Effects of increasing levels of corn distillers dried grains with solubles to steers offered moderate-quality forage

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Effects of increasing levels of corn distillers dried grains with solubles to steers offered moderate-quality forage[1]

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ABSTRACT: Supplementation of forage-fed livestock has been studied for decades; however, as by-products become available research is needed to determine optimal feeding rates for increased efficiency. Five ruminally and duodenally cannulated beef steers (446 ± 42 kg of initial BW) were used in a 5 × 5 Latin square to evaluate effects of increasing level of supplemental corn distillers dried grains with solubles (DDGS; 25.4% CP, 9.8% fat, DM basis) on DMI, rate and site of digestion, ruminal fermentation, and microbial efficiency. Diets consisted of ad libitum quantities of moderate-quality smooth brome hay (10.6% CP; DM basis), free access to water and trace mineral salt block, and 1 of 5 levels of DDGS (0, 0.3, 0.6, 0.9, and 1.2% of BW daily of DDGS; DM basis). Diets were formulated to meet or exceed the estimated rumen degradable protein requirements (assumed microbial yield = 10.5%). All supplements were fed at 0600 h before forage was fed. Steers were adapted to diets for 14 d followed by a 7-d collection period. Hay OM intake decreased (linear; $P < 0.001$), whereas total OM intake increased (linear; $P < 0.001$) with increasing DDGS level. Total CP intake, duodenal OM and CP flows, and total tract OM and NDF digestibilities increased (linear; $P \leq 0.01$) with increasing level of DDGS. Apparent ruminal and true ruminal CP digestibilities increased linearly ($P \leq 0.007$), and total-tract CP digestibility increased quadratically ($P = 0.02$) with increasing DDGS level. Average ruminal pH was not different ($P = 0.89$) among treatments. Ammonia concentration increased (quadratic; $P = 0.02$) with increasing DDGS. Acetate proportions (molar %) decreased linearly ($P < 0.001$), whereas butyrate (molar %) increased linearly ($P = 0.007$), and propionate (molar %) increased quadratically ($P = 0.04$) with increasing DDGS. Ruminal DM fill decreased quadratically ($P = 0.03$), whereas fluid dilution rate tended to increase cubically ($P = 0.08$) with increasing DDGS. In situ rate of hay and DDGS DM disappearance responded cubically ($P \leq 0.03$) with greatest disappearance occurring with the 0.9% treatment. In situ rate of ruminal CP degradation of hay and DDGS increased (linear; $P \leq 0.003$) with increasing DDGS. Feeding 0.3% up to 1.2% of BW daily of DDGS as a supplement to forage-based diets resulted in no adverse effects on forage digestion or fermentation and resulted in increased nutrient supply in steers fed moderate-quality smooth brome hay.

Key words: digestion, distillers dried grains with solubles, fermentation, moderate-quality forage, steer, supplementation

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INTRODUCTION

Cost of feeding beef cows is rising steadily as a result of increased forage and pasture costs (NASS, 2007). Because of the cost of forage, it may be economical to partially replace forage with grain-milling by-products in some situations. By-products such as distillers dried grains with solubles (**DDGS**) are gaining popularity as feedstuffs for beef cattle because of availability, nutrient value, and cost. Distillers dried grains with solubles contains approximately 30% CP (52% ruminally undegraded protein; **RUP**) and 11% fat (NRC, 2000) and often costs less than corn (NASS, 2008).

Although the use of DDGS in finishing diets for beef cattle has been extensively researched, data evaluating supplemental DDGS for cattle consuming forage diets are limited. Grings et al. (1992) reported no differences in DMI when lactating dairy cows fed alfalfa-based diets were supplemented with DDGS at 0, 10.1, 20.8, or 31.5% of diet DM as a replacement for ground corn. Conversely, when evaluating DDGS as a forage substi-

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tute, MacDonald and Klopfenstein (2004; 0 or 0.46% of BW daily as DDGS; smooth brome pastures) and Morris et al. (2005; 0, 0.24, 0.48, 0.71, or 0.95% of BW daily as DDGS; low- and high-quality forage diets), reported decreased forage intake with increasing levels of DDGS offered to heifers. In addition, Loy et al. (2007) supplemented DDGS at 0.4% of BW daily to heifers consuming grass hay (8.2% CP) and reported an increased rate of hay NDF disappearance compared with nonsupplemented controls.

We hypothesized that DDGS supplementation for cattle consuming forage-based diets would not adversely affect diet fermentation or digestion, while increasing overall nutrient intake and intestinal nutrient flow. Therefore, our objective was to determine effects of increasing levels of supplemental DDGS for steers consuming moderate-quality hay on intake, rate and site of digestion, ruminal fermentation, 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 study initiation.

Animals and Diets

Five ruminally and duodenally cannulated beef steers (446 ± 42 kg of initial BW) were used in a 5 × 5 Latin square. Steers were housed in a climate-controlled room in individual pens (3.0 × 3.7 m) during each 14-d adaptation period and housed in individual metabolism stalls (1.0 × 2.2 m) during each 7-d collection period. The basal diet consisted of a moderate-quality smooth brome hay (*Bromus inermis*) chopped through a 10.16-cm screen, offered for ad libitum intake, free access to water and trace mineral salt block (minimum 955 g of NaCl, 4.0 g of Zn, 1.6 g of Fe, 1.2 g of Mn, 0.26 g of Cu, 0.10 g of I, and 0.04 g of Co/kg; North American Salt Company, Overland Park, KS), and 1 of 5 supplemental levels of DDGS (0, 0.3, 0.6, 0.9, and 1.2% of BW daily of DDGS; DM basis). Distillers dried grains with solubles was fed at 0600 h immediately before the time forage was fed. Steers were allowed 30 min to consume the DDGS, after which the remaining DDGS was placed directly into the rumen. Steers were offered hay once daily at 0630 h after consumption of DDGS. Supplement amounts were calculated based on steer BW that were collected at the beginning of every period (21 d).

Sample Collection

Experimental periods consisted of 14 d of adaptation followed by a 7-d collection period. Hay and DDGS samples were collected weekly (approximately 200 g) and composited separately within period. Ort samples (10% of total) were taken daily, before the morning feeding (0530 h), throughout a 7-d collection period. Five days before and throughout collections, 8 g of chromic oxide was dosed ruminally twice daily at 0700 and 1900 h via gelatin capsule (Torpac Inc., Fairfield, NJ) for use as a digesta flow marker. Total fecal collections were performed using stainless-steel pans placed directly behind the stalls and total fecal output was measured daily. Fecal subsamples (10% of output; wet weight 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), where another subsample was taken and frozen (−20°C) until chemical analyses were performed. Duodenal samples (200 mL) were collected over 4 d in a manner that allowed for digesta to be sampled every other hour in a 24-h period. 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 chemical analyses were performed.

In situ DM, CP, NDF, and ADF disappearance were determined using Dacron bags (Ankom, Fairport, NY; 10 × 20 cm, 53 ± 10 μm pore size) containing 5 g of hay or DDGS. Grass hay and DDGS were ground in a Wiley mill (Arthur H. Thomas, Philadelphia, PA) to pass through a 2-mm screen before in situ analyses. Bags were presoaked in water at 39°C and ruminally incubated, in duplicate, for 96, 72, 48, 36, 24, 14, 9, 5, 2, or 0 h. The 0-h bags were used as correction factors. Extent of digestion was calculated according to Mertens and Loften (1980) using nonlinear procedures (SAS Inst. Inc., Cary, NC). After incubation, all bags were removed and rinsed with tap water to remove large particulate matter. Bags were then rinsed using a top-loading washing machine (General Electric, Louisville, KY) on delicate cycle. Bags were agitated for 1 min, drained, and spun for 2 min. This cycle was repeated until rinse water was clear with a minimum of 6 cycles. Bags were dried in a forced-air oven (55°C; The Grieve Corporation, Round Lake, IL) for 48 h and stored at room temperature until chemical analyses were performed. In situ forage DM, NDF, and ADF disappearance were calculated using the equation: residual = b × $e^{-k(t-lag)}$ + i, where b = slowly degraded fraction, k = rate, t = time, and i = indigestible fraction (Mertens and Loften, 1980). In situ forage N disappearance was calculated using the equation: a + b(1 − e^{-kt}), where a = fraction degraded at time 0, b = slowly degraded fraction, k = rate, and t = time (Ørskov and McDonald, 1979).

Liquid dilution rate was estimated using Co-EDTA as a liquid flow marker. Two hundred milliliters of Co-EDTA (1,734 mg of Co; Uden et al., 1980) was dosed intraruminally 2 h before feeding on d 6 of each collection period. Ruminal fluid samples (200 mL) were collected with a suction strainer at −2, 0, 2, 4, 6, 8, 10, and 12 h

postfeeding, and pH was immediately determined with a combination electrode (model 2000 pH/temperature meter, VWR Scientific Products, West Chester, PA). The sample (200 mL) was acidified with 2 mL of 6.0 *M* HCl and frozen (−20°C) until analyzed for Co concentration. 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 concentration.

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 random samples. Grab samples of ruminal contents were analyzed for DM, OM, ADF, and NDF. A second ruminal-content sample (4 kg) was taken, and 2 L of formalin/saline solution (3.7% formaldehyde/0.9% NaCl) was added for isolation of bacterial cells (Zinn and Owens, 1986). These samples were frozen (−20°C) and later analyzed for DM, ash, N, and purine.

Laboratory Analysis

Diet, ort, and fecal samples were dried using a forced-air oven (55°C; The Grieve Corporation) for 48 h. Dried samples were ground in a Wiley mill to pass a 2-mm screen. Duodenal samples were lyophilized (Virtis Genesis 25LL, The Virtis Company Inc., Gardiner, NY) and ground with 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). Concentrations of NDF (Robertson and Van Soest, 1991, as modified by Ankom Technology) and ADF (Goering and Van Soest, 1970, as modified by Ankom Technology) were determined using an Ankom 200 Fiber Analyzer (Ankom Technology) without sodium sulfite, with amylase, and without ash correction as sequentials. Distillers dried grains with solubles were analyzed for crude fat, P, and S (procedure numbers: 945.16, 965.17, and 923.01, respectively; AOAC, 1990). Chromic-oxide concentrations in duodenal samples were determined by a spectrophotometric method (Fenton and Fenton, 1979). In situ residues from duplicate bags were composited and analyzed for DM, N, NDF, and ADF (AOAC, 1990) and for purines (Zinn and Owens, 1986).

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 was analyzed by atomic absorption spectroscopy (model 3030B, PerkinElmer Inc., Wellesley, MA) with an air-plus-acetylene flame using methods described by Uden et al. (1980).

Ruminal contents 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 the mixture was 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. 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 (Zinn and Owens, 1986) as a microbial marker.

Statistical Analysis

Data were analyzed as a 5 × 5 Latin square using the MIXED procedures of SAS. 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 first-order autoregressive covariance structure in the MIXED procedures of SAS. The model included period, animal, diet, time, and diet × time as fixed effects, and animal nested within diet × period as the random effect. Means were separated using linear, quadratic, and cubic contrasts and are discussed when significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Analyzed composition of the smooth brome hay averaged 10.6% CP, 11.1% ash, 65.1% NDF, and 37.6% ADF (DM basis). Analyzed composition of the distillers dried grains with solubles averaged 25.4% CP, 9.6% ash, 34.6% NDF, 10.6% ADF, 9.8% crude fat, 0.91% S, and 0.87% P (DM basis).

Hay OM intake (kg/d) decreased (linear; $P < 0.001$) and total OM intake (hay plus DDGS; kg/d) increased (linear; $P < 0.001$; Table 1) with increasing DDGS offered. Hay OM intake decreased 0.47 kg for every 1 kg increase in DDGS OM intake. Morris et al. (2006) supplemented DDGS (levels ranged from 0 to 1% of BW daily; DM basis) to steers grazing summer Sandhills range and reported forage intake declined by 0.53 kg for every 1 kg of DDGS offered. In addition, Loy et al. (2007) reported heifers supplemented with 0.4% of BW daily of DDGS decreased hay DMI by 0.55 kg for every 1-kg increase in DDGS intake, whereas total DMI (forage plus DDGS) increased in supplemented heifers compared with nonsupplemented controls. These data indicated supplementing DDGS up to 1% of BW daily resulted in reduced hay intake. Depending on objectives and price relationships between forage and DDGS, supplementing with DDGS may be an important management tool in times of reduced forage availability or when cattle producers desire to increase numbers of cattle fed with a limited forage base.

Table 1. Effect of corn distillers dried grains with solubles (DDGS) supplementation on OM intake, flow, and digestion in steers fed moderate-quality smooth brome hay

	Treatment[1]						Contrast *P*-value		
OM	Control	0.3%	0.6%	0.9%	1.2%	SEM[2]	Linear	Quadratic	Cubic
Intake, kg/d									
Hay	8.19	7.97	6.44	6.45	5.83	0.30	<0.001	0.21	0.18
DDGS	0.00	1.32	2.50	3.83	4.97	0.12	<0.001	0.63	0.85
Total	8.19	9.29	8.94	10.28	10.80	0.28	<0.001	0.36	0.19
Duodenal flow, kg/d									
Bacterial	0.83	0.84	0.85	0.85	0.86	0.21	<0.001	0.10	0.98
Apparent feed	3.43	3.92	3.57	4.25	4.02	0.19	0.02	0.57	0.91
Total	3.51	4.00	3.65	4.33	4.10	0.19	0.02	0.56	0.91
Digestibility, % of intake									
Apparent ruminal	56.5	56.9	58.7	58.4	62.8	1.9	0.03	0.38	0.58
True ruminal	57.6	57.8	59.7	59.2	63.6	1.9	0.04	0.39	0.58
Total tract	65.5	68.6	71.5	72.6	74.7	0.9	<0.001	0.15	0.55

[1]Control = hay only; 0.3 to 1.2% = hay plus 0.3 to 1.2% of BW daily of DDGS supplement.
[2]n = 5 observations per treatment.

Responses for duodenal OM flow reflected trends in total OM intake. Bacterial and apparent feed OM flow to the duodenum increased linearly ($P \leq 0.02$); therefore, total OM flow to the duodenum increased linearly ($P = 0.02$) with increasing DDGS. Elizalde et al. (1999) offered steers ad libitum quantities of alfalfa (20.4% CP) and supplemented cracked corn at 0.4, 0.8, or 1.2% of BW daily. As corn supplementation increased, total duodenal OM flow linearly increased which followed trends for total OM intake. Similarly, Brokaw et al. (2001) reported increased total OM flow to the duodenum when cracked corn was supplemented (0.35% of BW daily). Elizalde et al. (1999) and Brokaw et al. (2001) fed higher-quality forages than what was offered in our experiment, which is reflected in the greater intakes they reported compared with the current study. Based on these studies and the data reported in this manuscript, it seems that responses in OM flow to the duodenum are similar when supplementing DDGS or corn regardless of hay quality.

Apparent ruminal and true ruminal OM digestion increased ($P \leq 0.04$) with increasing DDGS supplementation. Total-tract OM digestibility increased linearly ($P < 0.001$) with increasing DDGS. This is likely a direct result of the DDGS being more digestible than the moderate-quality hay offered. Similarly, Sanson and Clanton (1989) and Elizalde et al. (1999) reported a linear increase in total OM digestibility in steers supplemented cracked corn (0.4 to 1.2% of BW daily) or whole shelled corn (0.75% of BW daily), respectively. In agreement with our hypothesis, our data suggested supplemental DDGS in moderate-quality forage-based diets increased total-tract OM digestibility.

Because of the differences in CP between the grass hay and DDGS, total CP intake increased (linear; $P < 0.001$; Table 2) with increasing DDGS supplementation. Similar to hay OM intake, hay CP intake decreased (linear; $P < 0.001$) with increasing supplementation. Similar to duodenal OM flow, bacterial, apparent feed, and total CP flow to the duodenum increased linearly ($P < 0.001$) with increasing DDGS supplementation. Because DDGS are relatively high in RUP (52% of CP; NRC, 2000), increased CP flow to the duodenum was expected. A linear increase ($P < 0.001$) was observed for fecal CP output with increasing DDGS. Supplementation increased (linear; $P \leq 0.007$) apparent and true ruminal CP digestibilities. A quadratic effect ($P = 0.02$) was noted for total tract CP digestibility. Archibeque et al. (2008) offered a corn-based or DDGS-based supplement at 0.17% of BW daily to wether lambs consuming moderate-quality smooth brome hay (8.44% CP). They reported increased N digestibility in lambs consuming DDGS-based supplements compared with corn-based supplements. In spite of the fact that we fed DDGS at greater levels than those evaluated by Archibeque et al. (2008), we also reported increased CP digestibility when DDGS was supplemented in forage-based diets.

Microbial efficiency tended to increase linearly ($P = 0.09$) as supplemental DDGS increased. The nonsupplemented controls had a microbial efficiency of 13.1 g of microbial N/kg of OM truly fermented, and steers consuming 1.2% of BW daily of DDGS had an efficiency of 14.8 g of microbial N/kg of OM truly fermented. Brokaw et al. (2001) reported decreased microbial efficiency in heifers grazing smooth brome pastures and supplemented with 0.35% of BW daily of cracked corn when compared with nonsupplemented controls. The decrease in microbial efficiency was attributed to decreased ruminal passage rates and microbial N flows in supplemented heifers. In our study, supplemented steers had increased fluid dilution rates and duodenal bacterial N flow when compared with nonsupplemented controls. Differences in these studies may be related to ruminal pH. Ørskov and Ryle (1990) suggested that a minimum ruminal pH of 6.2 was necessary for optimal fiber digestion. The average ruminal pH in our study was 6.5 ± 0.09 which was not altered by treatment. Conversely, Brokaw et al. (2001) reported ruminal pH

Table 2. Effect of corn distillers dried grains with solubles (DDGS) supplementation on CP intake, flow, and digestion in steers fed moderate-quality smooth brome hay

	Treatment[1]						Contrast *P*-value		
CP	Control	0.3%	0.6%	0.9%	1.2%	SEM[2]	Linear	Quadratic	Cubic
Intake, g/d									
Hay	949	899	729	715	648	38	<0.001	0.20	0.39
DDGS	0	368	707	1,079	1,403	40	<0.001	0.69	0.88
Total	949	1,268	1,436	1,794	2,051	42	<0.001	0.85	0.68
Duodenal flow, g/d									
Bacterial	380	448	439	529	551	32	<0.001	0.94	0.93
Apparent feed	514	725	707	843	841	55	0.001	0.19	0.59
Total	863	1,167	1,141	1,389	1,417	82	<0.001	0.39	0.69
Fecal output, g/d	401	455	428	477	488	15	<0.001	0.86	0.28
Microbial efficiency[3]	13.1	12.5	12.7	13.7	14.8	0.8	0.09	0.21	0.81
Digestibility, % of intake									
Apparent ruminal	7.0	10.6	23.7	22.9	24.7	4.7	0.007	0.36	0.67
True ruminal	44.8	43.4	50.3	53.7	60.3	3.5	0.003	0.32	0.63
Total tract	57.5	64.5	70.6	73.5	76.1	1.3	<0.001	0.02	0.82

[1]Control = hay only; 0.3 to 1.2% = hay plus 0.3 to 1.2% of BW daily of DDGS supplement.
[2]n = 5 observations per treatment.
[3]Grams of microbial N/kg of OM truly fermented. Truly fermented OM = OM intake − apparent feed OM flow at the duodenum.

values of 6.1 and 6.0, which were similar between treatments (0 or 0.35% of BW daily of cracked corn, respectively). Because most of the starch is removed from DDGS, supplementation did not result in pH suppression, which may have resulted in a more favorable ruminal microbial population for fermentation of fibrous feedstuffs (NRC, 1985). Moreover, supplemented steers had increased CP intake, which may have supported greater microbial growth compared with the nonsupplemented control treatment.

A linear decrease ($P < 0.001$; Table 3) was observed for ADF intake as DDGS intake increased; however, NDF intake did not differ ($P \geq 0.23$) linearly, quadratically, or cubically among treatments. Duodenal ADF flow also decreased linearly ($P = 0.005$) as DDGS intake increased. Fecal NDF and ADF output decreased ($P \leq 0.04$) with increasing DDGS supplementation. No differences ($P \geq 0.12$) in ADF digestibility were observed; however, ruminal and total tract NDF digestibilities increased linearly ($P \leq 0.03$) with increasing DDGS. Decreased fiber digestibility has been reported in cattle and sheep offered low- to moderate-quality hay and supplemented increasing levels of corn up to 0.9% of BW daily (Chase and Hibberd, 1987; Matejovsky and Sanson, 1995). Because DDGS contain less starch (approximately 7% total starch; Stein and Shurson, 2009) than corn (approximately 72% total starch; Huntington, 1997), we expected fiber digestibilities would not be affected in our study as level of DDGS increased.

Treatment did not affect ($P \geq 0.31$) ruminal pH or total ruminal VFA concentration (Table 4); furthermore, there were no time × treatment interactions (P

Table 3. Effect of corn distillers dried grains with solubles (DDGS) supplementation on NDF and ADF intake, flow, and digestion in steers fed moderate-quality smooth brome hay

	Treatment[1]						Contrast *P*-value		
Item	Control	0.3%	0.6%	0.9%	1.2%	SEM[2]	Linear	Quadratic	Cubic
NDF									
Intake, kg/d	6.06	6.34	5.66	6.15	6.14	0.22	0.94	0.24	0.28
Duodenal flow, kg/d	1.77	1.82	1.58	1.81	1.59	0.08	0.14	0.78	0.48
Fecal output, kg/d	2.03	2.08	1.78	1.98	1.89	0.08	0.04	0.30	0.71
Digestibility, % of intake									
Ruminal	70.1	71.0	72.1	71.0	74.4	1.6	0.03	0.50	0.25
Total tract	66.3	67.2	68.8	68.1	69.2	1.2	0.01	0.44	0.65
ADF									
Intake, kg/d	3.48	3.52	3.03	3.18	3.03	0.12	<0.001	0.31	0.26
Duodenal flow, kg/d	1.10	1.08	0.90	1.04	0.88	0.05	0.005	0.81	0.33
Fecal output, kg/d	1.25	1.26	1.07	1.14	1.02	0.05	<0.001	0.96	0.93
Digestibility, % of intake									
Ruminal	68.3	68.7	70.8	67.5	70.4	2.0	0.44	0.93	0.29
Total tract	64.2	64.4	65.0	64.4	66.2	1.3	0.12	0.53	0.46

[1]Control = hay only; 0.3 to 1.2% = hay plus 0.3 to 1.2% of BW daily of DDGS supplement.
[2]n = 5 observations per treatment.

Table 4. Effect of corn distillers dried grains with solubles (DDGS) supplementation on ruminal pH, ammonia, and VFA in steers fed moderate-quality smooth brome hay

	Treatment[1]						Contrast *P*-value		
Item	Control	0.3%	0.6%	0.9%	1.2%	SEM[2]	Linear	Quadratic	Cubic
pH	6.57	6.51	6.45	6.47	6.48	0.09	0.45	0.51	0.95
Ammonia, m*M*	1.54	3.15	4.04	4.91	4.45	0.45	<0.001	0.02	0.67
VFA									
Total, m*M*	150.4	155.5	150.7	149.7	139.5	8.3	0.31	0.40	0.98
Acetate, mol/100 mol	77.4	75.8	74.0	72.1	68.8	0.7	<0.001	0.26	0.59
Propionate, mol/100 mol	12.6	12.9	13.7	15.2	17.5	0.5	<0.001	0.04	0.91
Butyrate, mol/100 mol	7.37	8.24	9.06	8.98	9.09	0.42	0.007	0.15	0.85
Acetate:propionate	6.16	5.89	5.42	4.79	4.08	0.17	<0.001	0.12	0.81

[1]Control = hay only; 0.3 to 1.2% = hay plus 0.3 to 1.2% of BW daily of DDGS supplement.
[2]n = 5 observations per treatment.

$\geq$ 0.14) for pH or VFA. Similarly, Loy et al. (2007) reported no differences in ruminal pH in heifers offered ad libitum access to grass hay (8.2% CP) and supplemented with 0.4% of BW daily of dry-rolled corn or DDGS; however, they reported greater total VFA concentrations in supplemented heifers compared with nonsupplemented controls. In the present study, the molar proportion of acetate linearly decreased ($P \leq$ 0.001), whereas molar proportion of butyrate linearly increased ($P = 0.007$) with increasing DDGS. The molar proportion of propionate increased quadratically ($P = 0.04$), and acetate:propionate ratio linearly decreased ($P < 0.001$) with increasing supplemental DDGS. It is well documented that supplementation decreases the acetate:propionate ratio when forage-based diets are fed (Horn and McCollum, 1987). Loy et al. (2007) reported the molar proportion of propionate tended to be greater in supplemented heifers compared with nonsupplemented controls; moreover, heifers supplemented with dry-rolled corn had a greater acetate:propionate ratio compared with DDGS-supplemented heifers. Similarly, Elizalde et al. (1999) reported acetate decreased and propionate increased as corn supplementation increased. It is unclear if the decrease in the acetate:propionate ratio was due to increasing dietary fat levels as DDGS increased or the increased rate of fermentation of the carbohydrates in the DDGS compared with the basal forage.

A quadratic ($P = 0.02$; Table 4) response was observed for ruminal ammonia concentration. The greatest numerical ruminal ammonia concentration occurred at the 0.9% and the least at the 0% DDGS inclusion level. The nonsupplemented control treatment had ruminal ammonia concentrations above the recommended minimum for maximum microbial growth (1.4 m*M*; Satter and Slyter, 1974). Even though DDGS have relatively less ruminally degraded protein (**RDP**) and relatively more RUP (NRC, 2000), indirect recycling of RUP to supply RDP may occur, thus increasing ammonia concentration in supplemented steers (Archibeque et al., 2008).

Time $\times$ treatment interactions ($P < 0.001$) were detected for ruminal ammonia concentrations. Ruminal ammonia concentrations peaked at 2 h postfeeding for steers supplemented with 0.3 and 0.6% of BW daily of DDGS, whereas all other treatments peaked at 4 h postfeeding. After peaking, ammonia concentrations dropped rapidly to prefeeding levels by 12 h postfeeding. Immediately before feeding, steers supplemented with 0.9% DDGS had greater ($P = 0.02$) ruminal ammonia concentrations than nonsupplemented controls, and all other treatments were intermediate. At 2 and 4 h postfeeding, supplemented steers had greater ($P \leq$ 0.009) ammonia concentrations than nonsupplemented controls; however, at 6 h postfeeding steers fed the 0.3% DDGS treatment had similar ($P = 0.37$) ruminal ammonia concentrations as the nonsupplemented controls. By 8 h postfeeding, no differences ($P \geq 0.14$) were observed for ruminal ammonia concentration.

Hess et al. (1996) supplemented 0 or 0.34% of BW daily of cracked corn to steers grazing fescue pasture and reported that corn-supplemented steers had greater ruminal ammonia concentrations immediately before and 1 h after supplementation. Loy et al. (2007) reported heifers supplemented with dry-rolled corn or DDGS had greater ruminal ammonia concentrations when compared with nonsupplemented controls. Conversely, in steers grazing summer blue grama, Pordomingo et al. (1991) reported ruminal ammonia concentrations decreased as corn supplementation increased up to 0.6% of BW daily. Similarly, Chase and Hibberd (1987) reported decreased ruminal ammonia with corn supplementation up to 0.9% of BW daily. In the current study, increased ruminal ammonia concentrations and increased flow of CP to the duodenum were observed with increasing DDGS level.

In situ ruminal disappearance rate of hay NDF was not altered ($P \geq 0.17$; Table 5) by treatment and averaged 3.74 $\pm$ 0.45%/h. Ruminal disappearance of hay ADF tended ($P = 0.10$) to respond cubically with the greatest numerical disappearance occurring at 0.9% DDGS and the least at 1.2% DDGS. Loy et al. (2007) reported nonsupplemented heifers had a faster rate of hay NDF disappearance than supplemented heifers, which was consistent with ruminal pH; however, heifers supplemented with DDGS had a faster rate of dis-

Table 5. Effect of corn distillers dried grains with solubles (DDGS) supplementation on in situ rate of DM, NDF, and ADF disappearance and CP kinetic parameters of forage and corn DDGS in steers fed moderate-quality smooth brome hay

	Treatment[1]						Contrast *P*-value		
Item	Control	0.3%	0.6%	0.9%	1.2%	SEM[2]	Linear	Quadratic	Cubic
Hay, %/h									
DM disappearance	4.08	3.82	3.74	4.62	3.27	0.31	0.41	0.30	0.02
NDF disappearance	3.81	3.79	3.55	4.45	3.10	0.45	0.61	0.37	0.17
ADF disappearance	3.86	3.71	3.39	4.57	3.08	0.46	0.63	0.50	0.10
CP[3]									
Soluble, %	25.8	25.1	25.9	25.0	25.7	1.7	0.95	0.88	0.99
Slowly degradable, %	63.8	63.8	62.1	62.7	62.5	1.7	0.50	0.77	0.88
Degradation rate, %/h	4.80	5.16	5.51	5.75	5.70	0.24	0.003	0.29	0.71
Potentially degradable, %	89.6	88.9	88.0	87.7	88.2	0.3	<0.001	0.02	0.44
DDGS, %/h									
DM disappearance	—	2.15	1.54	3.56	3.04	0.52	0.06	0.93	0.03
NDF disappearance	—	3.51	2.08	3.54	3.04	0.71	0.99	0.52	0.15
ADF disappearance	—	3.19	2.07	3.94	2.57	0.94	0.99	0.90	0.16
CP[3]									
Soluble, %	—	58.2	57.9	57.2	55.7	0.7	0.01	0.40	0.91
Slowly degradable, %	—	41.4	41.6	42.3	44.3	0.7	0.002	0.39	0.83
Degradation rate, %/h	—	2.65	2.73	3.19	3.65	0.13	<0.001	0.14	0.51
Potentially degradable, %	—	99.6	99.5	99.5	100.0	0.2	0.07	0.96	0.33

[1]Control = hay only; 0.3 to 1.2% = hay plus 0.3 to 1.2% of BW daily of DDGS supplement.
[2]n = 5 observations per treatment.
[3]$a + b(1 - e^{-kt})$, where a = fraction degraded at time 0, b = slowly degraded fraction, k = rate, and t = time (Ørskov and McDonald, 1979). Not corrected for microbial CP.

appearance compared with heifers supplemented dry-rolled corn despite no differences in ruminal pH. Chase and Hibberd (1987) observed a linear decrease in NDF disappearance as supplemental corn increased.

Hay DM disappearance responded in a cubic ($P = 0.02$) manner with the numerically greatest disappearance occurring at 0.9% DDGS and the least at 1.2% DDGS. Pordomingo et al. (1991) supplemented 0, 0.2, 0.4, and 0.6% of BW daily of whole-shelled corn to steers grazing summer blue grama rangeland and reported a cubic response in OM disappearance with steers supplemented 0.2% having the fastest disappearance rate and 0.6% having the slowest disappearance rate 24, 72, and 96 h after ruminal incubation. Soluble and slowly degradable CP fractions of hay were not different ($P \geq 0.93$) between treatments and averaged 25.4 ± 1.7 and 63.0 ± 1.7%, respectively. Degradation rate of hay CP increased (linear; $P = 0.003$) with DDGS intake. This may have been due to a RDP deficiency in nonsupplemented control steers because the response was greatest from 0 to 0.6% DDGS. This is also supported by ammonia concentrations being least in nonsupplemented controls and greatest in steers consuming 0.9% DDGS. A quadratic decrease ($P = 0.02$) was observed for extent of hay CP degradation. Particle size and specific gravity of the DDGS may have affected the way degradation rate and extent of digestion reacted. As particle size of the diet decreases, the extent at which particulate matter is digested decreases while the rate at which it passes from the rumen is increased (Galyean et al., 1979).

Rates of NDF and ADF degradation from DDGS were similar ($P \geq 0.45$) across treatments; however, a cubic ($P = 0.03$) effect was observed for DM disappearance from DDGS with the fastest degradation occurring at 0.9% DDGS and the slowest at 0.6% DDGS. The soluble CP fraction of DDGS decreased (linear; $P = 0.01$), whereas the slowly degradable CP fraction increased (linear; $P = 0.002$) with increasing intake of DDGS. Degradation rate of CP from DDGS linearly increased ($P < 0.001$) and extent of CP degradation from DDGS tended to increase ($P = 0.07$) linearly as DDGS supplementation increased. Grings et al. (1992) reported similar degradation rates of DDGS (2.6%/h) in Holstein cows consuming alfalfa-based diets and supplemented with DDGS.

A quadratic ($P \leq 0.03$; Table 6) response was observed for total ruminal fill and ruminal DM fill. Bodine et al. (2000) found no differences in ruminal OM fill in steers fed prairie hay (6% CP) with or without corn supplementation. Heldt et al. (1999) reported decreased ruminal DM fill in protein-supplemented steers compared with nonsupplemented controls. Reasons for decreased DM fill in our study may be related to increased fluid dilution rates and OM digestion as supplemental DDGS increased. Fluid dilution rate tended ($P = 0.08$) to increase in a cubic manner.

In summary, DDGS can be fed up to 1.2% of BW daily to beef cattle consuming moderate-quality smooth brome hay with no adverse effects on forage digestion or ruminal fermentation. By decreasing hay intake with DDGS supplementation, producers may be able to feed

Table 6. Effect of corn distillers dried grains with solubles (DDGS) supplementation on total ruminal fill, ruminal DM fill, and fluid dilution rate in steers fed moderate-quality smooth brome hay

	Treatment[1]						Contrast *P*-value		
Item	Control	0.3%	0.6%	0.9%	1.2%	SEM[2]	Linear	Quadratic	Cubic
Total ruminal fill, kg	54.6	50.4	43.3	43.9	45.1	1.2	<0.001	0.002	0.37
Ruminal DM fill, kg	7.78	7.20	6.10	6.42	6.32	0.24	<0.001	0.03	0.91
Fluid dilution rate, %/h	9.0	9.3	11.5	12.0	11.1	0.5	0.003	0.07	0.08

[1]Control = hay only; 0.3 to 1.2% = hay plus 0.3 to 1.2% of BW daily of DDGS supplement.
[2]n = 5 observations per treatment.

less forage or increase stocking rates. Often times, cattle consuming moderate-quality forage diets are limited in RDP; however, DDGS have relatively more RUP, which may indirectly supply RDP via the urea cycle (Archibeque et al., 2008). These characteristics make DDGS an attractive supplement for ruminants fed diets based on moderate-quality forages.

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