

Optimum supplementation strategies for beef cattle consuming low-quality roughages in the western United States¹

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Abstract

Beef cattle production in the western United States is faced with many challenges unique to the region. Arid rangelands with limited forage production and seasonal and yearly extremes in forage quality create the need for dynamic and regionally specific supplementation programs. Moreover, some areas consist of cool-season forages and/or high-elevation rangelands characterized by significant snow accumulation, which necessitates heavy reliance on harvested forage during the winter. The ability of the western cow-calf producers to compete in a growing world meat market may hinge in part on the ability to lower production costs via strategic use of harvested feeds during periods of low forage quality and availability. Winter management strategies, in turn, often blend optimum production with low-input sustainable economic strategies that can differ from those in other regions of North America. This article, like many others, focuses on traditional protein, energy, and physical form of protein issues. However, this article also includes discussions of general supplementation concepts (matching production expectations with the resources available), strategies for supplement delivery, supplementation of vitamins and minerals, comparisons of hand-fed vs self-fed supplements, and supplementation concepts within an economically sustainable framework that is regionally focused on the western United States. Supplementation strategies need to be optimized with dynamic western range environments and compatible with extensive beef production systems.

Key Words: Beef Cattle, Feed Supplements, Rangelands, Roughage, Sustainability

Introduction

Beef cattle producers in the western United States are faced with never-ending dilemmas of maintaining economic viability during times of low market values and, more recently, increased public criticism of beef product quality and compatibility of the industry with the environment. Unlike the swine and poultry industries, the beef industry in the Western United States is dynamic, ever adapting to changing arid environments and subsequent effects on forage quality, quantity, and associated relationships to beef cattle nutritional requirements. As a result, the western beef cattle industry is very extensive, and optimal production is a function of the resources each ranching unit has available and how successfully the manager can match the type of cow and/or production expectations to the available resources. Successful beef producers are not necessarily the ones who wean the heaviest calves, obtain 95% conception, or provide the most optimal winter nutrition. Improved production can only be achieved within the physiological constraints of the environment. Thus, increased production may involve costs that exceed its value. Therefore, successful producers are the ones who demonstrate economic viability (optimum balance between input costs per cow and production) despite the economic and public pressures that plague the industry.

Discussion

Rangeland Forage Resources. The western United States has several unique geographic features that shape and influence the beef cattle industry. First, much of the land area fits the general classification of "rangeland," and hence it is not suitable for tillage due to arid environments, shallow/rocky soils, high elevations, and a short growing season. From arid rangelands in the northern Great Basin (cold desert) to southern New Mexico, ranchers are faced with limited forage resources and challenging nutritional calendars characterized by significant periods of nutritional deficiencies. Arid and high-elevation rangelands also are characterized by dynamic, highly variable climates that change drastically from season to season and year to year. For example, the CP content of diets selected by cattle in the northern Great Basin differed dramatically across seasons and years (Figure 1). The extremes in CP content were, in turn, related to wide variation in crop year precipitation, averaging 158, 246, 231, and 524 mm for 1990, 1991, 1992, and 1993, respectively (40-yr average = 277 mm). Extreme fluctuations of precipitation also have significant effects on forage availability; 1990 to 1992 averaged 240 kg/ha, whereas 1993 forage availability was 580 kg/ha. Thus, efficient beef producers must adapt to wide ranges of forage quality and quantity.

Other Challenges. Perhaps the greatest nutritional challenge to western beef producers relates to the need for supplemental inputs. Seasonal deficiencies of nutrients (protein and/or energy) are frequent in arid and high elevation rangelands. Producers who are dependent on rangeland forage resources must develop strategies that maximize the use of the forage resources and minimize supplemental inputs while maintaining acceptable levels and cost of beef cattle production. Likewise, high-elevation and high-latitude beef cattle operations are likely to have significant periods of snow accumulations, which necessitates the feeding of harvested forages. In the Pacific Northwest and Intermountain West, many producers feed 1,500 to 3,000 kg of hay to their mature cows during the winter feeding period. The success of producers in these regions may depend on their ability to find an economical alternative to winter feeding of hays, such as stockpiled forages and crop residues. However, like dormant range forages, stockpiled forage and crop residues are low-quality roughages that require nutritional inputs for optimal use. Hence, the objective of this review is to summarize information relative to supplementing low-quality roughages for beef cattle production in the western United States.

Protein Supplementation

In general, when low-quality roughages are not limited in quantity, protein is the most beneficial supplemental nutrient (Campling, 1970). Responses to supplemental protein are usually observed when the CP content of the basal forage is less than 6 to 8% (Campling, 1970; Kartchner, 1981; Table 2). Nonetheless, several other factors also need to be considered. First, as the digestibility of the forage decreases, the availability of the CP to the microbial population and the host animal also decreases (Allden, 1981). The availability of essential nutrients such as energy, vitamins, and minerals might also affect perceived responses to supplemental protein. Sulfur: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 and adults at high production levels are more likely to respond with increased intake and gain when provided protein supplements and respond when consuming higher-quality basal diets (8 to 10% CP, 50 to 55% total tract DMD). Therefore, forage availability, digestibility, stage/production requirements, other limiting nutrients, and the CP content of the forage must be considered when predicting performance responses to supplemental protein.

Protein Supplementation Response. Numerous researchers have observed increases in beef cattle performance with the addition of supplemental protein to high-fiber, low-quality roughage diets (Tables 2 and 3). With mature cows, the benefits are often observed as decreased loss in percent-

age BW and BCS during the winter feeding or grazing period (Clanton and Zimmerman, 1970; Lusby and Wetteman, 1988; Horney et al., 1996). Adequate maintenance of cow BW and condition, in turn, tends to promote greater reproductive efficiency and calf weaning weights (Clanton, 1982; Wallace, 1987).

Energy Supplementation. In contrast to protein supplements, energy supplements have been reported to decrease both the intake and digestibility of low-quality forage. Supplementing low-quality native grass hay, Chase and Hibberd (1987) reported a linear decrease in forage intake with increasing quantities of corn. Likewise, beef cattle grazing dormant forage displayed decreased forage digestibility and intake when supplemented with corn, barley, or sorghum (Cook and Harris, 1968; Lamb and Eadie, 1979; 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 forage often exerts little or no influence on beef cattle performance (Clanton and Zimmerman, 1970; DelCurto et al., 1990b; Sanson et al., 1990).

Energy supplementation should be discouraged when the producer's goal is to optimize beef cattle performance with a basal diet of high-fiber, low-quality roughage. However, when the availability of the low-quality forage is limiting, energy supplementation becomes a viable alternative.

Protein:Energy Ratios. Some consideration of the supplemental protein:energy ratios is warranted. In a series of studies evaluating yearling heifer gains as influenced by supplemental protein vs energy, Clanton and Zimmerman (1970) reported variable results from year to year. In yr 1, heifer gain was increased with the addition of supplemental protein but was unaffected by supplemental energy. In yr 2, a protein \times energy interaction was observed; the addition of energy at low protein levels depressed 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 (greater than 120% of NRC requirements), increasing energy typically has little effect on intake and digestibility of the low-quality roughage (Hennessy et al., 1983; DelCurto et al., 1990b).

Physical Form of Supplemental Protein

Many high-protein feedstuffs have been evaluated as supplemental protein sources, yet expressing comparative value for the different feeds remains difficult. The most common supplemental protein feed sources are derived from oilseed by-products such as soybean meal and cottonseed meal (Table 1). These sources of supplemental protein offer several advantages, including high concentrations of CP (soybean and cottonseed meal consistently have at least 50 and 45% CP, respectively) and energy densities similar to those of cereal grains. Thus, although we usually consider these as supplemental protein sources, they also provide significant energy to the diet. However, these feed sources can be expensive at times, and identifying inexpensive alternative

native feed sources that provide supplemental protein would be beneficial to ruminant livestock producers.

Other potential oilseed supplements include canola meal, sunflower meal, rapeseed meal, and crambe meal. However, little research has been conducted to evaluate their value as supplements to low-quality forages for beef cattle. Seoane et al. (1992) supplemented steers receiving a medium-quality grass hay (15.8% CP) with canola meal and found that ADG was improved by 60% and hay intake was improved by 8% compared to unsupplemented steers. Total diet dry matter digestibility was unaffected, but fiber digestion was decreased by canola meal. Coombe et al. (1987) evaluated rapeseed or sunflower meals as supplements for growing sheep grazing low-quality grass pastures. Sheep receiving no supplement or a urea supplement lost weight, whereas sheep receiving sunflower meal gained weight. Intake of rapeseed meal was low and variable, and resultant sheep performance was also variable and intermediate compared to the performance of control and sunflower meal-supplemented sheep. Crambe seed is another oilseed that provides a high-protein meal after oil extraction. Caton et al. (1994) compared crambe meal to soybean meal and found that OM and fiber digestion were similar but N digestion was greater for crambe meal, indicating that it may have higher DIP than soybean meal.

Other potential supplements include whole soybeans (Albro et al., 1993) and wheat middlings (Ovenell et al., 1991; Sunvold et al., 1991). In a study evaluating whole soybeans, extruded soybeans, and soybean meal supplements with low-quality meadow hay (6.5 % CP), feed efficiency and gain of growing steers was similar (Albro et al., 1993). Likewise, wheat middlings have been shown to improve low-quality forage utilization, but not to the same extent as isonitrogenous mixtures of soybean meal and sorghum grain (Sunvold et al., 1991) or soybean meal and corn grain (Ovenell et al., 1991).

In the Pacific Northwest and Intermountain West, alfalfa hay or cubes are often the supplement of choice because of competitive pricing and availability. Studies comparing alfalfa and alfalfa products to oilseed-based supplements have yielded variable results. 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 3). DelCurto et al. (1990c) found that sun-cured alfalfa pellets promoted higher forage intake and improved mature cow weight and body condition status compared to long-stem alfalfa hay or soybean meal/sorghum grain. Increasing levels of supplemental alfalfa often cause a quadratic effect on intake of low-quality forages (DelCurto et al., 1991; Vanzant and Cochran, 1994). Thus, total rations should be balanced, but exceeding the CP requirements with increased supplemental alfalfa will substitute for potential intake of low-quality forage. In general, these results suggest that alfalfa provides the same benefits as other protein supplements when fed on an equal CP basis (Table 1). Alfalfa hay may have an added advantage because it is easily transported and handled by ranchers, whereas oilseed supplements may re-

quire additional equipment such as feed bunks and storage bins. Furthermore, alfalfa hay has been shown to be comparable to alfalfa pellets whether fed daily or on alternate days (Brandyberry et al., 1994).

Although alfalfa is a very versatile protein supplement with easy application to many beef production scenarios, producers should be careful to make sure that energy requirements are met and body condition reserves are adequate during winter feeding periods. Although alfalfa can effectively meet CP requirements in rations with low-quality roughages, alfalfa does not have the caloric density of oilseed meals or other by-product feeds (Table 1). In fact, the energy density of alfalfa is similar to that of high-quality grass hay. Thus, if cows are energy-deficient and marginal in body condition (fat reserves), supplements with higher energy density may be more appropriate. However, alfalfa protein and energy densities may be proportionally lower than those of oilseed supplements such as soybean and cottonseed meal. Thus, the increased quantities of alfalfa needed to provide an equivalent quantity of protein compared to an oilseed supplement may provide similar or greater supplemental energy as long as the greater quantities of supplement do not negatively influence intake of the low-quality roughage.

Another potential supplement for low-quality forages is high-quality grass hay. Horney et al. (1996) suggested that high-quality fescue hay (11.9 % CP) supplementation of grass straw (4.1% CP) yielded beef cattle performance that was similar to or better than that of cows receiving alfalfa hay supplements (19% CP). Likewise, Villalobos et al. (1997) evaluated cow performance and steer digestion responses to supplementation with a 15% CP grass compared to a soybean meal and wheat grain mixture while the cattle were consuming dormant Nebraska Sandhills range forage. Both supplements improved cow weight and body condition by a similar amount over control cattle not receiving supplements. Forage intake was unaffected, but both supplements slightly depressed forage digestibility. These studies suggest that higher-quality grass hays are adequate supplements for low-quality roughages.

Use of feeds with high undegradable intake protein (UIP) or "bypass" protein is generally not a preferred strategy for supplementing low-quality roughages consumed by adult, nonlactating beef cattle. In addition, there are many factors that influence the UIP requirements of cattle and use of low-quality roughages. First, the optimal time to use low-quality roughages is the period of time between weaning and parturition. During this time, cows are most suited to utilize cheap, low-quality roughage resources because they are not lactating and thus are at the lowest nutrient requirements of their annual production cycle. Also during this time, amino acid requirements of the cow seem to be adequately met by microbial cell protein reaching the lower gut. Thus, feeds with high levels of UIP such as feather meal, corn gluten meal, blood meal, or other "bypass" supplements can be used (Alawa et al., 1986; Fleck et al., 1988), but they do not offer an advantage over less-expensive feeds with high levels of degradable intake protein (DIP) (Table 1). In fact, the NRC

(1996) beef level 1 model generally underscores that DIP is the critical CP fraction when supplementing beef cattle.

The relative successes of the numerous supplements described above illustrate the need to provide supplemental protein to beef cattle consuming low-quality, nitrogen-deficient diets. Furthermore, the general success of all physical forms of supplements (Table 3) suggests that site of protein degradation (ruminal vs bypass) is not a major consideration with the mature, nonlactating beef cow despite the suggested DIP requirements indicated by the NRC level 1 model.

Optimum Protein Concentration. Numerous researchers have evaluated different protein concentrations and protein:energy ratios with variable results in terms of providing consistent recommendations. DelCurto et al. (1990a,b) suggested that a 26% CP soybean meal-sorghum grain supplement was an optimal concentration for the intake and subsequent performance of beef cattle consuming low-quality tallgrass prairie forage compared to 13 or 39% CP supplements. In the above studies, supplements provided the same amount of energy but were somewhat confounded by source of energy, with a high starch content in the low-protein supplements. Likewise, in a study evaluating wheat middlings in 15, 20, and 25% CP supplements, Sunvold et al. (1991) suggested that 20% was best for enhancement of forage intake, whereas reduced benefits were reported at the 25% CP level. Both researchers indicated negative effects of low protein concentrations, including reduced intake and digestibility, which was presumably due to the high starch content (> 35%) of the low-protein supplements.

Optimal protein concentration of forage supplements is less easily defined. Horney et al. (1996) found that high-quality meadow hay (11.9% CP) was comparable to alfalfa hay (19.0% CP) when used as a supplement to tall fescue straw (4.1% CP). In fact, cows supplemented with meadow hay gained more weight and tended to lose less body condition than alfalfa hay-supplemented cows; this was presumably due to the greater quantity of meadow hay fed to provide similar protein levels. Likewise, Weder et al. (1999) conducted a series of experiments evaluating the influence of alfalfa hay quality on intake, forage use, and subsequent performance by beef cattle consuming low-quality roughages. Alfalfa hays ranging in quality from 15 to 21% CP did not differentially influence intake and digestibility of the low-quality basal diets or dramatically alter beef cattle weight and body condition status when fed to provide equal amounts of protein. Therefore, in an alfalfa hay market that places a premium on CP concentration, beef cattle producers should look at feeder-quality alfalfa (< 17 % CP) as a viable supplement to low-quality roughages.

Use of NPN Supplements. Nonprotein nitrogen (NPN) supplements are commonly used in both hand-fed and self-fed supplements. Compared to natural protein supplements, NPN sources are usually substantially cheaper on a unit of CP basis. Therefore, the use of NPN ingredients would yield substantial economic advantages if utilized to the same efficiency as natural protein. However, NPN has not been as effective as natural protein sources when supplemented to

cattle consuming low-quality roughages. Summarizing six experiments evaluating the efficacy 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 compared to performance of cattle receiving similar energy densities but 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 compared to isonitrogenous supplements containing urea or 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). Köster et al. (1997) substituted graded levels of urea for sodium caseinate so all supplement treatments were based entirely on DIP and were isonitrogenous but differed in ratio of NPN to true protein. Intake of dormant tallgrass prairie forage (2.4% CP) was unaffected by treatment, but ruminal and total tract digestibility of OM and NDF, as well as digestible OM intake, all declined quadratically, and the rate of decline increased as urea content increased. It should be noted that in all of the above performance studies special attention was devoted to ensuring proper sulfur:nitrogen ratios in the NPN supplements. Likewise, although the NPN supplements did not yield equal responses in terms of weight gain compared to natural protein supplements, positive responses to the improved N status were observed when comparisons were made between supplemented and unsupplemented animals.

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 associated with 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, which 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, if the ammonia absorbed into the blood exceeds the animals' ability to recycle the urea back to the rumen, some loss of nitrogen in the urine should be expected. Chalupa (1968) suggested that assimilation of ammonia by ruminal bacteria might also be limited by availability of carbon skeletons, such as branched-chain VFA, and other nutrients. Sulfur is a common nutrient suggested to affect the utilization of ruminal nitrogen due to its interrelated role in microbial cell protein synthesis. The advantage of natural protein sources, in this scenario, is that degradable proteins are broken down and deaminated, providing carbon skeletons and other essential nutrients for microbial cell protein assimilation. These results indicate that NPN might be a more viable supplement if the availability of ammonia were more closely synchronized with fermentative processes and essential nutrients for bacterial growth. Therefore, feed delivery systems that allow frequent consumption

of small amounts of supplement may be more suited to high-NPN supplements, although additional research is needed to validate this hypothesis. Additionally, the value of more-frequent delivery systems does not seem warranted when evaluating the value of less-frequent supplementation strategies of natural protein described in the next section.

Supplementation Strategies

Although some researchers have suggested that synchrony of release of nitrogen from protein supplements is an important factor for obtaining optimal ruminal digestion of low-quality roughages (Ørskov, 1982; Pritchard and Males, 1982), most studies conducted under practical conditions do not support this contention. Alternate-day, once-weekly, and daily feeding of protein supplements have yielded similar responses (Wallace, 1987; Hunt et al., 1989; Huston et al., 1999). Less-frequent supplementation, in turn, decreases labor costs and may offer other advantages. In a study by Huston et al. (1999), variation in animal weight change was decreased with less-frequent supplementation. This effect was presumably due to less competition for the supplement when greater quantities were provided in a single setting.

Research has also suggested that timing of supplementation may influence response to supplementation. Adams (1985) demonstrated greater gains of stockers when supplements were fed during nongrazing time periods. Limited data are available, however, relative to timing of supplementation and the performance of cattle grazing low-quality forages.

One strategy or goal of supplementation should be to use the most efficient delivery system to minimize costs and variation of animal intake within a group of cattle. In a recent review, Bowman and Sowell (1997) suggested that trough space, supplement allowance, supplement form, and supplement formulation all influence the variation of intake of self-fed supplements. Although most researchers suggest that self-fed supplements may have more intake variation than hand-fed supplements, Bowman and Sowell (1997) suggested that high levels of competition for the supplement (i.e., limited trough space) generally increases the proportion of nonfeeders, whereas low levels of competition, as with self-fed supplements, generally increases variation in individual supplement intake. Studies evaluating the causes of variation in supplement intake are needed with respect to both hand-fed and self-fed supplements. In particular, factors such as cow age and nutritional status (body condition) need to be evaluated in terms of relationship to supplement intake. By providing a supplement delivery system that optimizes uniformity of consumption and minimizes economic inputs, we can effectively improve beef cattle production systems.

Supplementation for Reproductive Success

Early researchers demonstrated that reproductive success in nutritionally stressed beef cattle could be improved by increased energy intake during the postpartum interval (Wiltbank et al., 1964). Furthermore, sufficient energy intake postpartum to ensure good conception was related to energy

intake before calving (Dunn et al., 1969). Selk et al. (1988) found that pregnancy rates highly correlated with changes in live body weight leading up to parturition and body condition scores at calving if body weights were maintained postpartum. However, drastic loss of weight after calving (up to 10%) increased days to onset of first estrus and decreased conception rate (Cantrell et al., 1981). Because body weight change and body condition can be manipulated more easily during pregnancy than after calving, the general strategy for supplemental feeding in beef cows is to target a BCS at calving of at least 5 (Randel, 1990) on a 9-point scale and avoid severe live body weight losses between calving and the beginning of the breeding season.

Both high-protein supplements and those low in protein but high in energy can enhance reproduction in range cattle. Feeding high-energy supplements increases energy intake directly, although forage intake and digestibility may decrease (Rittenhouse et al., 1970; Chase and Hibberd, 1987; Marston and Lusby, 1995). The net effect in many instances is higher energy intake, an increase or maintenance of body condition, and increased reproductive rate (Huston et al., 1995; Marston et al., 1995). In other instances, high substitution rates of starchy feeds for forage erase most of the benefits or cause negative effects (Bellows and Thomas, 1976; Sanson et al., 1990; Huston et al., 1993). This variation in response to high-energy supplements is well documented (Bowman and Sanson, 1996; Caton and Dhuyvetter, 1997). High-protein supplements also provide energy directly, and, in addition, increase forage intake, and thus energy intake, in cows grazing protein-deficient range vegetation (Kartchner, 1981; Hess et al., 1994; Marston and Lusby, 1995), resulting in increased reproductive performance (Clanton and Zimmerman, 1970; Bellido et al., 1981; Cochran et al., 1986).

Supplementation can be a tool to improve reproductive performance in beef cows by providing specific compounds having direct effects on reproductive processes. Monensin was reported to reduce age at puberty (Lalman et al., 1993) and increase breeding performance in beef heifers (Moseley et al., 1977), presumably as a result of a shift in the relative proportions of acetate and propionate produced during ruminal fermentation (McCarter et al., 1979). Several researchers have reported indications of improved conception rates with feeding of elevated UIP, especially in cows in marginally low states of nutrition (Wiley et al., 1991; Dhuyvetter et al., 1993; Triplett et al., 1995). However, increases in reproductive success are not apparent in all circumstances in which high levels of UIP are fed (Rusche et al., 1993; Menges, 1994) and may only relate to cows with higher nutrient requirements associated with growth and/or lactation. Lipids, especially polyunsaturated fats, when fed at high levels (> 15%) in supplements enhance follicular development (Williams, 1989) and pregnancy rates in beef cows (De Fries et al., 1998; Bellows, 1999), improve cold tolerance of neonatal calves from fat-supplemented dams (Lammoglia et al., 1999), and reduce days to conception in beef heifers (Whitney et al., 2000). These benefits apparently are separate from the value of fat as a source of energy.

Evaluation of NRC Models

The NRC (1996) Tabular System Model (NRC1) and Rumen Simulation Model (NRC2) were evaluated by comparing model-predicted ADG with observed ADG of cattle consuming forage-based diets (Table 4). This evaluation only included data published in the *Journal of Animal Science* from studies that were conducted in the western United States in which intake and ADG data were collected from the same animals. Predicted and observed ADG were determined from data reported for replacement heifers (Whitney et al., 2000), steers fed in confinement (Hunt et al., 1989; Albro et al., 1993), and steers consuming pasture (Adams, 1985). Reported forage and supplement composition was used in model evaluations when available. Complete descriptions of forage or supplement protein fractions and degradability were not provided in the studies used in the evaluation. Estimated (NRC, 1996) composition of forage and individual supplement ingredients was used when these data were not reported. Microbial efficiency was set at 11% of TDN intake (NRC1) as suggested by Patterson et al. (1996) in their review of the literature on DIP requirements of cattle consuming forages. Default values for environmental conditions were used for both models unless this information was described in the research publications.

Model evaluations (NRC1 or NRC2) were made by determining the square of Pearson correlation coefficients within and across studies. Each resulting R^2 was interpreted as the ability of the model to predict ADG, or the proportion of variance in observed ADG that could be accounted for by the NRC1 or NRC2 model.

Considering data from all of the studies in the evaluation, the NRC2 model predicted ADG better than the NRC1 model ($R^2 = .32$, $P = .02$ vs $R^2 = .03$, $P = .49$). Although none of the evaluations was statistically significant ($P \geq .71$), the NRC2 model accounted for a greater proportion of the variation in observed ADG than NRC1 for both data sets of Whitney et al. (2000). Prediction of ADG by both models was improved with the exclusion of the replacement heifer data set ($R^2 = .56$, $P = .007$ for NRC1; $R^2 = .49$, $P = .02$ for NRC2). The NRC1 model accounted for more of the variation than NRC2 when evaluating only the steer data sets, largely due to lower predictability of NRC2 for two of the three steer data sets. For the grazing steer data of Adams (1985), the NRC2 model accounted for 42% of the variation ($P = .55$), whereas the NRC1 model accounted for 96% of the variation ($P = .14$) in observed ADG. The NRC1 model also accounted for approximately 10% more of the variation in observed ADG than the NRC2 model ($P = .04$ vs $.07$) for the data of Albro et al. (1993).

With the exception of the replacement heifers, each of the two models often accounted for a reasonably large proportion of variation in observed ADG. Differences in the ability between the two models to predict ADG are likely attributed to quality of input variables necessary for adequate outputs. The underlying premise of each of the models is that the user provides appropriate descriptions of the animals, environment, and diet. Although actual dietary chemical and nutrient

composition was used for our evaluation when possible, none of the cited studies provided complete descriptions of the dietary ingredients' specific components. This was particularly the case for forage protein and carbohydrate fractions and degradability, which are required to operate the NRC2 model. Thus, we relied on NRC (1996) estimates to run the models. This is perhaps problematic because forages grown in the western United States are grossly underrepresented in the NRC (1996) feed composition tables.

In addition to inadequate data for input variables, many other problems were encountered when reviewing the literature that precluded the inclusion of several studies in this evaluation. For example, many studies reported intake by animals that were a different sex or physiological type than the animals used in performance trials. Other major difficulties precluding evaluation included mixing of animals with different nutrient requirements (e.g., effects of dietary treatment were not separated for primiparous and multiparous cattle); reporting overall effects rather than partitioning dietary effects into different stages of production (i.e., late pregnancy vs lactation); and changing basal diets and/or providing supplemental feeds to animals before terminating the study (e.g., provision of supplemental feed may have occurred 30 d before the completion of a 90-d trial).

Beef cattle researchers are encouraged to recognize the potential pitfalls in using their data for evaluation of NRC models. We suggest that efforts be made to increase the value of research trials to make future improvements to the NRC by including complete descriptions of animal factors, environment conditions, and diets.

Summary

Numerous supplements are available that will provide protein to beef cattle consuming low-quality roughages. The "ideal supplement" is one that best fits the target animal's nutritional needs, is easiest to handle and present to the target animal, and is most economical to purchase and feed. Obviously, many supplements may be appropriate in specific situations. Although oilseed supplements are the most common supplements used with low-quality forages, numerous other supplements such as alfalfa, wheat middlings, and high-quality meadow hays can be used effectively. Protein supplementation is critical to the optimal use of low-quality roughages, yet energy content or density may be important, depending on body condition status, and can affect subsequent reproductive success of the cow herd.

Implications

In general, natural protein seems to be the most beneficial supplement for high-fiber, low-quality roughages in ruminant diets. Nonprotein nitrogen does not seem to be as beneficial as natural protein supplementation. However, the differences in response can be minimized and, nonprotein nitrogen can offer economic advantages over natural protein. Furthermore, feeding of slowly degraded or bypass protein, as well as potentially "rate-limiting" amino acids, yields inconsistent

responses and does not seem to provide any substantial improvements over traditional supplemental protein sources when used with mature, nonlactating beef cows consuming low-quality roughages. Further research is needed, however, to continue refining optimum supplement strategies and effectiveness of supplement strategies in terms of reproductive performance and ultimately profitability.

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Notes

1. Oregon State Univ. Agric. Exp. Sta. Special Rep. 11691.
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3. Publication is a cooperative effort of the Western Coordinating Committee 110 "Improving Ruminant Use of Forages in Sustainable Production Systems for the Western US."

Table 1. Chemical composition of some feed ingredients with potential for use as supplemental protein for low-quality forages^a

Protein source	CP, %	DIP, %	UIP, %	TDN, %	ME, Mcal/kg
Brewers grain	26.0	40.9	59.1	70.0	2.53
Canola meal	40.9	67.9	32.1	69.0	2.49
Coconut meal	21.5	61.6	38.4	64.0	2.31
Corn gluten meal	46.8	38.1	61.9	84.0	3.04
Cottonseed meal, mech	44.0	57.0	43.0	78.0	2.82
Cottonseed meal, sol-41% CP	46.1	57.0	43.0	75.0	2.71
Cottonseed meal, sol-43% CP	48.9	57.0	43.0	75.0	2.71
Distillers grain	29.7	45.1	54.9	90.0	3.25
Soybean meal-44	52.9	80.0	20.0	84.0	3.04
Soybean meal-49	49.9	65.0	35.0	87.0	3.15
Soybean whole	40.3	65.0	35.0	94.0	3.40
Sunflower meal	25.9	38.3	61.7	65.0	2.35
Urea	291.0	100.0	0.0	0.0	0.00
Alfalfa hay, vegetative	21.7	86.0	14.0	64.0	2.31
Alfalfa hay, early bloom	19.9	84.0	16.0	62.0	2.24
Alfalfa hay, mid bloom	17.0	82.0	18.0	60.0	2.17
Alfalfa hay, full bloom	13.0	77.0	23.0	56.0	2.02
Wheat middlings	18.4	77.2	22.8	83.0	3.00
Tall fescue hay	9.1	67.0	33.0	56.0	2.02
Meadow hay	13.4	77.0	23.0	60.0	2.17

^aAdapted for the NRC (1996) *Nutrient Requirements of Beef Cattle*.

Table 2. A summary of investigations comparing supplementation strategies with low-quality roughages: Effect on beef cattle weight change, body condition (BC) change, and reproductive efficiency^a

Reference	Forage or substrate	Supplement treatments	Class of livestock	BW change	BC change	Supplementary information
Cochran et al., 1986	Dormant mixed-grass prairie forage 3.0-6.5% CP. Feeding period: 84 d, yr 1; 98 d, yr 2	1) Control, no suppl.	517-kg pregnant cows (n = 151)	-11	-0.5	Quantities of supplement provided were adjusted to ensure equal portions of CP
		2) Alfalfa cubes, 16.5% CP		24	.5	
		3) Cottonseed meal/barley cake, 21.6		14	0	
DelCurto et al., 1990b	Dormant tallprairie forage Feeding period: mid-November to early February (84 d)	1) 13% CP suppl. fed @ .5% BW	454-kg pregnant cows (n = 99)	-11	-0.7	Supplements were isocaloric mixtures of soybean meal and sorghum grains. Tendency for increased birth weights and calf ADG with dams that received high concentrations of supplemental protein
		2) 26% CP suppl. fed @ .5% BW		12	-0.4	
		3) 39% CP suppl. fed @ .5% BW		17	-0.2	
DelCurto et al., 1990c	Dormant tallprairie forage Feeding period: mid-November to early February (84 d)	4) 25% CP SBM/sorghum suppl. @ .48% BW	488-kg pregnant cows (n = 84)	-3	-0.4	Quantities of supplements provided were adjusted to ensure isonitrogenous treatments. No reproductive differences were observed.
		5) 17% CP alfalfa hay fed @ .7% BW		2	-0.5	
		6) 17% CP dehydrated alfalfa pellets fed @ .7% BW		19	-0.3	
Judkins et al., 1987	Dormant blue grama range, 11.5% CP. feeding: mid-February to late April (104 d)	1) Control, no suppl.	241-kg heifers	-3	—	Quantities of supplements provided were adjusted to ensure isonitrogenous treatments.
		2) Cottonseed meal (47%) fed alternate days @ 1.7 kg/animal		25	—	
		3) Alfalfa hay (17.5% CP) fed alternate days @ 3.6 kg/animal		24	—	
Wallace, 1987	Dormant blue grama range, 9.6% CP. Feeding period: mid-December to mid-May (150 d)	1) Cottonseed cake (41% CP): 3.2 kg 2x weekly	227-kg heifers	34	—	Heifers receiving cottonseed cake were heavier at breeding and had greater conception rates.
		2) Corn grain cube (9.4% CP): 2.91 kg 2x weekly		-2	—	
		3) Corn grain cube (9.4% CP): 83 kg daily		10	—	
DelCurto et al., 1991	Dormant sagebrush-steppe rangelands: Year 1: 6.8 to 5.4% CP, 112-d feeding period	1) Control, no suppl.	463-kg pregnant cows (n = 48) (5.3 BC)	-30	-1.2	Calf ADG and birth weight tended 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.
		2) 1.5 kg alfalfa· animal ⁻¹ · d ⁻¹		9	-1.2	
		3) 3.0 kg alfalfa· animal ⁻¹ · d ⁻¹		30	-0.1	
		4) 4.5 kg alfalfa· animal ⁻¹ · d ⁻¹		44	.2	
	Year 2: 4.2 to 4.8% CP, 70-d feeding period	1) Control, no suppl.	471-kg pregnant cows (n = 72) (5.3 BC)	-62	-2.1	Calf ADG and birth weight were increased with 3.0 and 4.5 kg suppl. treatments. All cows were individually fed supplements during 70-d feeding period.
		5) 1.5 kg alfalfa· animal ⁻¹ · d ⁻¹		-15	-0.8	
		6) 3.0 kg alfalfa· animal ⁻¹ · d ⁻¹		5	-0.2	
		2) 4.5 kg alfalfa· animal ⁻¹ · d ⁻¹		11	.2	

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

Table 3. A summary of investigations comparing supplementation strategies with low-quality roughages: Effect on intake and digestion^a

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 suppl.	242-kg steers	.87	.87	35.5	37.9	Isocaloric supplement fed at .4% BW	
		2) 13% CP suppl.		.85	1.27	44.8	29.9		
		3) 26% CP suppl.		1.36	1.76	48.4	39.9		
		4) 39% CP suppl.		1.21	1.62	48.8	38.6		
Sanson et al., 1990	Sanhills 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 suppl.		2.1	2.3	56.7	52.7		
		3) 24.5% CP suppl.		2.0	2.4	59.2	51.1		
		4) 16.0% CP suppl.		1.6	2.2	60.0	49.5		
Sunvold et al., 1991	Dormant tallgrass prairie hay (2.0% CP)	1) Control, no suppl.	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 suppl.		1.12	1.49	49.3	51.2		
		3) 20% CP suppl.		1.62	1.99	48.8	53.2		
		4) 25% CP suppl.		1.70	1.07	49.8	55.5		
DelCurto et al., 1990a	Dormant tallgrass prairie hay (2.6% CP)	1) 22% CP suppl. fed @ .3% BW	332-kg steers	1.21	1.51	39.1	49.2	2 × 2 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 suppl. fed @ .6% BW		.82	1.42	46.1	44.3		
		3) 44% CP suppl. fed @ .3% BW		1.07	1.37	45.9	50.9		
		4) 22% CP suppl. fed @ .6% BW		1.51	1.75	47.5	48.0		
			1) 22% CP suppl. fed @ .3% BW	401-kg steers	1.30	1.60	—		—
			2) 11% CP suppl. fed @ .6% BW		1.17	1.77	—		—
			3) 44% CP suppl. fed @ .3% BW		1.71	2.01	—		—
			4) 22% CP suppl. fed @ .6% BW		1.49	1.09	—		—
McCollom and Galyean, 1985	6.1% CP prairie hay	1) Control, no suppl.	214-kg steers	1.69	1.69	49.9	—	Early rates of in vitro digestion were improved with supplementation. Digesta kinetics was increased with supplementation.	
		2) Cottonseed meal, .8 kg/d (.37% BW)		2.15	2.52	53.5	—		

B. Physical form of supplemental protein

DelCurto et al., 1990c	Dormant tallgrass prairie hay (2.6% CP)	1)	Control, no suppl.	259-kg	.49	.49	42.7	57.3	Supplemental treatments provided equal quantities of ME and crude protein
		2)	Soybean meal/sorghum grain @ .48% BW.	steers	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 suppl.	230-kg	1.08	1.08	—	—	Quantities of supplemented feed were adjusted to be isonitrogenous
		2)	23% CP alfalfa pellets	steers	.77	1.41	—	—	
		3)	47.7% CP cottonseed cake		.96	1.29	—	—	
Sunvold et al., 1991	Dormant tallgrass prairie hay (2.4% CP)	1)	Control, no suppl.	374-kg	.87	.87	43.9	54.3	Treatments 2 & 3 provide equal energy levels
		2)	Soybean meal/sorghum grain fed at .32% BW	steers	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., 1988	Blue grama rangelands 8.1% CP (OM basis)	1)	Control, no suppl.	Hereford × Angus	.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)	454-kg steers	1.16	1.34	49.6	3.4%/h	
Judkins et al., 1987	Blue grama range (11.5%)	1)	Control, no suppl.	230-kg steers	1.08	1.08	—	—	Quantities of supplemented feed were adjusted to be isonitrogenous
		2)	23% CP alfalfa pellets		.77	1.41	—	—	
		3)	47.7% CP cottonseed cake		.96	1.29	—	—	
Kartchner, 1981	Winter range forage: Blue grama range 6.0% CP – Year 1	1)	Control, no suppl.	458-kg	1.89	1.89	54.9	54.9	Differences between yr 1 and 2 were attributed to severity of weather and limited availability of forage in yr 2
		2)	1.5 kg cottonseed meal fed on alternate days	nonlactating, pregnant Hereford	1.78	1.94	53.2	52.9	
		3)	1.4 kg barley fed alternate days	cows	1.71	1.86	54.2	51.7	
	1)	Control, no suppl.	497-kg	1.37	1.37	40.6	40.6		
	2)	1.5, 1.5 and 2 kg SBM fed Monday, Wednesday, and Friday, respectively	nonlactating, pregnant Hereford	1.61	1.75	46.4	48.6		
	3)	1.3, 1.3 and 2 kg barley	cows	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.

Table 4. Observed vs NRC-predicted BW change (kg/d) of investigations comparing supplementation strategies of western forages

Reference	Study description	Dietary treatment	Class of livestock	BW change	NRC1 ^a predicted BW change	NRC2 ^b predicted BW change	NRC1 R ² ^c , P ^d	NRC2 R ² , P		
Whitney et al., 2000	Limit-fed bromegrass hay-based diet individually for 104 d	Fed @ 2.87% of BW; contained 19.0% corn and 5.9% soybean meal (CON)	260-kg (initial BW) replacement heifers (n = 36)	.81	1.47	.77	.002, .97	.01, .92		
		Fed @ 2.7% of BW; contained 12.2% corn, 6.6% soybean meal, and 3.1% soybean oil (OIL3)		.91	1.41	.84				
		Fed @ 2.56% of BW; contained 4.1% corn, 7.5% soybean meal, and 6.5% soybean oil (OIL6)		.79	1.37	.90				
	Limit-fed bromegrass hay-based diet group fed on a limited basis for 90 d	CON	289-kg (initial BW) replacement heifers (n = 42)	.72	1.50	.78			.11, .79	.19, .71
		OIL3		.69	1.45	.87				
		OIL6		.71	1.40	.93				
Albro et al., 1993	Mature, native cool-season grass hay available ad libitum for 112 d; feed refusals were collected		250-kg (initial BW) weanling steer calves (n = 40)	.40	.37	.22	.96, .02	.86, .07		
		Hay + 1.4 kg whole soybeans		.99	.91	.93				
		Hay + 1.3 kg extruded soybeans		1.10	.89	.81				
		Hay + 1.3 kg 62% soybean meal and 38% barley		1.10	1.03	.66				
		Hay only		.74	.70	.73				
Hunt et al., 1989	Chopped grass hay fed individually using electronic gates (91 d)		297 kg (initial BW) steers (n = 24)	.92	1.03	.66	.92, .04	.90, .04		
		Hay only		.74	.70	.73				

Adams, 1985	Russian wild ryegrass was grazed for 84 d and intake was estimated via total fecal collection	291 kg (initial BW) yearling steers (n = 18)	Hay + 850 g cottonseed meal/d delivered over a 12-h interval	.96	.95	.93		
			Hay + 850 g cottonseed meal/d delivered over a 24-h interval	.88	.95	.93		
			Hay + 850 g cottonseed meal/d delivered over a 48-h interval	.99	1.04	.99	.96, .14	.42, .55
			Grazed forage only	.62	.88	.61		
			Forage + supplemental corn @ .3% of BW in the a.m.	.62	.90	.77		
			Forage + supplemental corn @ .3% of BW in the p.m.	.82	.97	.81		

^aTabular System Model of the NRC (1996) assuming an 11% microbial efficiency (Patterson et al., 1996).

^bRumen Simulation Model of the NRC (1996).

^cWithin study R² was determined as the square of Pearson correlation coefficients.

^dObserved significance level of the simple correlation.

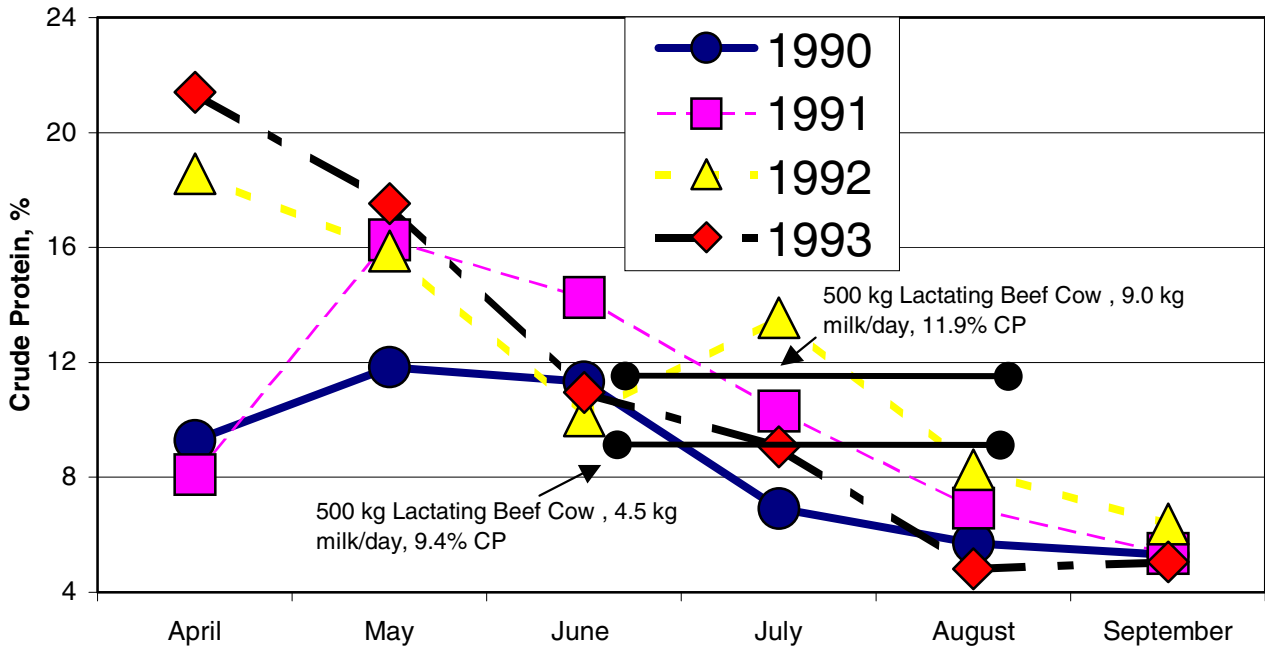


Figure 1. Crude protein content of diets selected by cattle grazing Northern Great Basin native rangelands (DelCurto, unpublished data). Crude protein content displayed a year \times month interaction ($P < .05$). Standard errors averaged across years were .56, .52, .40, .43, .20, and .23 for April, May, June, July, August, and September collections, respectively.