Effect of distillers grains or corn supplementation frequency on forage intake and digestibility[1]

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ABSTRACT: Ten ruminally cannulated heifers (BW = 416 kg; SD = 24) were used to test the effect of the form and frequency of supplemental energy on forage DMI and digestibility. Five treatments were arranged in a replicated, 5 × 4 Latin rectangle (n = 8), and included no supplement (control), dry-rolled corn (DRC) fed daily, DRC fed on alternate days (DRC-A), dried distillers grains plus solubles (DDGS) fed daily, and DDGS fed on alternate days (DDGS-A). Supplements fed daily were fed at 0.40% of BW, whereas alternate day-fed supplements were fed at 0.80% of BW every other day. Chopped grass hay (8.2% CP) was fed to allow ad libitum DMI, and the intake pattern was measured. Control heifers had greater ($P < 0.01$) hay DMI than supplemented heifers (1.88 vs. 1.66% of BW daily, respectively), although total DMI was lower ($P < 0.01$) for control. Hay DMI did not differ ($P = 0.45$) between DRC and DDGS, and tended to be lower ($P = 0.08$) by heifers on DDGS-A and DRC-A than by heifers supplemented daily. Hay intake was lower ($P < 0.01$) on supplementation days for DDGS-A and DRC-A than on nonsupplemented days. Heifers in alternate-day treatments had fewer ($P < 0.01$) and larger ($P < 0.01$) meals and spent less ($P < 0.01$) time eating than those supplemented daily. Average rumen pH was greater ($P = 0.05$) for control than supplemented heifers (6.30 vs. 6.19). Control heifers had greater ($P = 0.04$) rates and extents of NDF disappearance than supplemented heifers. Rate of hay NDF disappearance was lower ($P = 0.02$) for DRC than for DDGS. Supplementation decreased hay DMI and changed digestion kinetics. Supplementation frequency affected amount and pattern of DMI. Rate of hay NDF disappearance was greater for DDGS than DRC.

Key words: beef, digestibility, forage, intake, supplementation

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INTRODUCTION

Reducing the frequency of supplement delivery has been explored as a means of reducing the costs of supplementing ruminants consuming low-quality forages. Protein supplementation has been shown to increase intake of low-quality forages (DelCurto et al., 1990; Köster et al., 1996; Bandyk et al., 2001). Response to protein supplementation may be dependent on the frequency with which it is fed (Farmer et al., 2001; Bohnert et al., 2002a,b), although some authors have reported no effect of protein supplementation frequency on forage DMI (Krehbiel et al., 1998; Huston et al., 1999).

Supplemental energy often comes in the form of cereal grains, which generally are high in starch. Kartchner and Adams (1982), Chase and Hibberd (1987), and Beaty et al. (1994) reported negative effects of less frequent supplementation with grains. Distillers grains plus solubles (**DDGS**) is a product of the dry corn milling industry (Stock et al., 2000). Although low in starch, DDGS is high in digestible fiber, contains 11 to 12% fat (Lodge et al., 1997), and may represent a viable source of supplemental energy to forage-based ruminant diets.

The objectives of this research were to compare the effects of corn or DDGS, fed daily or on alternate days, on DMI, intake pattern, rumen pH, fiber digestibility, and ruminal ammonia and VFA concentrations. Our hypothesis was that DDGS may improve forage utilization relative to dry-rolled corn (**DRC**), particularly when fed in larger amounts, less frequently.

MATERIALS AND METHODS

Procedures involving animals in this study were reviewed and approved by the University of Nebraska Institutional Animal Care and Use Committee. Ten ruminally cannulated heifers (BW = 416 kg, SD = 24)

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Table 1. Composition of supplements fed to heifers fed grass hay[1] to allow ad libitum DMI

	Composition, % of DM	
Ingredient	DRC[2]	DDGS[3]
Dry rolled corn[4]	86.8	—
Dried distillers grains plus solubles[5]	—	89.1
Molasses	5.4	5.6
Limestone	2.4	3.3
Urea	2.6	1.6
Dicalcium phosphate	2.4	—
Vitamin premix	0.2	0.2
Mineral premix	0.2	0.2

[1]Bromegrass hay: 87% DM, 8.2% CP (DM basis), 56% in vitro OM disappearance.
[2]DRC = dry-rolled corn supplement fed daily (0.4% of BW) or on alternate days (0.8% of BW).
[3]DDGS = dried distillers grains plus solubles supplement fed daily (0.4% of BW) or on alternate days (0.8% of BW).
[4]9% CP (DM basis).
[5]31% CP, 41.7% NDF, 9.67% ether extract (DM basis).

were used in a replicated, 5 × 4 Latin rectangle to test the effects of DDGS or DRC fed daily or every other day on forage intake and digestibility. Using 10 heifers in a 5 × 4 design allowed 8 observations per treatment. Heifers were housed individually in 2.4 × 1.5-m pens in controlled-temperature rooms and were under continuous lighting throughout the study.

Treatments were arranged in a 2 × 2 plus 1 factorial and included no supplement (control), or 1 of 4 supplements (Table 1): DRC fed daily, DRC fed on alternate days, DDGS fed daily, or DDGS fed on alternate days. Heifers were weighed before feeding on consecutive days at the beginning of each period. Supplements were fed at 0.4% of BW daily, or 0.8% of BW on alternating days. This level was chosen because it falls between the levels used in a growth study (Loy, 2003) and was expected to supply 15 to 25% of the diet, which are levels commonly used in applied feeding situations. Chopped grass hay [87% DM, 8.2% CP (DM basis), 56% in vitro OM disappearance] was fed to allow ad libitum intake. Refused feed was removed and weighed before each feeding, which was at approximately 0730. A minimal amount of refused feed was targeted to minimize sorting. Supplements were then fed, and the heifers were allowed approximately 30 min to consume the offering. Refused supplement was removed, weighed, and fed with the hay. Hay was fed once daily at approximately 0800. In most cases, all of the supplement was consumed in the allotted 30 min. There was no evidence of refused supplement at the subsequent feeding.

Each of the 5 periods was 14 d, with 8 d for adaptation and 6 d for data collection. During the 6-d collection period, heifers were tethered in individual stanchions. Feed bunks were suspended from load cells (Omega, Stamford, CT) linked to a computer, and feed disappearance was measured continuously from d 9 through 14. Bunk weights were recorded every minute, and the data were stored (Labtech, Wilmington, MA). Total DMI, number of meals per day, meal size, and time spent eating were calculated (Cooper et al., 1999). Meals were determined when the feed bunk weights did not change for 20 min (Erickson et al., 2003).

Rumen fluid samples were collected at feeding and at 2, 4, 6, 8, and 10 h after feeding via a suction-strainer (Raun and Burroughs, 1962) inserted through the rumen cannula, then strained through 2 layers of cheesecloth. A collection was made at each time point on even- and odd-numbered days to represent supplement (d 9, 11, 13) and nonsupplement (d 10, 12, 14) days for heifers in alternate-day treatments. Samples were analyzed at collection for pH, then composited within heifer within period, and across even- and odd-numbered days. Composited samples were frozen and later analyzed for VFA and NH_3 concentrations. The VFA were measured according to Erwin et al. (1961) in a Hewlett Packard GLC (Avondale, PA) with a Supelco 12144 column (Supelco, Bellefonte, PA). Ammonia concentrations were determined according to Murphy et al. (1994) using spectrophotometry (Spectramax 250, Molecular Devices Corp., Sunnyvale, CA).

Hay disappearance kinetics were determined using in situ incubations. Hay samples (2 g) were ground through a 2-mm screen in a Wiley Mill (Thomas Scientific, Swedesboro, NY), placed in Dacron bags (50-μm pore size), and suspended in the cranial portion of the rumen beneath the fiber mat. Bags were soaked before placing them in the rumen. Empty bags were included to adjust for particle influx into the bags. All bags were machine washed (five 1-min cycles) and then analyzed for NDF in the Dacron bags. Hay samples were incubated for 0, 12, 24, 48, and 96 h. For heifers on the alternate-day treatments, 2 incubations per period were conducted for the 0-, 12-, and 24-h time points, occurring once on even- and once on odd-numbered days, with single 48- and 96-h incubations. Rate and extent of NDF (Van Soest et al., 1991) disappearance (Grant and Mertens, 1992) were calculated.

Spot urine samples were collected before feeding on each of the 6 collection days by stimulating the heifers to urinate. Urine samples were pooled (equal volume daily) for each heifer and analyzed for purine derivative (**PD**) content and creatinine content using HPLC (Waters Corp., Milford, MA) according to the procedure of Shingfield and Offer (1999). The PD:creatinine ratio was used as an indicator of microbial growth in the rumen (Shingfield, 2000; Whittet et al., 2004; Loy, 2003).

Data were analyzed as repeated measures (auto-regressive covariance structure) using the MIXED procedure (SAS Inst. Inc., Cary, NC). The covariance structure was tested and selected based on the lowest Akaike statistic. Animal was considered a random effect. Treatments were analyzed for the supplement by frequency interaction. When nonsignificant ($P > 0.05$), main effects were used to test preplanned contrasts that included control vs. supplemented, DRC vs. DDGS, and daily vs. alternate-day supplementation. If a significant

Table 2. Hay and total DMI and intake pattern of heifers fed no supplement, or dry-rolled corn or dried distillers grains plus solubles daily or every other day

	Treatment[1]					
Item	Control	DRC-D	DRC-A	DDGS-D	DDGS-A	SEM
Hay DMI,[2,3] % of BW daily	1.88	1.70	1.58	1.69	1.66	0.05
Total DMI,[2,3] % of BW daily	1.88	2.10	1.98	2.12	2.09	0.09
Meals eaten per day[4]	5.7	6.5	3.9	5.9	4.9	0.4
Time spent eating,[4] h/d	13.2	15.4	11.0	13.9	12.7	0.7
Meal size,[3] kg	1.94	1.26	2.24	1.52	1.83	0.22

[1]Control = no supplement, DRC-D = dry-rolled corn fed daily, DRC-A = DRC fed every other day, DDGS-D = dried distillers grains plus solubles fed daily, and DDGS-A = DDGS fed every other day.
[2]Control vs. supplemented, $P < 0.05$.
[3]Supplement frequency effect, $P < 0.10$.
[4]Supplement × frequency interaction, $P < 0.05$.

interaction was observed, simple effects of supplement type by supplementation frequency were tested and are presented.

RESULTS AND DISCUSSION

Supplementation reduced ($P < 0.01$) hay DMI (Table 2) from 1.88% of BW daily for control to 1.66% of BW daily for supplemented heifers. Heifers supplemented daily tended ($P = 0.09$) to have higher hay DMI than those fed every other day (**ALT**; Table 2). No difference was observed ($P = 0.41$) in forage DMI between DRC and DDGS treatments. Although hay DMI was greater, total intake was lower ($P < 0.01$) for control heifers (Table 2) than for supplemented heifers. No differences ($P = 0.40$) in total DMI were observed between supplement type. A time × treatment interaction was detected ($P < 0.01$) for total DMI. On days ALT heifers were not supplemented, total DMI was lower ($P < 0.01$) than daily heifers, whereas no differences were observed ($P > 0.20$) on days ALT heifers were supplemented (Figure 1). A similar pattern was observed for forage DMI (Figure 2), though a time × treatment interaction was not detected ($P = 0.11$). On days when ALT heifers were fed supplement, hay DMI decreased 11%. However, supplement intake resulted in a 36% increase in total DMI on those days. Using chromium oxide and ytterbium nitrate as markers, Huston et al. (1999) reported no differences in grazed forage intake in cows fed cottonseed meal supplemented daily, 3 times weekly, or once weekly. Conversely, Bohnert et al. (2002b) reported a linear decrease in DMI as protein supplementation frequency was reduced from daily, to every 3 d, and every 6 d, which supports our research. In lambs supplemented every 6 d, forage intake increased 18%, whereas total intake decreased 43% from the day supplement was fed to 5 d after supplementation (Bohnert et al., 2002b). This is consistent with our results on alternate day supplementation.

The effects of supplementation frequency on intake pattern (Table 2) differed between DRC and DDGS. In general, effects were more pronounced with DRC than with DDGS. A supplement × frequency interaction was observed ($P = 0.05$) for the number of meals consumed per day (Table 2). Reducing DRC supplementation from daily to every other day reduced the number of meals per day by 39%, compared with 15% for DDGS. Similarly, the amount of time spent eating (Table 2) was reduced 29% for DRC and 9% for DDGS by reducing supplementation frequency (supplement × frequency, $P = 0.03$). Heifers supplemented daily ate smaller ($P < 0.01$) meals than heifers supplemented on alternate days (Table 2) regardless of supplement type (supplement × frequency, $P = 0.12$).

No differences were observed in minimum ruminal pH (6.00, $P = 0.12$) or pH change from prefeeding to minimum (0.43 pH units, $P = 0.59$). Average pH was higher ($P = 0.01$) for control than supplemented heifers (6.34 vs. 6.18; Table 3). Ruminal pH was not affected by supplement type ($P = 0.22$) or feeding frequency ($P = 0.52$; Table 3). Ruminal pH depression has been discussed as an explanation for observations of reduced forage digestibility associated with energy supplemen-

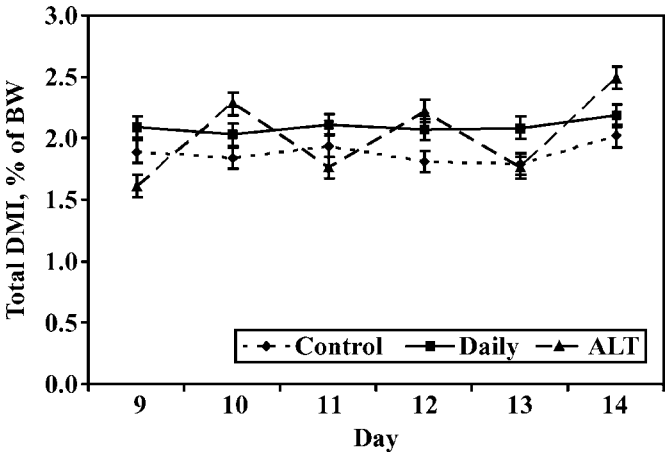

Figure 1. Total DMI of heifers fed no supplement (control) or supplemented daily or every other day (ALT). Heifers in ALT treatments were supplemented on d 10, 12, and 14. Time × treatment interaction, $P < 0.01$. Control vs. supplemented, $P < 0.01$. Supplementation frequency effect, $P = 0.08$.

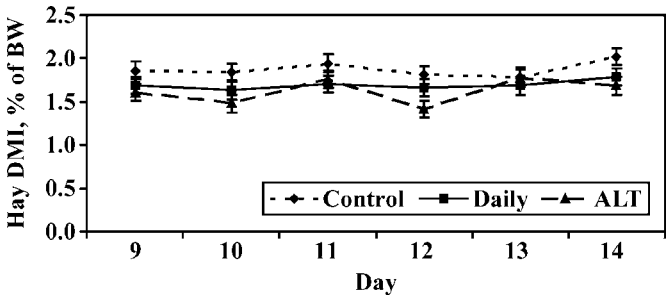

Figure 2. Hay DMI of heifers fed no supplement (control) or supplemented daily or every other day (ALT). Heifers in ALT treatments were supplemented on d 10, 12, and 14. Time × treatment interaction, $P = 0.11$. Control vs. supplemented, $P < 0.01$. Supplementation frequency effect, $P = 0.09$.

tation (Caton and Dhuyvetter, 1997). Russell et al. (1979) reported a reduction in cellulolytic bacterial numbers when pH fell to a range of 5.7 to 6.2, and the shift in composition of the microbial community elicited by grain supplementation has been implicated in reduced forage intake and digestibility (Horn and McCollum, 1987). Although supplementation reduced ruminal pH in our study, all means were above 6.1, and average minimum was 6.0. Still, differences in forage intake and rate of NDF disappearance (Table 3) between supplemented and nonsupplemented cattle were noted. Moore et al. (1999) reviewed 66 publications to estimate the effect of supplements on forage intake. They found that supplements reduced forage intake if the TDN:CP ratio was <7, which is consistent with our research where supplementation with either DRC or DDGS reduced intake of forage (6.8 in vitro OM disappearance:CP).

Supplements high in digestible fiber have been suggested as a means of supplementing energy in a form that could maintain ruminal pH and fiber digestibility (Horn and McCollum, 1987; Bowman and Sanson, 1996). In this study, providing DDGS as opposed to DRC did not affect rumen pH. Similarly, Carey et al. (1993) reported ruminal pH of corn-, barley-, and beet pulp-supplemented steers to be lower than nonsupplemental controls. Beaty et al. (1994) and Farmer et al. (2001) reported lower ruminal pH in animals supplemented infrequently on days when all animals received supplement, presumably due to larger amounts fed per offering. It is unclear why animals in this study did not respond similarly.

Rate of in situ hay NDF disappearance (Table 3) was 4.3%/h for control and 3.8%/h for supplemented heifers (control vs. supplemented, $P < 0.01$). Differences observed in rate of NDF disappearance were consistent with observations of ruminal pH. In agreement with our data, Leventini et al. (1990) reported a linear decrease in rate of NDF disappearance with increasing amounts of barley replacing forage. Freeman et al. (1992) reported no change in NDF disappearance rates due to supplementation, but supplements in that study were fed at lower levels. Supplementing DDGS resulted in a faster ($P = 0.03$) rate of hay NDF disappearance compared with DRC supplementation (4.05 and 3.54%/h; Table 3). This occurred in spite of no observed differences in ruminal pH and did not translate into increased forage intake. Supplementation frequency did not affect ($P = 0.75$) NDF disappearance rate. The per-

Table 3. In situ hay NDF disappearance, rumen pH, NH_3, and VFA concentration of heifers fed no supplement, or dry-rolled corn or dried distillers grains plus solubles daily or every other day

	Treatment[1]					
Item	Control	DRC-D	DRC-A	DDGS-D	DDGS-A	SEM
In situ hay NDF disappearance						
Rate,[2,3] %/h	4.34	3.43	3.65	4.09	4.01	0.26
Extent, % at 96 h	75.1	73.8	74.0	73.7	73.4	0.6
Rumen pH[2]	6.34	6.20	6.22	6.12	6.17	0.06
Rumen NH_3,[2,4] m*M*	2.11	4.34	4.92	4.52	4.91	0.64
Ruminal VFA						
Total,[2,5] m*M*	87.0	86.1	104.0	102.1	93.7	7.1
Acetate,[3] mol/100 mol	73.5	73.5	73.2	72.0	72.3	0.5
Propionate,[6] mol/100 mol	16.4	16.7	16.6	17.9	17.7	0.4
Acetate:propionate[3,6]	4.5	4.4	4.4	4.0	4.1	0.1
Butyrate, mol/100 mol	7.8	7.5	8.0	7.9	7.7	0.2
PD:Cr[3,4,7]	0.671	0.665	0.658	0.852	0.730	0.067

[1]Control = no supplement, DRC-D = dry-rolled corn fed daily, DRC-A = DRC fed every other day, DDGS-D = dried distillers grains plus solubles fed daily, and DDGS-A = DDGS fed every other day.
[2]Control vs. supplemented, $P < 0.05$.
[3]DRC vs. DDGS, $P < 0.05$.
[4]Supplementation frequency effect, $P = 0.07$.
[5]Supplement × frequency interaction, $P \leq 0.05$.
[6]Control vs. supplemented, $P < 0.10$.
[7]PD:Cr = the PD purine derivative:creatinine ratio.

centage of hay NDF that had disappeared after 96 h of incubation (Table 3) was 74% and was not affected ($P = 0.13$) by treatment.

Ruminal NH_3 concentration (Table 3) was higher ($P < 0.01$) for supplemented heifers than control. Considerable variation in ruminal NH_3 required for maximal microbial synthesis has been reported (Petersen, 1987). Ruminal NH_3 in control heifers was about half of values for supplemented heifers, and may have been limited given published values. There was a tendency ($P = 0.07$) for ALT heifers to have greater ruminal NH_3 concentrations than heifers supplemented daily. These data are in agreement with Bohnert et al. (2002a), who noted a linear increase in NH3 as protein supplementation decreased from daily to every 3 or 6 d.

Supplemented heifers had greater ($P < 0.05$) total VFA concentrations than nonsupplemented heifers. Supplementation frequency interacted ($P < 0.05$) with supplement type as total VFA increased with alternate day feeding of the corn supplement and decreased with the DDGS supplement. No differences ($P > 0.20$) were observed in ruminal acetate, propionate, or butyrate molar ratios (Table 3). The molar ratio of propionate tended ($P = 0.08$) to be higher for supplemented than for nonsupplemented heifers. Heifers supplemented with DDGS had lower ($P < 0.01$) acetate:propionate than those supplemented with corn. In the study of Bohnert et al. (2002a), total VFA concentration increased linearly as supplementation frequency decreased. This was a result of linear increases in propionate and butyrate, which occurred simultaneously to a linear decrease in acetate.

The PD:creatinine was higher ($P < 0.05$) for DDGS than for corn-supplemented calves (Table 3). There was no response to supplementation, even though there was an observed increase in DMI. The decreased rate of NDF disappearance resulting from supplementation may have offset the increased total DMI, thereby negating any differences in PD:creatinine. Loy (2003) reported increased PD:creatinine in heifers fed a high level of supplemental corn or DDGS compared with those fed a lower level. However, a nonsupplemented control was not used in that study.

Loy (2003) did not show a difference between corn and DDGS in PD:creatinine, although the ratio in DDGS-fed heifers was 8% higher. Although not significant in either experiment, DMI differences may explain the relative responses in PD:creatinine to supplement type. In the experiment of Loy (2003), DMI was 2.5% lower for DDGS than for corn, whereas in the current study, DMI was 3.1% higher for DDGS. Although DDGS may have more energy than corn, much of it (lipid and rumen undegradable protein) is not available to rumen microbes. Conversely, corn has more ruminally available energy, but may lower ruminal pH and decrease NDF digestion. The net effect seems to favor microbial growth in calves supplemented with DDGS rather than corn.

Supplementation of distillers grains or corn at 0.4% of BW daily reduced forage intake. Supplementing every other day depressed forage intake and altered intake pattern, decreasing hay intake but increasing total intake on days supplements were fed. Changes in intake pattern elicited by infrequent supplementation were more marked for corn-supplemented heifers than those fed DDGS, though effects on total intake did not differ by supplement type.

LITERATURE CITED

Bandyk, C. A., R. C. Cochran, T. A. Wickersham, E. C. Titgemeyer, C. G. Farmer, and J. J. Higgins. 2001. Effect of ruminal vs. postruminal administration of degradable protein on utilization of low-quality forage by beef steers. J. Anim. Sci. 79:225–231.

Beaty, J. L., R. C. Cochran, B. A. Lintzenich, E. S. Vanzant, J. L. Morrill, R. T. Brandt, Jr., and D. E. Johnson. 1994. Effect of frequency of supplementation and protein concentration in supplements on performance and digestion characteristics of beef cattle consuming low-quality forages. J. Anim. Sci. 72:2475–2486.

Bohnert, D. W., C. S. Schauer, M. L. Bauer, and T. DelCurto. 2002a. Influence of rumen protein degradability and supplementation frequency on steers consuming low-quality forage: I. Site of digestion and microbial efficiency. J. Anim. Sci. 80:2967–2977.

Bohnert, D. W., C. S. Schauer, and T. DelCurto. 2002b. Influence of rumen protein degradability and supplementation frequency on performance and nitrogen use in ruminants consuming low-quality forage: Cow performance and efficiency of nitrogen use in wethers. J. Anim. Sci. 80:1629–1637.

Bowman, J. G. P., and D. W. Sanson. 1996. Starch- or fiber-based energy supplements for grazing ruminants. In Proc. 3rd Grazing Livestock Nutrition Conf. M. B. Judkins and F. T. McCollum III, ed. Proc. West. Sect. Am. Soc. Anim. Sci. (Suppl. 1):118–135.

Carey, D. A., J. S. Caton, and M. Biondini. 1993. Influence of energy source on forage intake, digestibility, in situ forage degradation, and ruminal fermentation in beef steers fed medium-quality brome hay. J. Anim. Sci. 71:2260–2268.

Caton, J. S., and D. V. Dhuyvetter. 1997. Influence of energy supplementation on grazing ruminants: Requirements and responses. J. Anim. Sci. 75:533–542.

Chase, C. C., and C. A. Hibberd. 1987. Utilization of low-quality native grass hay by beef cows fed increasing quantities of corn gain. J. Anim. Sci. 65:557–566.

Cooper, R. J., T. J. Klopfenstein, R. A. Stock, C. T. Milton, D. W. Herold, and J. C. Parrott. 1999. Effects of imposed feed intake variation on acidosis and performance of finishing steers. J. Anim. Sci. 77:1093–1099.

DelCurto, T., R. C. Cochran, L. R. Corah, A. A. Beharka, E. S. Vanzant, and D. E. Johnson. 1990. Supplementation of dormant, tallgrass-prairie forage. II. Performance and forage utilization characteristics in grazing beef cattle receiving supplements of different protein concentrations. J. Anim. Sci. 68:532–542.

Erickson, G. E., C. T. Milton, K. C. Fanning, R. J. Cooper, R. S. Swingle, J. C. Parrott, G. Vogel, and T. J. Klopfenstein. 2003. Interaction between bunk management and monensin concentration on finishing performance, feeding behavior and ruminal metabolism during an acidosis challenge with feedlot cattle. J. Anim. Sci. 81:2869–2879.

Erwin, E. S., D. J. Marco, and E. M. Emery. 1961. Volatile fatty acid analysis of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44:1768–1770.

Farmer, C. G., R. C. Cochran, D. D. Simms, E. A. Klevesahl, T. A. Wickersham, and D. E. Johnson. 2001. The effects of several supplementation frequencies on forage use and the performance of beef cattle consuming dormant tallgrass prairie forage. J. Anim. Sci. 79:2276–2285.

Freeman, A. S., M. L. Galyean, and J. S. Caton. 1992. Effects of supplemental protein percentage and feeding level on intake, ruminal fermentation, and digesta passage in beef steers fed prairie hay. J. Anim. Sci. 70:1562–1570.

Grant, R. J., and D. L. Mertens. 1992. Impact of in vitro fermentation techniques upon kinetics of fiber digestion. J. Dairy Sci. 75:1263–1272.

Horn, G. W., and F. T. McCollum. 1987. Energy supplementation of grazing ruminants. Pages 125–136 in Proc. Graz. Livest. Nutr. Conf., Jackson Hole, WY.

Huston, F. E., H. Lippke, T. D. A. Forbes, J. W. Holloway, and R. V. Machen. 1999. Effects of supplemental feeding interval on adult cows in western Texas. J. Anim. Sci. 77:3057–3067.

Kartchner, R. J., and D. C. Adams. 1982. Effects of daily and alternate day feeding of grain supplements to cows grazing fall-winter range. Proc. West. Sect. Am. Soc. Anim. Sci. 33:308. (Abstr.)

Köster, H. H., R. C. Cochran, E. C. Titgemeyer, E. S. Vanzant, I. Abdelgadir, and G. St-Jean. 1996. Effect of increasing degradable intake protein on intake and digestion of low-quality, tallgrass-prairie forage by beef cows. J. Anim. Sci. 74:2473–2481.

Krehbiel, C. R., C. L. Ferrell, and H. C. Freetly. 1998. Effects of frequency of supplementation on dry matter intake and net portal and hepatic flux of nutrients in mature ewes that consume low-quality forage. J. Anim. Sci. 76:2464–2473.

Leventini, M. W., C. W. Hunt, R. E. Ruffler, and D. G. Casebolt. 1990. Effect of dietary level of barley-based supplements and ruminal buffer on digestion and growth by beef cattle. J. Anim. Sci. 68:4334–4340.

Lodge, S. L., R. A. Stock, T. J. Klopfenstein, D. H. Shain, and D. W. Herold. 1997. Evaluation of corn and sorghum distillers byproducts. J. Anim. Sci. 75:37–43.

Loy, T. W. 2003. Utilization of grain milling byproducts in high-forage diets. PhD Diss. University of Nebraska, Lincoln.

Moore, J. E., M. H. Brant, W. E. Kunkle, and D. I. Hopkins. 1999. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. J. Anim. Sci. 77(Suppl. 2):122–135.

Murphy, T. A., F. L. Fluharty, and S. C. Loerch. 1994. The influence of intake level and corn processing on digestibility and ruminal metabolism in steers fed all-concentrate diets. J. Anim. Sci. 72:1608–1615.

Petersen, M. K. 1987. Nitrogen supplementation of grazing livestock. Pages 115–121 in Proc. Graz. Livest. Nutr. Conf., Jackson Hole, WY.

Raun, N. S., and W. Burroughs. 1962. Suction strainer technique in obtaining rumen fluid samples from intact lambs. J. Anim. Sci. 21:454–457.

Russell, J. B., W. M. Sharp, and R. L. Baldwin. 1979. The effect of pH on maximum bacterial growth rate and its possible role as a determinant of bacterial competition in the rumen. J. Anim. Sci. 48:251–260.

Shingfield, K. J. 2000. Estimation of microbial protein supply in ruminant animals based on renal and mammary purine metabolite excretion. A review. J. Anim. Feed Sci. 9:169–121.

Shingfield, K. J., and N. W. Offer. 1999. Simultaneous determination of purine metabolites, creatinine, and pseudouridine in ruminant urine by reversed-phase high-performance liquid chromatography. J. Chromatogr. B 723:81–94.

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 byproducts in feedlot diets. Proc. Am. Soc. Anim. Sci., 1999. http://www.asas.org/jas/symposia/proceedings/0924.pdf Accessed Sep. 25, 2003.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.

Whittet, K. M., T. J. Klopfenstein, G. E. Erickson, T. W. Loy, R. A. McDonald, and K. W. Creighton. 2004. Evaluation of the variability in urinary creatinine and purine derivative excretion in growing and finishing heifers. J. Anim. Sci. 82(Suppl. 2):90. (Abstr.)