grains with solubles in combination with steam-flaked corn: Feedlot cattle performance, carcass characteristics, and apparent total tract digestibility. J. Anim. Sci. 88:2433.

May, M. L., M. J. Quinn, C. D. Reinhardt, L. Murray, M. L. Gibson, K. K. Karges, and J. S. Drouillard. 2009. Effects of dry-rolled or steam-flaked corn finishing diets with or without 25% distillers dried grains on ruminal fermentation and apparent total tract digestion. J. Anim. Sci. 87:3630.

Miller, D. N., and V. H. Varel. 2001. In vitro study of the biochemical origin and production limits of odorous compounds in cattle feedlots. J. Anim. Sci. 79:2949.

Montgomery, S. P., J. S. Drouillard, T. G. Nagaraja, E. C. Titgemeyer, and J. J. Sindt. 2008. Effects of supplemental fat source on nutrient digestion and ruminal fermentation in steers. J. Anim. Sci. 86:640.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th ed. Natl. Acad. Press, Washington, DC.

Pedersen, C., M. G. Boersma, and H. H. Stein. 2007. Digestibility of energy and phosphorus in ten samples of distillers dried grains with soluble fed to growing pigs. J. Anim. Sci. 85:1168.

Plascencia, A., M. Estrada, and R. A. Zinn. 1999. Influence of free fatty acid content on the feeding value of yellow grease in finishing diets for feedlot cattle. J. Anim. Sci. 77:2603.

Plascencia, A., G. D. Mendoza, C. Vasquez, and R. A. Zinn. 2003. Relationship between body weight and level of fat supplementation on fatty acid digestion in feedlot cattle. J. Anim. Sci. 81:2653.

Ramirez, J. E., and R. A. Zinn. 2000. Interaction of dietary magnesium level on the feeding value of supplemental fat in finishing diets for feedlot steers. J. Anim. Sci. 78:2072.

Shi, Y., D. B. Parker, N. A. Cole, B. W. Auvermann, and J. E. Mehlhorn. 2001. Surface amendments to minimize ammonia emissions from beef cattle feedlots. Trans. Am. Soc. Agric. Eng. 44:677.

Spiehs, M. J., and V. H. Varel. 2009. Nutrient excretion and odorant production in manure from cattle fed corn wet distillers grains with solubles. J. Anim. Sci. 87:2977.

Stock, R. A., J. M. Lewis, T. J. Klopfenstein, and C. T. Milton. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. J. Anim. Sci. 77(E. Suppl.):1–12.

Uwituze, S., G. L. Parsons, M. K. Shelor, B. E. Depenbusch, K. K. Karges, M. L. Gibson, C. D. Reinhardt, J. J. Higgins, and J. S. Drouillard. 2010. Evaluation of dried distillers grains and roughage source in steam-flaked corn finishing diets. J. Anim. Sci. 88:258.

Vander Pol, K. J., M. K. Luebbe, G. I. Crawford, G. E. Erickson, and T. J. Klopfenstein. 2009. Performance and digestibility characteristics of finishing diets containing distiller's grains, composite of corn processing coproducts, or supplemental corn oil. J. Anim. Sci. 87:639.

Vasconcelos, J. T., L. M. Shaw, K. A. Lemon, N. A. Cole, and M. L. Galyean. 2007. Effects of graded levels of sorghum wet distiller's grains and degraded intake protein supply on performance and carcass characteristics of feedlot cattle fed steam-flaked corn-based diets. Prof. Anim. Sci. 23:467.

Vogel, K. P., J. F. Pedersen, S. D. Masterson, and J. J. Toy. 1999. Evaluation of a filter bag system for NDF, ADF, and IVDMD forage analysis. Crop Sci. 39:276.

Zinn, R. A., S. K. Gulati, A. Plascencia, and J. Salinas. 2000. Influence of ruminal biohydrogenation on the feeding value of fat in finishing diets for feedlot cattle. J. Anim. Sci. 78:1738.