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INFLUENCE OF PROTEIN SUPPLEMENTS ON THE INTAKE AND UTILIZATION OF LOW-QUALITY ROUGHAGES

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Introduction

One of the distinct advantages of ruminants over other livestock species is their ability to effectively utilize high-fiber, low-quality roughage resources. In a recent review, Males (1987) estimated that if one-half of the crop residues in the United States from wheat, barley and oat straw were properly supplemented and fed to beef cows, 17.5 million brood cows could be wintered for a 5-month period. This represents about 50% of the total beef cow herd in the United States. In Oregon, residues from grass seed production (800 thousand to 1 million tons) could be utilized to feed greater than 50% of the mature producing cows in the state. Likewise, low-quality hays and dormant range forages are additional feed resources available for ruminant livestock production providing appropriate steps are taken to improve their nutritive value. The potential to utilize low-quality, high-fiber feed resources that are noncompetitive with human food resources may be the key to the future of the ruminant livestock industry.

One of the future challenges facing nutritionists, as well as producers, however, is promoting efficient utilization of high-fiber, low-quality feedstuffs by ruminants. Numerous approaches have been taken to improve the nutritive value of poor-quality roughages. Physical modification such as grinding, pelleting and high pressure steam; chemical modification such as use of anhydrous ammonia, urea and alkaline hydrogen peroxide; and various supplementation strategies have all been effective in increasing the use and nutritive value of poor quality roughages. This paper will focus on supplementation strategies to improve the intake and utilization of poor-quality roughages.

Protein Supplementation

Factors Influencing Response. In general, when low-quality roughages are not limited in quantity, protein is the most beneficial supplement. Responses to supplemental protein are usually observed when the crude protein (CP) content of the basal forage is less than 6 to 8 % (Campling, 1970; Kartchner, 1981). However, several other factors also need to be considered. First, as the digestibility of the forage declines, the availability of the CP to the microbial population and host animals also declines (Allden, 1981). The availability of essential nutrients may also impact perceived responses to supplemental protein. Sulfur to nitrogen ratios have been suggested to have a significant role in supplemental protein influences on the intake and digestibility of low-quality roughages (Hunter, 1991). Likewise, if forage availability is limited, responses to supplemental protein are often not observed because of the animal's inability to express increased intake (Rittenhouse *et al.*, 1970; Kartchner, 1981). In addition, stage of production and(or) growth requirements also influence response to supplemental protein. Young growing animals, as well as high producing ruminants display responses of greater magnitude on similar basal forage, and display responses with higher quality basal diets. Therefore, forage availability, digestibility, stage/production requirements, other limiting nutrients, as well as, the CP content of the forage must be considered when predicting performance responses to supplemental protein.

Performance Response. Numerous researchers have observed increases in beef cattle performance with the addition of supplemental protein to high fiber, low-quality roughage diets (Table 1). With mature cows, the benefits are often observed as decreased loss in body weight and condition during the winter feeding or grazing period (Clanton and Zimmerman, 1970; Lusby and Wetteman, 1988; DelCurto *et al.*, 1990a). Adequate maintenance of cow body weight and condition, in turn, tends to promote greater reproductive efficiency and calf weaning weights (Clanton, 1982; Wallace, 1987).

Intake Response. The primary mechanism in which supplemental protein improves ruminant performance is by increasing the intake of the low-quality roughage (Table 2). The exact mechanisms involved with the stimulation of feed intake, however, are not clearly defined, and, in all likelihood, are a combination of several factors. There can be little doubt that protein supplementation of protein/nitrogen deficient ruminal environments aids in the digestion of feeds and the subsequent contribution of nutrients to the host animal. However, several of the studies with protein supplementation and ad libitum intake of low quality roughage display no net increase in digestibility (expressed as % of total) of the low-quality roughage diet (Table 2). Intake is increased, digestibility remains relatively constant and, as a result, total digestible nutrients available to the host animal are improved.

Digesta kinetics have been shown to be improved substantially by providing supplemental protein. In particular, increases in ruminal fill with supplemental protein additions to low-quality forage diets have been reported (Egan, 1965; Thornton and Minson, 1973; DelCurto *et al.*, 1990b & c; Hannah *et al.*, 1991). Such increases suggest that factors other than distension per se may play an important role in the regulation of intake of forages of very poor quality. Increases in digesta fill are usually accompanied by increases in digesta and liquid outflow from the rumen (McCollum and Galyean, 1985; DelCurto *et al.*, 1990b & c; Hannah *et al.*, 1991). Digesta passage rate (expressed as % of fill exiting the rumen per hour), however, is often unaltered by protein supplementation. Thus, exposure of ruminal contents to microbial digestion is often the same regardless of nitrogen status. These results suggest that ruminal digestive efficiency and kinetics are not the controlling factor in the improvement of feed intake with protein supplementation. Instead, increases in fill and outflow of ruminal digesta appear to be a function of increased intake rather than a factor promoting increased intake.

Work by Egan (1965) with sheep, and Owens (1991) with steers shows that post ruminal infusions of nonprotein nitrogen (NPN) or casein substantially improve the intake, fill and passage of low-quality feed digesta. In both of these studies, the magnitude of response in terms of feed intake and digesta kinetics was similar to studies in which animals consumed the supplements. As a result, these results suggest that the largest effect of supplemental protein on feed intake is a metabolic one, mediated by the bodies improved protein status. In a recent review, Owens (1991) speculated that increase intake with protein supplementation of low-quality forages is due primarily to post ruminal effects or tissue protein/energy status of the host animal. Furthermore, the rumen or specifically passage of digesta from the rumen, does not appear to be the "bottleneck" in terms of the intake and utilization of low-quality diets. Obviously, further research is needed to define the true physiological limitations for the intake and use of low-quality roughages.

Energy Supplementation

In contrast to protein supplements, energy supplements have been reported to depress both the intake and digestibility of low quality forage (Table 2). Supplementing low-quality native grass hay, Chase and Hibberd (1987) reported a linear decrease in forage intake with increasing quantities of corn. Likewise, with beef cattle grazing dormant forage, supplementation with corn, barley or sorghum decreased forage digestibility and intake (Cook and Harris, 1968; Lamb and Eadie, 1979; Kartchner, 1980; DelCurto *et al.*, 1990b; Sanson *et al.*, 1990). Energy supplements tend to replace or substitute for the intake of low quality forages. As a result, energy supplementation of low-quality forages often exerts little or no influence on beef cattle performance (Clanton and Zimmerman, 1970; DelCurto *et al.*, 1990b; Sanson *et al.*, 1990).

Energy supplements should be discouraged if your goal is to optimize beef cattle performance with the utilization of the high-fiber, low-quality roughage. However, if the availability of the low-quality forage is limiting, energy supplementation becomes a viable alternative.

Protein to Energy Ratios. Likewise, some consideration of the supplemental protein to energy ratios is also warranted. In a series of studies evaluating yearling heifer gains as influenced by supplemental protein versus energy, Clanton and Zimmerman (1970) reported variable results from year to year. In year 1, heifer gain was increased with the addition of supplemental protein but was unaffected by supplemental energy. In year 2, a protein by energy interaction was observed with the addition of energy at the low protein level depressing heifer gain, whereas energy addition at the high levels of protein increased gain. In digestion studies, increasing energy at low levels of supplemental protein has been observed to decrease low-quality roughage intake and digestibility. At high levels of supplemental protein, increasing energy typically has little effect on intake and digestibility of the low-quality roughage (Elliot, 1967; Hennessy *et al.*, 1983; DelCurto *et al.*, 1990b).

Negative Energy Responses. Energy supplementation (grain/starch base supplements) of low-quality, high fiber diets has been reported to depress cellulytic activity (cellulose digesting bacterial activity). In a study evaluating the influence of starch on in vitro cellulose digestion by ruminal microorganisms, El-Shazly and coworkers (1961) reported that reduced cellulose digestion was not due to decreased pH or the production of an inhibitor by starch digesting microorganisms. Instead, starch digesting bacteria were proposed to have a competitive advantage over cellulytic bacteria with respect to the uptake and utilization of essential nutrients. Likewise, in more recent reviews, Wallace (1986), as well as, Demeyer and Van Nevel (1986) further support the contention that energy additions to low-quality diets promote increased nutrient deficiencies in cellulytic bacteria due to greater, more rapid, nutrient utilization by noncellulytic bacteria.

Physical Form of Supplemental Protein

Type of Supplemental Protein. There is limited information available in terms of the efficacy of various types of feed sources which might be used as supplemental protein sources. The most common supplemental protein feed sources are derived from oilseed byproducts such as soybean meal and cottonseed meal. These feed sources, however are expensive at times and, as a result, identifying cheaper alternative feed sources to provide supplemental protein would be beneficial to ruminant livestock producers.

Work from eastern Montana (Cochran *et al.*, 1986) and New Mexico (Judkins *et al.*, 1987) have indicated that alfalfa pellets or cubes are as effective as cottonseed cake when fed on an equal protein basis (Table 1). DelCurto and coworkers (1990c) found that sun-cured alfalfa pellets promoted higher forage intake and better maintenance of mature cow weight and body condition compared to long-stem alfalfa hay or soybean meal/sorghum grain supplements. Additionally, wheat middlings have also been successfully used as supplemental protein sources for beef cattle consuming low-quality roughages (Sunvold *et al.*, 1991).

In general, supplements with high bypass potential do not seem to offer any advantages over supplements with high degrees of rumen degradability (DelCurto *et al.*, 1990; Karges *et al.*, 1991). These results suggest that cattle on low-quality roughages diets are not limiting in digestible protein above that supplied by the rumen microorganisms. Researchers have also suggested that methionine is a rate limiting nutrient for ruminal digestion, as well as host animal metabolism (Petersen, 1987; Clark and Petersen, 1988). Subsequent research has yielded mixed results (Sorensen *et al.*, 1991), and suggest that sulfur, not sulfur containing amino acids, may be limiting in these situations (Momont *et al.*, 1991).

Synchrony of release of nitrogen from protein supplements has also been suggested an important factor in obtaining optimal ruminal digestion of low-quality, high-fiber feedstuffs (Orskov, 1982). In a study evaluating soybean meal supplementation of wheat straw diets, Pritchard and Males (1982) observed increased beef cattle performance with twice daily versus once daily feeding of supplements. The increased performance was attributed to a more uniform release of protein in the rumen and subsequent maintenance of ruminal ammonia levels optimal for microbial digestion (> 5 mol/dl; Satter and Slyter, 1974). In contrast, alternate day to once weekly feeding of protein supplements has yielded similar responses as daily feeding (Wallace, 1988; Hunt *et al.*, 1989). Therefore, the value of synchrony of protein release does not seem as important as simply taking care of a nutrient deficiency. The importance of synchrony of protein degradation, as well as rumen ammonia levels to optimize ruminal digestive efficiency warrants further investigation.

Although there is some difference in beef cattle response to various types of supplemental protein sources, most are effective as long as the CP content is adequate (>17% CP). Based on current research, the physical form of the supplement does not appear nearly as important as simply providing the animal with protein. Therefore, when purchasing a supplemental protein source, look for one that is most economical for your given production situation. It is also important to compare costs of protein supplements on a crude protein equivalent basis.

NPN Supplementation

Ruminants have a unique ability to assimilate nonprotein nitrogen (NPN) into microbial cell protein. The microbial cell protein is then ultimately available for digestion and absorption by the host animal. Based on these observations, the use of NPN such as urea or biuret would seem to offer tremendous potential as an alternative to natural protein supplementation of low-quality roughages.

However, NPN has not been as effective as natural protein sources when supplemented to cattle consuming low-quality roughages. Summarizing six experiments evaluating the value of urea and feed-grade biuret in supplements fed to cattle on winter range, Clanton (1978) reported decreased performance with supplements containing greater than 3% urea or 6% biuret as compared to cattle receiving all natural protein supplements. Likewise, Rush and Totusek (1976) found that cows maintained on winter range forage lost less weight when a natural protein supplement was fed as compared to isonitrogenous supplements containing urea and biuret. Numerous other researchers have also observed depressions in expected beef cow performance when NPN is substituted for a portion of a natural protein in a supplement (Raleigh and Turner, 1968; Williams *et al.*, 1969; Oltjen *et al.*, 1974). It should be noted that in all the above performance studies, special attention was devoted to assuring proper sulfur to nitrogen ratios in the NPN supplements.

Many potential explanations exist regarding why NPN is limited in potential as a source of N for ruminants consuming low-quality roughages. One of the major problems in efficient utilization of urea, the most common NPN source, is the rapid release of ammonia. Bloomfield *et al.*, (1960) indicated that urea hydrolysis occurred four times faster than uptake of the liberated ammonia. The increased concentration of ruminal ammonia, in turn, increases the passive transport gradient and pH, thus making conditions optimal for absorption of ammonia into the blood (Bloomfield *et al.*, 1963). As a result, much of the ammonia released from urea is absorbed before the ruminal bacteria can efficiently utilize it. Additionally, Chalupa (1968) suggests that assimilation of ammonia by ruminal bacteria might also be limited by availability of carbon skeletons, such as branch-chain VFA, and other nutrients. Sulfur is a common nutrient suggested to impact the utilization of ruminal nitrogen due to their interrelated role in microbial cell protein synthesis. The advantage of natural protein sources, in this scenario, is that as proteins are being broken down and eventually deaminated, carbon skeletons and other essential nutrients for microbial cell protein assimilation are being made available. These results indicate that NPN might be a more viable supplement if the availability of ammonia was more closely synchronized with fermentative processes and essential nutrients for bacterial growth.

Protein Supplementation of Grazing Livestock

Most of the studies discussed in the preceding sections were conducted in a controlled setting and involved low-quality hays or straws. Supplementing livestock grazing dormant and(or) low-quality forage yields more variable results (Table 2) and necessarily involves more management. First, forage quality and availability is dynamic and changes dramatically from season to season, as well as within season of use. Second, environmental stress on the livestock and changes in livestock nutrient demands across the grazing season further complicate the supplementation strategy to be implemented.

In grazing studies; forage quality, forage availability and environmental extremes (snow cover, precipitation, temperature, etc...) have been suggested to have large influences on livestock responses to supplemental protein (Rittenhouse *et al.*, 1970; Kartchner, 1980). In a recent study, DelCurto and coworkers (1991) found a similar pattern of livestock response during two consecutive years of supplementing graded levels alfalfa pellets. However, the magnitude of response was dramatically different between consecutive years due to observed changes in forage quality, forage availability and environmental stress imposed on the livestock (Table 1). While these examples do not adequately describe all the considerations needed for supplementing grazing livestock, they do point out some of the complexities in achieving optimal response to supplementation strategies. In addition, these examples suggest that further research is needed to describe the interaction of environment, forage quality/quantity and livestock nutrient demands, so that optimal use of the forage resource, minimal use of supplements and acceptable levels of beef cattle production can be obtained.

Summary and Implications

Improved beef cattle performance with protein supplementation is usually mediated through increased intake of low-quality roughages. Although ruminal digestive characteristics are dramatically altered, the mechanism by which supplemental protein improves intake appears to be mediated by digestive responses post ruminally and metabolic responses of the host animal (Owens, 1991).

Natural protein appears to be the most beneficial supplement for high-fiber, low-quality roughages in ruminant diets. In contrast to energy supplements, supplemental protein encourages the intake and digestibility of the low-quality roughages. Nonprotein nitrogen does not appear to be as beneficial as natural protein supplementation of low-quality roughages. Furthermore, feeding of slowly degraded or bypass protein, as well as, potentially "rate limiting" amino acids appear to show inconsistent responses and do not appear to show any substantial improvements over traditional supplemental protein sources.

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TABLE 1. A SUMMARY OF INVESTIGATIONS COMPARING SUPPLEMENTATION STRATEGIES WITH LOW QUALITY ROUGHAGES. EFFECT ON BEEF CATTLE WEIGHT CHANGE, BODY CONDITION CHANGE AND REPRODUCTIVE EFFICIENCY.[a,b]

Reference	Forage or substrate	Supplement treatments	Class of livestock	BW change, kg	BC change	Supplementary information
Cochran et al., 1986	Dormant mixed grass prairie forage 3.0-6.5% CP Feeding period: - 84 d, year 1 - 98 d, year 2	1) Control, no supple. 2) Alfalfa cubes, 16.5% CP 3) Cottonseed meal/barley cake, 21.6	517 kg pregnant cows (151 hd)	-11 24 14	-.5 .2 0	Quantities of supplement provided were adjusted to insure equal portions of CP
DelCurto et al., 1990b	Dormant tall prairie forage Feeding period: -Mid November to early February (84 d)	1) 13% CP supple. fed @ .5% BW 2) 26% CP supple. fed @ .5% BW 3) 39% CP supple. fed @ .5% BW	454 kg pregnant cows (99 hd)	-11 12 17	-.7 -.4 -.2	Supplements were isocaloric mixtures of soybean meal and sorghum grains. Tendency for increased birth weights and calf ADG with dams who received high concentrations of supplemental protein
DelCurto et al., 1990c	Dormant tallgrass prairie forage: -Mid November to early February (84 d)	1) 25% CP SBM/sorghum supple. @ .48% BW 2) 17% CP alfalfa hay fed @ .7% BW 3) 17% CP dehydrated alfalfa pellets fed @ .7% BW	488 kg pregnant cows (84 hd)	-3 2 19	-.4 -.5 -.3	Quantity of supplements provided were adjusted to insure isonitrogenous treatments. No reproductive differences were observed.
Judkins et al., 1987	Dormant Blue Grama range - 11.5% CP feeding: -Mid February to late April (104 d)	1) Control, no supple. 2) Cottonseed meal (47%) fed alternate days @ 1.7 kg/hd 3) Alfalfa hay (17.5% CP) fed alternate days @ 3.6 kg/hd	241 kg heifers	-3 25 24	- - -	Quantity of supplements provided were adjusted to insure isonitrogenous treatments.
Wallace, 1988	Dormant Blue Grama range - 9.6% CP Feeding Period: - Mid December to mid May (150 d)	1) Cottonseed cake (41% CP): 3.2 kg 2 x weekly 2) Corn grain cube (9.4% CP): 2.91 kg 2 x weekly 3) Corn grain cube (9.4% CP): 83 kg daily	227 kg heifers	34 -2 10	- - -	Heifers receiving cottonseed cake were heavier at breeding and had greater conception rates.
DelCurto et al., 1991	Dormant sagebrush-steppe rangelands: -Year 1 - 6.8 to 5.4% CP - 48 hd - 112 d feeding period	1) Control, no supple. 2) 1.5 kg alfalfa/hd/d 3) 3.0 kg alfalfa/hd/d 4) 4.5 kg alfalfa/hd/d	463 kg pregnant cows (5.3 BC)	-30 9 30 44	-1.2 -1.2 -.1 .2	Calf ADG and birth weight tend to increase with increasing levels of supplementation. Calving interval declined with increasing level of dam's nutrition. All cows were individually fed supplements during 112 d feeding period.
	-Year 2 - 4.2 to 4.8% CP - 72 hd - 70 d feeding period	1) Control, no supple. 2) 1.5 kg alfalfa/hd/d 3) 3.0 kg alfalfa/hd/d 4) 4.5 kg alfalfa/hd/d	471 kg pregnant cows (5.3 BC)	-62 -15 5 11	-2.1 -.8 -.2 .2	Calf ADG and birth were increased with 3.0 and 4.5 kg supple. treatments. All cows were individually fed supplements during 70 d feeding period.

[a] Summary is not all inclusive, but lists studies with differing forage bases, treatment structures and productive classes of livestock.

[b] Definition of abbreviations: BW = body weight, BC = body condition (1-9 scale), CP = crude protein, ADG = average daily gains.

TABLE 2. A SUMMARY OF INVESTIGATIONS COMPARING SUPPLEMENTATION STRATEGIES WITH LOW QUALITY ROUGHAGES: EFFECT ON INTAKE AND DIGESTION

Reference	Forage or substrate	Supplement treatments	Class of Livestock	Dry matter intake, % BW		Forage digestion		Supplementary information
				Forage	Total	DM	NDF	
A. Protein levels and protein/energy ratios:								
Church and Santos, 1981	3.8% CP wheat straw	1) 0 g/kg $BW^{.75}$ protein	270 kg heifers	1.32	1.32	47.1	-	Increasing levels of protein were achieved by supplementing increasing quantities of soybean meal.
		2) 1 g/kg $BW^{.75}$ protein		1.56	1.64	55.8	-	
		3) 2 g/kg $BW^{.75}$ protein		1.72	1.84	49.0	-	
		4) 3 g/kg $BW^{.75}$ protein		1.79	1.94	48.6	-	
		5) 4 g/kg $BW^{.75}$ protein		1.74	1.91	51.9	-	
DelCurto et al., 1990a	Dormant tallgrass prairie hay (2.9% CP)	1) Control, no supple.	242 kg steers	.87	.87	35.5	37.9	Isocaloric supplement fed at .4% BW
		2) 13% CP supple.		.85	1.27	44.8	29.9	
		3) 26% CP supple.		1.36	1.76	48.4	39.9	
		4) 39% CP supple.		1.21	1.62	48.8	38.6	
Sanson et al., 1990	Sandhills meadow hay (4.3% CP)	1) Control, no suppl.	550 kg steers	1.8	1.8	49.5	50.0	Supplements were isonitrogenous with increasing level of corn as CP concentration decreased.
		2) 48.5% CP supple.		2.1	2.3	56.7	52.7	
		3) 24.5% CP supple.		2.0	2.4	59.2	51.1	
		4) 16.0% CP supple.		1.6	2.2	60.0	49.5	
Sonvold et al., 1991	Dormant tallgrass prairie hay (2.0% CP)	1) Control, no supple.	422 kg steers	1.03	1.03	34.7	46.2	Supplements were isocaloric mixtures of 40% wheat middlings and mixtures of soybean meal and sorghum grain.
		2) 15% CP supple.		1.12	1.49	49.3	51.2	
		3) 20% CP supple.		1.62	1.99	48.8	53.2	
		4) 25% CP supple.		1.70	1.07	49.8	55.5	
DelCurto et al., 1990a	Dormant tallgrass prairie hay (2.6% CP)	1) 22% CP supple. fed @ .3% BW	332 kg steers	1.21	1.51	39.1	49.2	2x2 factorial contrasting high and low levels of crude protein (treatments 1 & 2 vs 3 & 4) with high and low levels of supplemental energy (treatments 1 & 3 vs 2 & 4).
		2) 11% CP supple. fed @ .6% BW		.82	1.42	46.1	44.3	
		3) 44% CP supple. fed @ .3% BW		1.07	1.37	45.9	50.9	
		4) 22% CP supple. fed @ .6% BW		1.51	1.75	47.5	48.0	
		1) 22% CP supple. fed @ .3% BW	401 kg steers	1.30	1.60	-	-	
		2) 11% CP supple. fed @ .6% BW		1.17	1.77	-	-	
		3) 44% CP supple. fed @ .3% BW		1.71	2.01	-	-	
		4) 22% CP supple. fed @ .6% BW		1.49	1.09	-	-	
McCollom and Galyean, 1985	6.1% CP prairie hay	1) Control, no supple.	214 kg steers	1.69	1.69	49.9	-	Early rates of in vitro digestion was improved with supplementation. Digesta kinetics was increased with supplementation.
		2) Cottonseed meal, .8 kg/d (.37% BW)		2.15	2.52	53.5	-	

TABLE 2. A SUMMARY OF INVESTIGATIONS COMPARING SUPPLEMENTATION STRATEGIES WITH LOW QUALITY ROUGHAGES: EFFECT ON INTAKE AND DIGESTION.[a,b] (CONTINUED)

Reference	Forage or substrate	Supplement treatments	Class of Livestock	Dry matter intake, % BW: Forage	Dry matter intake, % BW: Total	Forage digestion: DM	Forage digestion: NDF	Supplementary Information
B. Physical Form of Supplemental Protein								
DelCurto et al., 1990c	Dormant tallgrass prairie hay (2.6% CP)	1) Control, no supple.	259 kg steers	.49	.49	42.7	57.3	Supplemental treatments provided equal quantities of ME and crude protein.
		2) Soybean meal/sorghum grain @ .48% BW		1.07	1.55	46.3	48.5	
		3) 17% CP alfalfa hay fed at .7% BW		1.05	1.75	49.6	52.6	
		4) 17.4% CP dehydrated alfalfa pellets fed at .68% BW		1.21	1.88	44.2	45.8	
Judkins et al., 1987	Blue grama range (11.5%)	1) Control, no supple.	230 kg steers	1.08	1.08	-	-	Quantities of supplemented feed were adjusted to be isonitrogeous
		2) 23% CP alfalfa pellets		.77	1.41	-	-	
		3) 47.7% CP cottonseed cake		.96	1.29	-	-	
Sonvold et al., 1991	Dormant tallgrass prairie hay (2.4% CP)	1) Control, no supple.	374 kg steers	.87	.87	43.9	54.3	Treatments 2 & 3 provide equal energy levels.
		2) Soybean meal/sorghum grain fed at .32% BW		1.07	1.39	49.4	51.2	
		3) Wheat middlings fed at .39% bw		.99	1.38	50.6	54.1	
		4) Wheat middlings fed at .77% BW		1.15	1.92	50.4	49.8	
C. Supplementation Under Grazing Conditions:								
Caton et al., 1989	Blue grama rangelands 8.1% CP (OM basis)	1) Control, no supple.	Hereford x Angus 454 kg steers	.93	.93	46.7	3.0%/h	Initial rate of digestion was improved but evened out in later in situ periods
		2) Cottonseed meal, .83 kg/d (.18% BW)		1.16	1.34	49.6	3.4%/h	
Judkins et al., 1987	Blue grama range (11.5%)	1) Control, no supple.	230 kg steers	1.08	1.08	-	-	Quantities of supplemented feed were adjusted to be isonitrogeous
		2) 23% CP alfalfa pellets		.77	1.41	-	-	
		3) 47.7% CP cottonseed cake		.96	1.29	-	-	
						(Forage)		
Kartchner, 1981	Winter range forage: Blue grama range 6.0% CP - Year 1	1) Control, no supple.	458 kg dry pregnant Hereford cows	1.89	1.89	54.9	54.9	Differences between years 1 and 2 were attributed to severity of weather and limited availability of forage in year 2.
		2) 1.5 kg cottonseed meal fed on alternate days		1.78	1.94	53.2	52.9	
		3) 1.4 kg barley fed alternate days		1.71	1.86	54.2	51.7	
	Blue grama range 8.1% CP - Year 2	1) Control, no supple.	497 kg dry pregnant Hereford cows	1.37	1.37	40.6	40.6	
		2) 1.5, 1.5 and 2 kg SBM fed Monday, Wednesday and Friday, respectively		1.61	1.75	46.4	48.6	
		3) 1.3, 1.3 and 2 kg barley		1.27	1.40	38.8	34.3	

[a] Summary is not all inclusive, but lists studies with differing forage bases, treatment structures and productive classes of livestock.

[b] Definition of abbreviations: BW = body weight, CP = crude protein, DM = dry matter, NDF = neutral detergent fiber.