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Protein Supplementation of Ammoniated Wheat Straw: Effect on Performance and Forage Utilization of Beef Cattle[1]

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ABSTRACT: We studied the effects of supplement CP concentration on performance and forage use of cattle allowed ad libitum access to ammoniated wheat straw. During two consecutive winters, crossbred beef cows in late gestation (n = 87 in 1990–1991, n = 84 in 1991–1992) were used in a randomized complete block design with three pens per treatment. Cows were stratified by weight, body condition score (BCS), age, and breed and randomly assigned within strata to 1) control (C, no supplement), or 2 kg/d of 2) low-protein (LP) supplement (12% CP), 3) moderate-protein (MP) supplement (20.1% CP), or 4) high-protein (HP) supplement (31.7% CP) (DM basis). The feeding period was 84 d in 1990–1991 and 60 d in 1991–1992. Supplementation (C vs LP, MP, or HP) increased ($P < .01$) cow weight gains (32.7 vs 60.7, 62.8, and 72.4 kg, respectively) and improved ($P < .01$) BCS. Calf birth weights, weaning weights, and ADG were not affected by treatment ($P \geq .20$). Average calving date, percentage of cows cycling at the start of the breeding season and percentage pregnant after a 60-d breeding season were also similar ($P > .20$) among treatments. Sixteen ruminally fistulated steers (482 kg, four steers per treatment) were blocked by weight and assigned to the same four supplements in a 30-d digestion trial. Supplementation increased ($P < .01$) digestible DMI and forage DMI ($P \leq .04$) and tended ($P = .09$) to increase digestible NDF intake but did not alter ($P \geq .15$) apparent DM or NDF digestibility. However, DM and NDF digestibilities increased ($P \leq .03$) with increasing CP concentration. Ruminal NH_3 N concentration was increased ($P = .04$) by supplementation and, among supplemented steers, the increase was linear ($P < .01$) with increased protein concentration. All other fermentation characteristics measured, except butyrate proportion, responded significantly to increasing protein concentration in the supplements. In conclusion, although forage consumption, cow weight, and body condition increased with increasing CP concentration in supplement, the response was not sufficient to affect subsequent reproduction or calf gain.

Key Words: Ammoniated Feeds, Wheat Straw, Cows, Digestibility

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Introduction

An abundance of wheat straw is produced in the United States annually as a by-product of wheat grain production. Although the cellulose of wheat straw can be utilized by ruminant animals, digestibility often is limited by its low protein content and a high degree of lignification. These limitations can be partially overcome through supplemental protein or chemical treatment. Ammoniation has been considered the most practical chemical method for improving the nutritive value of wheat straw (Birkelo et al., 1986).

Previous research has shown that beef cattle performance improves when ammoniated wheat straw (**AWS**) diets are supplemented with protein (Nelson et al., 1985; Males et al., 1986; Beck et al., 1992). However, the optimal level for that protein supplementation has not been well defined. The purpose of our study was to examine the impact of CP concentration in supplements fed before calving to beef cows consuming AWS on weight change and reproduction, as well as its impact on nutrient digestibility, intake, rate of passage, and ruminal fermentation characteristics.

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Table 1. Composition of supplements and ammoniated wheat straw (AWS) fed to beef steers

Item[a]	DM, %	% of DM					
		OM	CP	ADF	NDF	ADL	IADF[b]
LP	92.7	94.9	12.0	6.5	11.5	4.2	.2
MP	93.4	94.2	20.1	6.4	11.4	2.9	.2
HP	94.1	90.7	31.7	5.7	15.5	3.0	.2
AWS	87.0	91.4	10.5	61.1	76.0	5.1	20.7

[a]LP = low protein, MP = moderate protein, HP = high protein, and AWS = ammoniated wheat straw. Supplements composed of various proportions of soybean meal and sorghum grain were fed at 2 kg/d.
[b]IADF = indigestible ADF.

Experimental Procedures

Experiment 1. A 2-year trial was conducted using mature Angus and Angus × Hereford beef cows in late gestation. The cows (n = 87 in 1990–1991, n = 84 in 1991–1992) were stratified at the initiation of the trial each year by weight, body condition score (**BCS**; 1 = emaciated, 9 = obese) (Wagner et al., 1988), age, and breed and randomly assigned within strata to one of four treatments. Treatments were control (**C**; no protein supplement) or 2 kg/d of a low-protein (**LP**) supplement with 12% CP, a moderate-protein (**MP**) supplement with 20.1% CP, or a high-protein (**HP**) supplement containing 31.7% CP (Table 1). There were three pens per treatment for a total of 12 pens each year. Trials were initiated in December each year and lasted 84 d in 1990–1991 and 60 d in 1991–1992. Cows were fed wheat straw that had been treated during the previous summers with anhydrous ammonia (3% wt/wt) via the "stack" method (Sundstøl et al., 1978). Before feeding, the forage was ground through a 7.6-cm screen with a tub grinder.

All cows received vitamin A injections at the start of each trial and were fed .23 kg/d of a mineral supplement formulated to meet macro and trace mineral requirements during late gestation (NRC, 1984). Supplements were fed once daily, just before feeding AWS. The supplements were formulated to the desired CP concentrations by altering the relative proportions of sorghum grain and soybean meal and were essentially isocaloric. Treatments were discontinued just before the onset of calving, at which time all cows were combined, placed on dormant, native bluestem pasture, and supplemented with 4.54 kg of alfalfa hay per cow daily. Calves were weighed and identified at birth. In 1991, jugular blood samples were taken from the cows 10 d before and at the start of the breeding season (0 d). Serum samples were analyzed for progesterone (Skaggs et al., 1986); levels higher than 1 ng/mL in either sample were considered indicative of cycling activity. Cows were weighed and scored for body condition at trial initiation, at the end of the experimental feeding period, at the beginning of the breeding season (May 15 in both years), and at weaning. At trial initiation and conclusion, weights were taken on two consecutive days after removal from feed and water for 16 h. The other weights were single, non-shrunk measurements. Cows were injected intramuscularly with 25 mg of prostaglandin $F_{2\alpha}$ (Upjohn, Kalamazoo, MI) to synchronize estrus before bull exposure. Bull calves were castrated and implanted with 36 mg of zeranol (Mallinckrodt Veterinary, Mundelein, IL), and all calves were vaccinated with a clostridial vaccine. Cows were allotted by treatment to breeding pasture and exposed to the bulls for 60 d in both years. During the breeding season, cows grazed native bluestem pasture and had free-choice access to mineral supplement (50% NaCl, 50% dicalcium phosphate).

Experiment 2. Sixteen 3-yr-old, ruminally fistulated, Angus × Hereford steers (482 kg, SE = 13 kg) were blocked by weight and assigned to the same supplementation treatments as in Exp. 1. Steers were held in individual pens (2 m × 6 m) in an open-fronted barn with a concrete floor and were fed supplements daily at 0800. Following supplement consumption, AWS (same straw as in Exp. 1) was offered to each steer at 130% of the previous 5-d average intake. Steers were adapted to the supplements and straw for 14 d. A 7-d voluntary intake period followed, during which orts were removed manually from the bunk, weighed, mixed, and sampled for DM determination. Intake measurements continued for the next 7 d, during which each steer was fitted with a fecal collection bag. Bags were removed daily at 0600 and 1800 and the contents weighed, mixed, and sampled (1% of total fecal output). Feed and ort samples were collected daily during this period. At 0600 and 1300 on d 29, each steer's ruminal contents were evacuated manually, weighed, sampled in triplicate, and returned to the rumen. On d 30, each steer was pulse-dosed intraruminally with 5.96 g of Cr EDTA (Binnerts et al., 1968) in 420 mL of distilled water to determine liquid dilution rate. The marker was dispersed evenly in the rumen to facilitate uniform distribution. Ruminal fluid samples were drawn before dosing (0 h) and at 3, 6, 9, 12, and 24 h after dosing using a suction strainer (19-mm diameter, 1.5-mm mesh). Ruminal fluid pH was measured immediately after sampling. Then 8 mL was frozen for Cr analysis, 8 mL was added to 2 mL of 25% metaphosphoric acid and frozen

Table 2. Influence of supplementation on beef cow weight and body condition score

Item	Treatment[a]				Contrast[b]			
	C	LP	MP	HP	SEM	N	L	Q
No. of cows	42	44	42	44				
Initial wt, kg	479	480	477	477	8	.98	.78	.87
Weight changes								
During feeding period, kg	32.7	60.7	62.8	72.4	4	<.01	.05	.45
End of feeding period to weaning, kg	−14.9	−43.3	−41.7	−43.5	6	<.01	.97	.79
Final wt, kg	496	497	498	506	8	.27	.13	.78
Body condition score[c]								
Start of feeding period	5.3	5.5	5.4	5.4	.07	.21	.36	.35
Change during the feeding period	−.5	0	.1	.1	.09	<.01	.53	.56
Change from end of feeding period to weaning	.5	−.1	0	0	.10	<.01	.68	.69
At weaning	5.3	5.4	5.4	5.4	.09	.35	.47	.70

[a]C = nonsupplemented control; LP = low protein (12%); MP = moderate protein (20.1%); HP = high protein (31.7%).
[b]Probability of observing a greater *F*-value: N = negative control vs supplement, L = linear response to supplement CP concentration, Q = quadratic response to supplement CP concentration.
[c]Body condition score: 1 = extremely emaciated; 9 = extremely obese.

for VFA analysis, and 2 mL was added to 8 mL of .1 *N* HCl and frozen for NH_3 *N* analysis. After thawing, ruminal samples were centrifuged at 33,000 × *g* for 15 min. Volatile fatty acids were analyzed via gas chromatography as described by Jacques et al. (1987). Ammonia concentrations were determined using an autoanalyzer (Technicon, Tarrytown, NY) and the hypochlorite method (Broderick and Kang, 1980). Atomic absorption spectrophotometry (air/acetylene flame) was used to determine Cr concentrations, and liquid dilution rate was determined by regressing the natural log of Cr concentration against sampling time (Warner and Stacy, 1968).

Samples of the AWS, supplements, orts, ruminal digesta, and feces were dried in a forced-air oven at 50°C. Forage and ort samples were ground in a Wiley mill to pass a 1-mm screen. Supplement, ruminal digesta, and fecal samples were ground using a 1-mm screen in a Cyclotec mill (Tecator, Herndon, VA).

Forage, ort, supplement, fecal, and ruminal digesta samples were analyzed for DM and OM by standard procedures (AOAC, 1990). Crude protein was calculated as Kjeldahl N (AOAC, 1990) × 6.25. Acid detergent fiber, NDF, and ADL were determined following procedures outlined by Van Soest et al. (1991) with the omission of sulfite and decalin. Acid detergent insoluble nitrogen was determined by Kjeldahl N analysis of the ADF residue. Indigestible ADF was analyzed in the forage, ort, supplement, and ruminal digesta samples (Cochran et al., 1986) using plastic, 100-mL centrifuge tubes fitted with Bunsen valves instead of glass screw-capped tubes.

The GLM procedures of SAS (1988) were used for all statistical analyses. In Exp. 1, cow BW and BCS change, calf birth weight, calf weaning weight, and calf ADG were analyzed as a randomized complete block design. The model statement included calf sex, year, treatment, and year × treatment, with pen serving as the experimental unit. The effect of supplementation was evaluated by a linear contrast that compared the negative control (C) and the other three treatments (LP, MP, and HP). Linear and quadratic contrasts were used within the supplemented treatments to evaluate the effect of increasing protein concentration. Pregnancy and cyclicity data were analyzed using the chi-square analysis (Steel and Torrie, 1980).

In Exp. 2, intake, digestibility, ruminal DM and liquid fill, liquid dilution rate, and rate of passage were analyzed as a randomized complete block design. The contrasts were as in Exp. 1; the model statement included treatment and block (weight = block). A split-plot analysis (Steel and Torrie, 1980) was used to evaluate ruminal pH, NH_3 N concentrations, molar proportions of VFA, and the acetate:propionate ratio (**A:P**). The whole-plot sources of variation, treatment, and weight block were tested using treatment × block as the error term. Subplot effects, time, and time × treatment interaction were tested using the residual error. If the time × treatment interactions were significant, data were sorted by time period and analyzed for treatment effects within each time period. The residual error was used as the testing term for these variables, and means were separated using the same contrasts mentioned previously.

Results

Treatment × year interactions were not significant for weight or body condition change, so data from both years were combined (Table 2). Cows gained faster during the feeding period ($P < .01$) when they received a supplement. Similarly, supplemented cows maintained body condition during the feeding period,

Table 3. Influence of supplementation on calf birth weight, weaning weight, and average daily gain

Item	Treatment[a]					Contrast[b]		
	C	LP	MP	HP	SEM	N	L	Q
Birth wt, kg	38.7	39.1	39.1	39.3	.90	.64	.64	.28
Weaning wt, kg	249	246	243	249	3.8	.53	.84	.28
Calf ADG, kg	.96	.95	.94	.95	.01	.20	.46	.17

[a]C = nonsupplemented control; LP = low protein (12%); MP = moderate protein (20.1%); HP = high protein (31.7%).
[b]Probability of observing a greater *F*-value: N = negative control vs supplement, L = linear response to supplement CP concentration, Q = quadratic response to supplement CP concentration.

whereas body condition in the control group decreased ($P < .01$). Within the supplemented cows, a linear ($P = .05$) increase in weight gain was observed in response to increasing protein in the supplement, although the differences were small (maximum of 11.7 kg). Changes in body condition within the supplemented groups were similar ($P \geq .53$).

Although cows were treated similarly from the end of the experimental period (early to mid-February) through weaning (early October), the control group lost less weight, and, in fact, showed improved body condition ($P < .01$) compared with groups previously supplemented. However, within supplemented cows, weight or body condition change was not affected ($P \geq .68$) by protein concentration in the supplement. Ultimately, all groups completed the trial with similar average body weight and condition ($P \geq .13$).

Calf birth weight, weaning weight, and calf ADG (Table 3) were not influenced substantially ($P \geq .17$) by any of the treatments. Similarly, the percentage of cows cycling at the beginning of the breeding season, the percentage pregnant (Table 4), and the average calving date were not influenced ($P \geq .24$) by treatment.

Supplemented steers ate approximately 27% more AWS ($P = .04$) than controls (Table 5), and consumption increased with increasing protein ($P = .05$). Because the amount of supplement was the same across treatments, total DM intake followed the same patterns ($P \leq .06$). Digestibility of DM and NDF were not altered significantly by supplementation, but both increased linearly with increasing protein ($P \leq .03$). Supplementation increased ($P < .01$) the consumption of digestible DM (the product of DM digestibility and total DM intake). Digestible DM intake also increased in direct proportion to protein content of supplements for supplemented steers. Consumption of digestible NDF also tended ($P \leq .09$) to follow the same pattern.

No significant treatment × time interactions occurred for ruminal IADF or liquid fill (Table 6). Ruminal fill of IADF was not influenced ($P = .58$) by supplementation in general; however, response to increasing protein content in the supplements was quadratic ($P = .05$) and greatest for the MP group. Ruminal liquid fill responded similarly ($P < .01$). The fractional passage rate of IADF from the rumen was not altered ($P = .48$) by supplementation in general but tended ($P = .08$) to increase linearly with increasing protein. Ruminal liquid dilution rate was not influenced ($P \leq .46$) by treatment.

Treatment × time interactions were not significant for the fermentation characteristics measured (Table 7) except the molar proportions of propionate and valerate. When propionate and valerate proportions were sorted by time and evaluated graphically, the interactions seemed to consist largely of variation in the magnitude of differences rather than variation in the order of response. Therefore, data were pooled and presented as mean values averaged over time. With the exception of ruminal NH_3, major fermentation characteristics and molar proportions of the three dominant VFA (acetate, propionate, and butyrate) were not altered ($P \geq .21$) by supplementation. Ruminal NH_3 was increased ($P = .04$) by supplementation and increased linearly ($P < .01$) with increasing protein. Similarly, isobutyrate and valerate were increased ($P < .01$) and isovalerate tended ($P = .13$) to be increased by supplementation. Among supplemented steers, ruminal pH; molar proportions of

Table 4. Influence of supplementation on cow reproductive performance

Item	Treatment[a]				*P*-value
	C	LP	MP	HP	
Percentage cycling[b]	61	86	76	81	.24
Percentage pregnant[c]	95	94	92	100	.40

[a]C = nonsupplemented control; LP = low protein (12%); MP = moderate protein (20.1%); HP = high protein (31.7%).
[b]At start of breeding season (data are for first year only). Cyclicity defined by serum progesterone concentrations > 1 ng/mL.
[c]Percentage pregnant determined from calving records in 1st yr and rectal palpation at weaning in 2nd yr.

Table 5. Influence of supplementation on voluntary dry matter intake and apparent digestibility by steers

	Treatment[a]					Contrast[b]		
Item	C	LP	MP	HP	SEM	N	L	Q
Steer wt, kg	487	494	478	468	13.3	.63	.20	.83
Intake								
Forage DM, %BW[c]	1.56	1.77	1.92	2.24	.15	.04	.05	.66
Total DM, %BW[c]	1.61	2.19	2.34	2.67	.16	<.01	.06	.66
Digestible DM, % BW[d]	.85	1.13	1.38	1.59	.10	<.01	.02	.86
Digestible NDF, %BW[d]	.83	.83	.99	1.20	.08	.09	.02	.78
Digestibility								
DM, %	52.9	51.7	58.9	60.2	2.34	.16	.03	.34
NDF, %	70.2	63.5	68.7	70.4	1.43	.15	<.01	.35

[a]C = nonsupplemented control; LP = low protein (12%); MP = moderate protein (20.1%); HP = high protein (31.7%).
[b]Probability of observing a greater *F*-value; N = negative control vs supplement, L = linear response, Q = quadratic response.
[c]Intake determined during the voluntary intake period.
[d]Intake determined during the digestibility measurement period.

acetate, propionate, isobutyrate, and valerate; and the acetate:propionate ratio changed quadratically with increasing protein in the supplement. Ruminal pH was lowest for the MP group. Because acetate proportion was the highest and propionate proportion the lowest for the LP group, the acetate:propionate ratio was also the highest for that treatment. Isobutyrate and valerate proportions were highest for the HP treatment. With the exception of butyrate proportion, the remaining fermentation characteristics measured increased in a linear fashion ($P < .01$) in response to increasing protein content in the supplements. Butyrate proportion did not respond ($P \geq .21$) to treatment.

Discussion

Supplements were composed of soybean meal and sorghum grain, which, because of their similar energy densities, allowed formulation of isocaloric supplements that differed in protein content. However, such an approach results in some change in the source of energy as soybean meal is substituted for sorghum grain. Although the magnitude of such changes is not great, they could have an effect on the response to the supplements. This possibility should be kept in mind by the reader when interpreting response to increasing protein content.

The body weight and condition responses to supplementation in our study concur with results of previous reports (Streeter et al., 1982; Faulkner et al., 1985; Grings and Males, 1987). In addition, the linear increase in gain with increasing protein in the supplement agrees with the research of Beck et al. (1992). Males et al. (1986) suggested that nonprotein nitrogen (**NPN**) in AWS is utilized poorly in meeting the protein needs of beef cows. In our study, the CP content of the AWS averaged 11.6% in yr 1 and 12.6% in yr 2 (DM basis). Assuming a minimum AWS intake of 1.6% of BW, a 500-kg cow would consume 968 g of CP, at least 30% over CP requirements (NRC, 1984) in the last third of pregnancy. The fact that our cows responded to increasing protein supports the conclusion of Males et al. (1986) that the N in AWS is used poorly.

The ability of the supplements to significantly enhance gain in our study probably is related to

Table 6. Influence of supplementation on ruminal fill and passage rates in beef steers

	Treatment[a]					Contrast[b]		
Item	C	LP	MP	HP	SEM[c]	N	L	Q
Ruminal DM fill, 0 h, %BW[d]	1.87	2.11	2.14	1.93	.13	.25	.38	.50
Ruminal DM fill, 4 h, %BW[d]	2.16	2.50	2.98	2.56	.19	.05	.84	.09
Ruminal IADF fill, %BW[e]	.57	.61	.65	.56	.05	.58	.24	.05
Ruminal IADF passage, %/h[de]	2.89	2.87	2.83	3.90	.37	.48	.08	.25
Ruminal liquid fill, mL/kg BW[e]	142	158	169	155	6.78	.04	.43	<.01
Liquid dilution rate, %/h	8.46	8.39	8.20	9.28	.82	.87	.46	.55

[a]C = nonsupplemented control; LP = low protein (12%); MP = moderate protein (20.1%); HP = high protein (31.7%).
[b]Probability of observing a greater *F*-value: N = negative control vs supplement, L = linear response, Q = quadratic response.
[c]Standard error of the mean. n = 4.
[d]Significant treatment × time interaction.
[e]IADF = Indigestible acid detergent fiber. Pooled 0 h and 4 h values (no treatment × time interaction).

Table 7. Influence of supplementation on ruminal fermentation characteristics in beef steers

Item	Treatment[a]					Contrast[b]		
	C	LP	MP	HP	SEM[c]	N	L	Q
pH	6.17	6.31	6.13	6.32	.10	.45	.72	<.01
VFA, m*M*	103.6	96.5	100.1	107.2	4.7	.69	<.01	.50
A:P[d]	3.5	3.6	3.4	3.4	.14	.77	<.01	<.01
NH_3 N, m*M*	5.6	5.8	6.7	9.4	.63	.04	<.01	.21
Acetate, mol/100 mol	71.0	71.1	69.8	69.7	.53	.21	<.01	<.01
Propionate, mol/100 mol[e]	20.3	19.7	20.9	20.6	.74	.86	<.01	<.01
Butyrate, mol/100 mol	7.7	7.9	7.9	8.1	.47	.62	.21	.23
Isobutyrate, mol/100 mol	.3	.4	.4	.5	.02	<.01	<.01	.02
Valerate, mol/100 mol[e]	.3	.4	.4	.5	.02	<.01	<.01	.03
Isovalerate, mol/100 mol	.5	.5	.6	.6	.06	.13	<.01	.34

[a]C = nonsupplemented control; LP = low protein (12%); MP = moderate protein (20.1%); HP = high protein (31.7%).
[b]Probability of observing a greater *F*-value: N = negative control vs supplement, L = linear response, Q = quadratic response.
[c]n = 4.
[d]Acetate:propionate ratio.
[e]Significant treatment × time interaction ($P < .04$).

increased digestible DMI (as seen in Exp. 2). Digestible DMI increased both because of an increase in AWS intake and an increase in DM digestibility, as protein concentration in the supplements increased. The linear increase in AWS intake with increasing protein supplied by the supplement seemed to be related closely to the linear increases in digestibility and passage rate. These factors seem particularly important in light of the poor relationship of DM and IADF fill with AWS intake. It is also possible that altered amino acid supply in the supplemented animals may have affected intake (Minson, 1990).

The first increment of supplemental protein (LP) decreased NDF digestibility (Table 5). Because passage rates of IADF were similar for the control and LP groups, this seemed to be a direct effect of the supplement. Mould et al. (1983) suggested that maintenance of pH above 6.0 to 6.1 should minimize the negative effects of readily fermentable carbohydrate on fiber digestion. In our study, pH of the LP group was 6.31 (vs 6.17 for the control group), and yet NDF digestion was reduced by 6.7 percentage units (a 9.5% reduction). This agrees with the research of Henning et al. (1980) and supports their suggestion that starch or its derivatives per se may inhibit fiber digestion. In our study, as protein increased, the negative impact of the supplements on fiber digestion decreased. A similar response was reported by DelCurto et al. (1990). Russell et al. (1992) noted that bacteria that ferment structural carbohydrates rely primarily on NH_3 as a N source. However, they also require branched-chain VFA, which come from fermentation of branched-chain amino acids. In Exp. 2, branched-chain VFA concentrations increased with increasing protein, which may have contributed to improved NDF digestion. Dry matter digestibilities for the LP and control groups were similar, probably because of the greater relative digestibility of the supplement.

The apparent discontinuity between body condition changes and weight gain during the feeding period (Table 2) was largely due to the effect of fetal growth during the prepartum period and loss at calving. For example, the small increase in BW by the control group and the concomitant decline in body condition suggests that unsupplemented AWS provided insufficient nutrients to maintain both fetal growth and dam tissue equilibrium. The cows seemed to mobilize body tissue to support pregnancy, thereby losing body condition. Between the end of the feeding period (supplement treatments terminated a few weeks before the average calving date) and weaning, the control group lost less BW than supplemented cows but gained body condition. The postsupplementation weight change included conceptus weight at the beginning but not at the end. Therefore, by weaning, the cows had lost weight but gained condition. Our supplemented cows lost more weight from precalving to weaning than those receiving unsupplemented AWS. Beck et al. (1992) reported similar results. At least two of the mechanisms generally considered to be responsible for compensation of this nature are increased forage intake and improved efficiency of energy use (Forbes, 1986).

The failure of prepartum supplementation of AWS to significantly alter calf performance and cow reproduction concurs with the research of Beck et al. (1992). Although chi-square analysis of the percentage of cows cycling at the beginning of the breeding season did not detect statistical significance, the magnitude of the difference (> 15%) between control and supplemented groups deserves consideration. The number of animals in each of the treatment groups in this experiment limits the power of the chi-square analysis. Thus, caution is warranted in interpreting the biological relevance of this observation.

Treatment responses for most fermentation characteristics seem to be consistent with the known effects of protein supplementation to cattle on lower-quality forage (Hannah et al., 1991; Sunvold et al., 1991). The linear increase in total VFA concentration with increasing protein is consistent with the additional

substrate fermented in the rumen. Similarly, the linear increase in NH_3 is consistent with the provision of additional ruminally degradable protein (NRC, 1985). The response patterns for acetate, propionate, and their ratio agree with the enhancement in fermentation and the increased intake associated with increasing supplemental protein (Van Soest, 1982). Provision of branched-chain amino acids in the supplement is likely responsible for the increase in branched-chain VFA and should have been beneficial for fiber digestion (Russell et al., 1992).

Implications

Ammoniated wheat straw is an acceptable "base" forage for pregnant beef cows. However, cow body weight and condition can be improved by feeding grain-based supplements in conjunction with ammoniated wheat straw. Increasing the protein concentration in grain-based supplements fed to cows consuming ammoniated wheat straw will improve the response to supplementation. Enhanced performance seems to be, at least partly, a response to increased digestible dry matter intake. Although increasing the protein concentration in supplements fed to pregnant cows consuming ammoniated wheat straw may improve their performance, the magnitude of the improvement does not seem sufficient to affect reproduction or subsequent calf performance.

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