Effects of increasing level of corn distillers dried grains with solubles on intake, digestion, and ruminal fermentation in steers fed seventy percent concentrate diets

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Effects of increasing level of corn distillers dried grains with solubles on intake, digestion, and ruminal fermentation in steers fed seventy percent concentrate diets[1]

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ABSTRACT: Five ruminally and duodenally cannulated steers (500 ± 5 kg of initial BW) were used in a 5 × 5 Latin square to evaluate effects of increasing level of corn distillers dried grains with solubles (DDGS) in growing diets (70% concentrate) on OM intake, site of digestion, ruminal fermentation, and microbial efficiency. Diets consisted of 30% grass hay, 6% concentrated separator by-product, 4% supplement, and 60% dry-rolled corn, sunflower meal, urea, or DDGS (DM basis). Treatments consisted of increasing DDGS at 0, 15, 30, 45, or 60% of diet DM replacing a combination of dry-rolled corn, sunflower meal, and urea. Diets were balanced for growing steers gaining 1.22 kg/d and included 0.25% (DM basis) chromic oxide as a digesta flow marker. Diets were offered to the steers for ad libitum intake each day (10% above the intake of the previous day). Each period consisted of 14 d for adaptation and 7 d for collections. Intake of OM responded quadratically ($P = 0.004$) with greatest intakes at 15% DDGS and least at 60% DDGS. No differences ($P \geq 0.14$) were observed in CP intake or duodenal flow of OM, CP, and NDF. Apparent and true ruminal OM digestibilities decreased (linear; $P \leq 0.009$) with increasing DDGS inclusion. Total tract CP digestibility increased (linear; $P < 0.001$) with increasing DDGS, but total tract OM digestibility was not different ($P = 0.74$). Microbial efficiency (g of microbial N/kg of OM truly fermented) was not affected ($P = 0.22$) by treatment. As DDGS increased, ruminal pH increased (linear; $P = 0.004$), whereas ammonia concentration remained unchanged ($P = 0.42$). Acetate proportions decreased (linear; $P < 0.001$) with increasing DDGS, whereas propionate and butyrate were not affected ($P \geq 0.19$). A cubic ($P = 0.02$) effect was observed for total ruminal fill (as is basis) with the greatest fill at 0% DDGS and the least fill at 45% inclusion. Replacing dry-rolled corn with up to 60% DDGS in 70% concentrate diets resulted in no adverse effects on total tract OM digestion, although OM intake was reduced at 60% DDGS inclusion.

Key words: digestion, distillers dried grains with solubles, fermentation, growing diet, steer

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INTRODUCTION

Increased production of ethanol has resulted in greater availability of by-products such as corn distillers dried grains with solubles (**DDGS**), which can be used as a substitute for corn and protein sources in beef cattle diets. For every bushel of corn, 10.2 L of ethanol, 8.2 kg of DDGS, and 8.2 kg of carbon dioxide are produced (Lardy, 2003).

Distillers dried grains with solubles are a common component in beef cattle finishing diets because of their availability and nutrient profile. According to the NRC (2000), DDGS contain approximately 30% CP (52% rumen undegradable), 11% ether extract, and 46% NDF. Because most of the starch has been removed and DDGS has relatively high NDF levels, DDGS are a source of readily digestible, nonforage fiber (Ham et al., 1994).

When DDGS are fed at levels of 6 to 15% of diet DM, their primary purpose is to serve as a protein source; however, when fed at greater levels, DDGS become a source of energy replacing corn (Klopfenstein, 2001). Researchers have demonstrated DDGS can be effectively included in growing and finishing diets, partially replacing corn in the diet (Ham et al., 1994; Peter et al., 2000).

Increased ADG and G:F has been reported with 40% DDGS inclusion in dry-rolled corn-based finishing diets (Ham et al., 1994). When fed at 20% of diet DM

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(cracked corn-based diets), DDGS had no effect on nutrient digestion or ruminal fermentation characteristics (Peter et al., 2000). Therefore, DDGS are attractive for growing and finishing cattle diets (Larson et al., 1993).

No research to date is available regarding the inclusion of 60% DDGS (DM basis) in 70% concentrate diets for growing steers. Our hypothesis was that 60% DDGS inclusion would result in small changes in OM intake, digestion, and fermentation. Therefore, our objective was to determine effects of increasing levels of supplemental DDGS in diets containing 70% concentrate offered to growing steers on OM intake, rate and site of digestion, ruminal fermentation, duodenal protein flow, and microbial efficiency.

MATERIALS AND METHODS

All animal care, handling, and surgical techniques followed protocols approved by the North Dakota State University Animal Care and Use Committee before the initiation of the study.

Animals and Diets

Five ruminally, duodenally, and ileally cannulated steers were used in a 5 × 5 Latin square. Steers were weighed at the initiation of the trial and housed in a climate-controlled room in individual pens (3.0 × 3.7 m) during each 14-d adaptation period and stalled in individual metabolism crates (1.0 × 2.2 m) during each 7-d collection period. Steers were offered ad libitum access to diets (10% above the intake of the previous day) and water. Diets consisted of 30% grass hay, 6% concentrated separator by-product, 4% supplement, and 60% dry-rolled corn, sunflower meal, urea, or DDGS (DM basis; Table 1). Hay was chopped through a 10.16-cm screen. Diets also included 0.25% (DM basis) chromic oxide added as a digesta marker. Treatments consisted of 1 of 5 levels of DDGS at 0, 15, 30, 45, or 60% of diet DM replacing a combination of dry-rolled corn, sunflower meal, and urea. The nutrient composition of the DDGS used was 29.5% CP, 11.1% crude fat, 28.6% NDF, 0.91% S, and 0.72% P. Crude fat content of the diets were 2.5, 3.5, 4.7, 5.9, and 6.7% for 0, 15, 30, 45, and 60%, respectively. Particle size of the DDGS averaged 250 μm and was determined using a Tyler Ro-Tap sieve shaker (W. W. Tyler, Mentor, OH) following procedures outlined by ASAE (1993). Diets were balanced to contain a minimum of 15% CP, 0.7% Ca, 0.3% P, and contained 27.5 mg/kg of monensin (Elanco Animal Health, Indianapolis, IN), 11 mg/kg of tylosin (Elanco Animal Health), and 6 mg/kg of thiamine.

Sample Collection

Weekly feedstuff samples were collected to determine diet DM and analyze nutrient composition. Diet samples were collected during 7-d collection periods (approximately 200 g) and composited within period. Ort samples (10% of total) were taken daily, before morning feeding (0630 h), throughout the 7-d collection period. Total fecal collections were performed using stainless-steel pans placed directly behind the crates, and total fecal output was determined daily. Fecal subsamples (10% of output; wet basis) were composited within steer and period. Subsamples were stored (−20°C), then thawed and mixed in a rotary mixer (model H-600, Hobart Manufacturing Co., Troy, OH) after which another subsample was taken and frozen (−20°C) until analyses. Duodenal and ileal samples (200 mL) were collected over 4 d in a manner that allowed for every other hour in a 24-h period to be sampled. Samples were taken on d 3 at 0800, 1400, and 2000 h; d 4 at 0200, 1000, 1600, and 2200 h; d 5 at 0400, 1200, 1800, and 2400 h; and d 6 at 0600 h of each collection period. Samples were composited by steer within period and stored (−20°C) until analyzed.

Liquid dilution rate was estimated using Co-EDTA as a liquid flow marker. A 200-mL dose of Co-EDTA (1.7 g of Co; Uden et al., 1980) was delivered intraruminally 2 h before feeding on d 6 of each collection period. Ruminal fluid samples (200 mL) were collected via a suction strainer at −2, 0, 2, 4, 6, 8, 10, and 12 h postfeeding, and pH was determined immediately with a combination electrode (model 2000 pH/temperature meter; VWR Scientific Products, West Chester, PA). A sample (200 mL) was acidified with 2 mL of 6.0 *M* HCl. A subsample (3 mL) of the initial, nonacidified ruminal fluid sample was collected and added to 0.75 mL of metaphosphoric acid and frozen (−20°C) until analyzed for VFA.

On d 7 of each collection period, before morning feeding, ruminal evacuations were conducted to determine ruminal fill. Ruminal contents were removed, weighed, and subsampled. Subsamples were obtained by hand mixing ruminal contents in 208-L tubs and taking samples from various locations. A grab sample was taken for analysis of DM, OM, ADF, and NDF. A second ruminal content sample (4 kg) was taken, and 2 L of formalin/saline solution (3.7% formaldehyde and 0.9% NaCl) was added (Zinn and Owens, 1986) for isolation of bacterial cells, which were later analyzed for DM, ash, N, and purines. Samples were stored frozen (−20°C) until analyzed.

Laboratory Analysis

Diet, ort, and fecal samples were dried using a forced-air oven (55°C; The Grieve Corporation, Round Lake, IL) for 48 h. Dried samples were ground in a Wiley mill (Arthur H. Thomas, Philadelphia, PA) to pass a 2-mm screen. Duodenal samples were lyophilized (Virtis Genesis 25LL, The Virtis Company Inc., Gardiner, NY) and ground in a Wiley mill to pass a 1-mm screen.

Diet, ort, duodenal, and fecal samples were analyzed for DM, ash, and N (procedure numbers 930.15, 942.05, and 984.13, respectively; AOAC, 1990). Diet samples were also analyzed for crude fat (procedure number 920.39; AOAC, 1990). Concentrations of NDF (Rob-

Table 1. Diet composition of growing diets with increasing level of corn distillers dried grains with solubles (DDGS; % diet DM)

	DDGS, % of dietary DM				
Item	0	15	30	45	60
Ingredient					
Dry-rolled corn	58	43	28	15	—
DDGS	—	15	30	45	60
Grass hay	30	30	30	30	30
CSB[1]	6	6	6	6	6
Sunflower meal	2.0	1.7	2.0	—	—
Urea	0.99	0.67	0.25	—	—
Supplement					
Limestone	1.5	2.0	2.5	2.5	2.5
Wheat middlings	0.84	1.26	0.88	1.13	1.13
Dicalcium phosphate	0.30	—	—	—	—
Vitamin A, D premix[2]	0.02	0.02	0.02	0.02	0.02
Vitamin E premix[3]	0.02	0.02	0.02	0.02	0.02
Trace mineral premix[4]	0.05	0.05	0.05	0.05	0.05
Monensin[5]	0.02	0.02	0.02	0.02	0.02
Tylosin[6]	0.01	0.01	0.01	0.01	0.01
Cr_2O_3	0.25	0.25	0.25	0.25	0.25
Analyzed composition					
CP	15.0	16.2	17.9	19.7	21.7
Ash	10.6	10.3	10.8	11.1	11.6
Crude fat	2.5	3.5	4.7	5.9	6.7
NDF	35.3	38.8	39.7	39.5	41.4
ADF	17.5	19.1	18.6	17.8	18.5

[1]Concentrated separator by-product (desugared molasses).
[2]Contained 48,496 IU/kg of vitamin A and 4,627 IU/kg of vitamin D.
[3]Contained 44 IU/kg of vitamin E.
[4]Contained 250 mg/kg of Co, 25,600 mg/kg of Cu, 1,050 mg/kg of I, 6,500 mg/kg of Fe, 40,000 mg/kg of Mn, and 160,000 mg/kg of Zn.
[5]Contained 176.4 g/kg of monensin (Elanco Animal Health, Indianapolis, IN) to provide 27.5 mg/kg of diet DM.
[6]Contained 88.2 g/kg of tylosin (Elanco Animal Health) to provide 11 mg/kg of diet DM.

ertson and Van Soest, 1991, as modified by Ankom Technology, Fairport, NY) and ADF (Goering and Van Soest, 1970, as modified by Ankom Technology) were determined sequentially using an Ankom 200 Fiber Analyzer (Ankom Technology) without sodium sulfite, with amylase, and without ash correction. Chromium concentrations were analyzed in duodenal and ileal samples by the spectrophotometric method (Fenton and Fenton, 1979).

Ruminal fluid samples were thawed for 12 h at 4°C before analysis. Ruminal fluid samples were centrifuged at 20,000 × *g* for 20 min at 4°C and supernatant taken for analysis of ammonia (Broderick and Kang, 1980). Ruminal VFA concentrations (Goetsch and Galyean, 1983) were quantified by GLC (Hewlett-Packard 5890A Series II GC, Wilmington, DE) using a capillary column. Cobalt concentration was analyzed by methods described by Uden et al. (1980) with an air-plus-acetylene flame using atomic absorption spectroscopy (model 3030B, PerkinElmer Inc., Wellesley, MA).

Ruminal content samples from total evacuations were analyzed for DM and ash (AOAC, 1990). A Waring blender (model 37BL19 CB6, Waring Products, New Hartford, CT) was used to blend ruminal contents. Samples were blended on high speed for 1 min and mixture strained through 4 layers of cheesecloth. Liquid was then placed in 250-mL centrifuge bottles and centrifuged at 500 × *g* for 20 min at 4°C to remove feed particles and protozoa. Supernatant was removed and re-spun at 500 × *g* for 20 min at 4°C. Bacteria were separated from free supernatant by centrifuging at 30,000 × *g* for 20 min at 4°C. Isolated bacterial cells and duodenal contents were analyzed for purines as a microbial marker (Zinn and Owens, 1986).

Statistical Analysis

Data were analyzed as a 5 × 5 Latin square using the Mixed procedures (SAS Inst. Inc., Cary, NC). The model included diet and period as fixed effects and steer as the random effect. Data over time were analyzed as a repeated measures design using the Mixed procedures of SAS. The first order autoregressive covariate structure was used for the repeated term. The model included period, diet, time, and diet × time with the random variable being animal. Means were separated using linear, quadratic, and cubic contrasts.

RESULTS AND DISCUSSION

Analyzed nutrient content of diets is provided in Table 1. Diets ranged from 15.0% CP in the 0% DDGS

Table 2. Effect of increasing level of corn distillers dried grains with solubles (DDGS) on OM intake, flow, and digestion in growing diets offered to steers

	DDGS, % of dietary DM						Contrast *P*-value		
OM	0	15	30	45	60	SEM[1]	Linear	Quadratic	Cubic
Intake									
kg/d	10.6	11.3	10.3	10.0	8.3	0.33	<0.001	0.004	0.73
g/kg of BW	20.0	21.0	19.5	18.7	15.2	0.60	<0.001	0.002	0.96
Duodenal flow, kg/d									
Bacterial	0.86	0.88	0.87	0.86	0.86	0.007	0.60	0.23	0.11
Apparent feed	4.07	4.46	4.47	4.79	4.08	0.33	0.71	0.11	0.49
Total	4.16	4.55	4.56	4.88	4.16	0.33	0.71	0.10	0.49
Fecal output, kg/d	2.61	2.62	2.28	2.24	1.97	0.12	<0.001	0.56	0.73
Digestibility, % of intake									
Apparent ruminal	61.3	59.7	55.9	50.5	50.9	3.0	0.008	0.83	0.41
True ruminal	62.1	60.5	56.7	51.4	52.0	3.0	0.009	0.80	0.41
Postruminal	14.2	17.0	21.7	27.1	26.0	2.5	0.001	0.47	0.32
Total tract	75.6	76.8	77.5	77.5	77.0	1.1	0.33	0.34	0.98

[1]n = 5 observations per treatment.

diet to 21.7% CP in the diet containing 60% DDGS. Ruminal degradable intake protein concentration was estimated to be 70.1, 62.1, 55.5, 50.8, and 49.2% of CP for the 0, 15, 30, 45, and 60% diets, respectively (NRC, 2000).

Intake of OM responded in a quadratic manner ($P = 0.004$), with greatest intakes at 15% DDGS and least at 60% DDGS (Table 2). Trenkle (2004) reported increased DMI in growing calves fed up to 40% DDGS (DM basis; 90% concentrate diets), whereas calves fed 40% wet distillers grains with solubles (**WDGS**; DM basis) had decreased intake. Vander Pol et al. (2006) reported DMI of finishing steers fed WDGS, partially replacing dry-rolled corn, was greatest at 30% inclusion, compared with 0, 10, 20, 40, and 50% WDGS inclusion (95% concentrate diets). Buckner et al. (2007) fed growing steers 15 or 30% DDGS (DM basis) replacing a portion of bromegrass hay and alfalfa haylage. Buckner et al. (2007) reported increased DMI in steers fed 30% DDGS diets when compared with steers consuming 15% DDGS diets. In the current study, decreased OM intake as DDGS increased in the diet may have been a result of increasing fat and sulfur content of the diets as DDGS increased. Nichols et al. (2009) reported a linear decrease in DMI of finishing steers as WDGS were added to the diet up to 40% of the diet DM (95% concentrate diets). Dietary sulfur and fat content ranged from 0.34 to 0.56% and 2.8 to 6.6%, respectively, in the Nichols et al. (2009) study. Similarly, Zinn et al. (1997) using ammonium sulfate as a sulfur source reported a linear decrease in DMI as dietary sulfur increased from 0.15 to 0.25% (DM basis) in finishing heifers fed a 90% concentrate diet.

Bacterial and apparent feed OM flow to the duodenum was not different ($P \geq 0.36$) and averaged 0.87 ± 0.01 and 4.37 ± 0.33 kg/d, respectively, across treatments. Total duodenal flow of OM tended to respond in a quadratic manner ($P = 0.10$) in which steers fed 0 and 60% DDGS had the least flow and steers fed 45% DDGS had the greatest total duodenal flow. Fecal OM output decreased linearly ($P < 0.001$) as DDGS increased in the diet. This follows the similar trend in OM intake. Apparent and true ruminal OM digestion decreased (linear; $P \leq 0.009$), whereas postruminal OM digestion increased (linear; $P = 0.001$), with increasing DDGS inclusion. This could be a result of increased passage rate due to DDGS small particle size (Firkins et al., 1985) and more incomplete ruminal digestion with increasing DDGS. Furthermore, as DDGS increased, so did fat content of the diets. At a fat intake of 1.2 g/kg of BW, expected intestinal digestibility of fat is 77% (Zinn, 1994). Vander Pol et al. (2009) reported 81% intestinal fat digestibility when WDGS (40% DM basis) were included in finishing diets. This suggests fat in WDGS may be partially protected from ruminal digestion and greater proportions of fatty acids may have entered the small intestine, which increased digestion of lipids. Total tract OM digestion was not affected ($P = 0.74$) by treatment, which agrees with Peter et al. (2000) comparing DDGS, dry corn gluten feed, and modified corn fiber (20% inclusion, DM basis) in finishing cattle diets (80% concentrate diets). Mateo et al. (2004) also reported no differences in total tract OM digestion when steers were fed 0, 20, or 40% DDGS replacing soybean meal and cracked corn in 90% concentrate finishing diets.

Intake of CP tended to respond in a quadratic manner ($P = 0.08$; Table 3) where steers fed 0% DDGS had the least CP intake and steers fed 45% had the greatest intake. Kalscheur et al. (2005) reported no differences in CP intake when including DDGS (0, 12.5, and 25%) replacing corn and soybean meal in 46% concentrate diets fed to dairy heifers. Similar to duodenal OM flow, no differences ($P \geq 0.63$) were observed for bacterial (558 ± 45 g/d), apparent feed (892 ± 99 g/d), or total CP (1,450 ± 135 g/d) flows at the duodenum. Firkins et al. (1984) reported no differences in total CP flow to the duodenum of steers fed wet or dry corn distillers grains in 65% concentrate diets (25% diet DM) compared with cracked corn and corn starch grits. Fecal

Table 3. Effect of increasing level of corn distillers dried grains with solubles (DDGS) on CP intake, flow, and digestion in growing diets offered to steers

	DDGS, % of dietary DM						Contrast *P*-value		
CP	0	15	30	45	60	SEM[1]	Linear	Quadratic	Cubic
Intake, kg/d	1.53	1.76	1.69	1.91	1.64	0.11	0.27	0.08	0.58
Duodenal flow, g/d									
Bacterial	545	576	563	593	515	45	0.76	0.29	0.64
Apparent feed	787	858	900	983	931	99	0.18	0.56	0.73
Total	1,332	1,434	1,464	1,576	1,445	135	0.37	0.43	0.68
Fecal output, g/d	491	513	434	421	367	18	<0.001	0.14	0.23
Microbial efficiency[2]	14.1	13.7	15.5	18.9	20.6	2.3	0.03	0.52	0.59
Digestibility, % of intake									
Apparent ruminal	12.2	18.9	12.1	16.8	9.8	9.9	0.82	0.65	0.95
True ruminal	48.3	51.4	47.2	47.9	43.9	6.7	0.56	0.71	0.90
Postruminal	55.6	52.0	61.7	61.3	67.3	8.3	0.21	0.76	0.79
Total tract	67.8	70.8	73.9	78.0	77.2	2.0	<0.001	0.35	0.41

[1]n = 5 observations per treatment.
[2]Grams of microbial N/kg of OM truly fermented. Truly fermented OM = OM intake − apparent feed OM flow at the duodenum.

CP output decreased (linear; $P < 0.001$) as DDGS increased in the diet. Total tract CP digestion increased (linear; $P < 0.001$) with increasing DDGS; however, no differences ($P \geq 0.67$) were observed for apparent ruminal, true ruminal, or postruminal CP digestion. These results indicate more N digestion occurred in the small intestine, therefore improving total tract digestion. Contrary to our findings, Kalscheur et al. (2005) reported decreased total tract CP digestibility in growing dairy heifers fed increasing levels of DDGS. However, Mateo et al. (2004) and Chen et al. (1977) found no differences in CP digestibility in steers fed DDGS compared with corn-based diets (90 and 70% concentrate diets, respectively). Microbial efficiency increased (linear; $P = 0.03$) as DDGS increased in the diet. This response is primarily from a decrease in OM truly fermented in the reticulorumen. Firkins et al. (1984) reported no differences in microbial efficiency in steers fed distillers grains compared with controls.

Intakes of NDF and ADF both responded quadratically ($P \leq 0.009$; Table 4). Steers consuming 15% DDGS had the greatest intake, whereas steers consuming 60% DDGS had the least intake, which followed trends in OM intake. Larson et al. (1993) fed 0, 5.2, 12.6, or 40% (DM basis) wet distillers by-products (wet distillers grains and thin stillage) and reported a linear increase in NDF intakes in steers offered 90% concentrate diets. Differences between our study and Larson et al. (1993) are likely due to type of distillers by-products fed. No differences ($P \geq 0.22$) were observed for fecal output of NDF or ADF. Duodenal NDF tended to respond in a quadratic manner ($P = 0.06$) with steers fed 45% DDGS having the greatest NDF flow and steers fed 0% DDGS having the least NDF flow. Similarly, ADF flow responded in a quadratic manner ($P = 0.02$) with steers consuming 45% DDGS having the greatest ADF flow to the small intestine and steers consuming 0 or 60% DDGS the least ADF flow when expressed on a

Table 4. Effect of increasing level of corn distillers dried grains with solubles (DDGS) on NDF and ADF intake, flow, and digestion in growing diets offered to steers

	DDGS, % of dietary DM						Contrast *P*-value		
Item	0	15	30	45	60	SEM[1]	Linear	Quadratic	Cubic
NDF									
Intake, kg/d	3.59	4.39	4.03	3.96	3.32	0.22	0.17	0.006	0.41
Duodenal flow, kg/d	0.77	0.97	0.99	1.11	0.87	0.11	0.29	0.06	0.65
Fecal output, kg/d	1.11	1.10	1.12	1.23	1.13	0.11	0.44	0.69	0.32
Digestibility, % of intake									
Ruminal	78.7	77.9	74.7	72.7	73.0	3.1	0.08	0.74	0.61
Total tract	68.0	75.3	70.8	69.3	65.6	3.9	0.29	0.13	0.36
ADF									
Intake, kg/d	1.76	2.18	1.92	1.81	1.50	0.12	0.03	0.009	0.21
Duodenal flow, kg/d	0.39	0.50	0.47	0.52	0.39	0.041	0.92	0.02	0.68
Fecal output, kg/d	0.58	0.58	0.57	0.60	0.55	0.054	0.54	0.53	0.48
Digestibility, % of intake									
Ruminal	77.1	77.5	74.7	71.6	73.8	2.5	0.09	0.70	0.25
Total tract	64.7	73.6	68.6	66.9	63.0	4.6	0.33	0.09	0.28

[1]n = 5 observations per treatment.

Table 5. Effect of increasing level of corn distillers dried grains with solubles (DDGS) on ruminal pH, ammonia, and VFA in growing diets offered to steers

	DDGS, % of dietary DM						Contrast *P*-value		
Item	0	15	30	45	60	SEM[1]	Linear	Quadratic	Cubic
pH	6.42	6.35	6.64	6.60	6.63	0.064	0.004	0.63	0.17
Ammonia, m*M*	10.0	9.5	8.3	9.7	10.5	0.83	0.62	0.11	0.92
VFA									
Total, m*M*	97.6	99.9	86.9	85.7	83.3	3.2	<0.001	0.85	0.19
Acetate, mol/100 mol	59.5	59.1	55.5	53.9	53.3	0.95	<0.001	0.63	0.19
Propionate, mol/100 mol	20.4	21.4	21.6	22.7	23.1	0.83	0.02	0.92	0.99
Butyrate, mol/100 mol	13.5	13.5	14.3	13.7	13.1	0.44	0.73	0.16	0.60
Acetate:propionate, mol/mol	2.95	2.81	2.58	2.39	2.34	0.13	0.001	0.67	0.60

[1]n = 5 observations per treatment.

kilogram per day basis. Ruminal NDF and ADF digestion tended to decrease (linear; $P \leq 0.09$) as DDGS increased. Total tract NDF digestion was unaffected ($P \geq 0.13$) by treatment; however, total tract ADF digestion tended to respond in a quadratic manner ($P = 0.09$) with steers consuming 15% DDGS having the greatest digestion and steers consuming 60% DDGS having the least total tract ADF digestion. Ruminal fiber digestibilities were greater than total tract fiber digestion which may be due to error in our digesta marker. Firkins et al. (1984) reported no differences in apparent ruminal NDF digestion in steers fed dry or wet distillers grains; however, those researchers observed increased NDF digestion in distillers-fed steers compared with steers fed cracked corn and corn starch grits.

As dietary DDGS increased, ruminal pH increased (linearly; $P = 0.004$; Table 5), whereas ammonia concentration remained unchanged ($P = 0.42$). Peter et al. (2000) reported no differences in ruminal pH when 20% DDGS (DM basis) was included in finishing diets. Increased ruminal pH in the current study may be the result of decreased starch levels in DDGS compared with corn. Starch from corn is degraded rapidly in the rumen; thus, it may decrease ruminal pH (Klopfenstein, 2001). Total VFA concentration decreased (linear; $P < 0.001$) with increasing DDGS inclusion. Ham et al. (1994) fed steers 40% WDGS, partially replacing dry-rolled corn in 90% concentrate diets, and reported no differences in pH or total VFA concentration when compared with steers consuming dry-rolled corn diets. Peter et al. (2000) included 20% DDGS, replacing cornstarch, in finishing diets and reported no differences in total VFA or molar proportions of acetate, propionate, and butyrate. In our study, acetate proportions decreased (linear; $P < 0.001$), whereas propionate proportions increased ($P = 0.02$) with increasing DDGS, which resulted in a decreased (linear; $P < 0.001$) acetate:propionate ratio. Butyrate was not affected ($P \geq 0.16$) by treatment. Vander Pol et al. (2009) reported decreased acetate and increased propionate, which resulted in a decreased acetate:propionate ratio in steers fed 40% WDGS compared with steers fed a composite of corn bran and corn gluten meal or corn oil (95% concentrate diets).

A cubic ($P = 0.02$) response was observed for total ruminal fill (as is basis; Table 6) with steers consuming 0% DDGS having the greatest fill and steers on 45% DDGS diet having the least fill. Ruminal DM fill, when expressed on a kilogram basis, tended to decrease (linear; $P = 0.06$), and when expressed on a grams per kilogram of BW basis, ruminal DM fill decreased (linear; $P = 0.01$) as DDGS increased in the diet. Montgomery et al. (2004) fed 0 or 40% wet corn gluten feed replacing steam-flaked corn in 80% concentrate diets and found no differences in ruminal DM fill. Fluid dilution rate was not different ($P = 0.86$) and averaged 8.22 ± 0.95%/h across treatments. Similarly, Firkins et al. (1984) reported no differences in fluid dilution rate in steers fed diets with or without distillers grains, although rates they reported were less than rates in the present study (5.39 vs. 8.22%/h, respectively).

In summary, OM intake was reduced as inclusion rate of DDGS increased; however, CP intake was similar across treatments. Ruminal OM and fiber digest-

Table 6. Effect of increasing level of corn distillers dried grains with solubles (DDGS) on total ruminal fill, ruminal DM fill, and fluid dilution rate in growing diets offered to steers

	DDGS, % of dietary DM						Contrast *P*-value		
Item	0	15	30	45	60	SEM[1]	Linear	Quadratic	Cubic
Total ruminal fill, kg wet	44.2	44.1	42.4	39.4	41.3	1.1	0.001	0.33	0.02
Ruminal DM fill, kg	6.79	7.41	6.85	6.47	5.95	0.39	0.06	0.18	0.43
g/kg of BW	12.9	13.9	12.8	12.0	10.8	0.66	0.01	0.11	0.47
Fluid dilution rate, %/h	7.9	8.5	8.0	7.7	9.1	0.95	0.59	0.67	0.41

[1]n = 5 observations per treatment.

ibility decreased, whereas postruminal OM and fiber digestibility increased. Therefore, total tract OM and fiber digestibility were unaffected by treatment. Total tract CP digestibility increased with increasing DDGS. Ruminal pH increased as DDGS increased in the diet; however, ammonia concentrations were similar. Our hypothesis was that 60% DDGS inclusion would result in little change in intake, digestion, and fermentation. Intake and ruminal digestion decreased, but postruminal digestion compensated for the changes in the rumen resulting in minimal changes in total tract digestion. Replacing dry-rolled corn with up to 60% DDGS in 70% concentrate diets for growing steers resulted in no adverse effects on total tract OM digestion, although OM intake was reduced at 60% DDGS inclusion. Based on this data, including 45% DDGS in growing diets will maximize digestion and fermentation in growing steers.

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