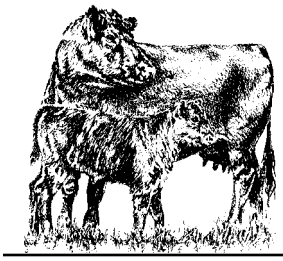

Western Beef Resource Committee *Fourth Edition*

Cattle Producer's Handbook

Nutrition Section 328

Supplementation of Beef Cattle Consuming Forage-Based Diets

David Bohnert, Associate Professor, Eastern Oregon Agriculture Research Center Oregon State University, Burns

Clay Mathis, Director & Endowed Chair, King Ranch Institute for Range Management, Kingsville, TX

Forages represent the predominant class of feed for beef cattle operations. Due to differences in plant variety, stage of maturity, and management practices, forages vary significantly with respect to quality parameters such as dry matter (DM) digestibility, crude protein (CP) concentration, and palatability. Also, most ruminants consume low-quality forages for extended periods during the year. To meet the nutritional needs of these animals, supplementation is often provided to increase forage intake and digestibility, weight gain, and reproductive performance.

Supplementation can be expensive; consequently, a reoccurring problem faced by beef producers is when, and with what, to supplement forages. The answer depends on a number of variables including the physiological state of the cattle, the nutrients required for a desired level of production, the nutrient content of the forage, the quantity of forage available, ranch infrastructure and facilities, and management objectives. The nutrient requirements of beef cattle are well documented and readily available to producers (see fact sheet 300). A supplementation program can be defined as a program that provides a portion or all of the difference between the nutrients required by the cattle and the nutrients provided by the forage.

Is Supplementation Necessary?

The first step in preparing a supplementation program is to determine if supplementation is necessary. This involves obtaining an estimate of forage quality, which can be obtained from historical records, observation and experience, or, preferably, from analysis of a representative sample of the forage source to be used (pasture, hay, etc.). Once this information has been collected, along with animal nutrient requirements, a beef producer can determine if supplementation is necessary to meet an expected level of performance (see 310). This will assist in minimizing the chance of over- or under-feeding supplemental nutrients; thereby, reducing supplementation costs and/or improving the efficiency of the supplementation program.

Protein Supplementation

Type of Protein Supplement

Protein supplements can be classified as natural (animal or plant origin) or non-protein nitrogen (NPN), such as urea and biuret. In addition, CP is divided into rumen degradable protein (RDP) and rumen undegradable protein (RUP). Rumen degradable protein is broken down within the rumen by ruminal microorganisms to yield ammonia and amino acids that they use to stimulate ruminal fermentation and synthesize microbial protein (the main source of protein for grazing ruminants). Rumen undegradable protein is not broken down by ruminal microorganisms and "escapes" ruminal degradation for potential enzymatic degradation in the small intestine.

Because ruminants have the ability to recycle nitrogen back to the rumen, absorbed RUP not utilized for growth or production can be converted to urea and used as a source of RDP. Therefore, microbial protein and dietary RUP are the protein sources available for use by the ruminant.

When forage availability is not limiting, the first priority in designing a protein supplement should be meeting the requirement for RDP. The reasons for this include: (1) ruminal microorganisms can use RDP to produce microbial protein; (2) sources of RDP are normally less expensive than RUP sources; (3) RDP may improve ruminal fermentation and digestion; and (4) RUP supplementation of low-quality forage does not appear to elicit substantial improvements in beef cattle performance compared with RDP.

Once the ruminal requirement for RDP is met, additional RDP will not increase microbial protein production or enhance ruminal fermentation. The microbes in the rumen will still break it down so it will not be available in the small intestine. Therefore, if additional protein is still required to obtain a desired level of production, it must be supplied by RUP.

Physical Form of Protein Supplement

The most common sources of supplemental protein are derived from oilseed byproducts such as soybean meal and cottonseed meal. These sources of supplemental protein offer several advantages, including a high concentration of CP (i.e., soybean and cottonseed meal consistently have at least 50 and 45 percent CP, respectively) and energy densities similar to cereal grains. Thus, while we usually consider these supplements as protein sources, they also provide significant energy contributions.

Byproduct feeds, such as distiller's grains and wet corn gluten feed, can also be effective sources of supplemental CP. Many byproduct feeds can be obtained at competitive prices but consistency of product, mineral imbalances, and hauling/storage/feeding issues need to be considered when developing a supplementation program with these feedstuffs.

Other common feedstuffs utilized as CP supplements include alfalfa hay or cubes and sources of nonprotein nitrogen (NPN), such as urea or biuret. In the western states, alfalfa is often the supplement of choice because of competitive pricing and accessibility. In general, alfalfa provides the same benefits as other protein supplements when fed on an equal CP basis. Alfalfa hay may have an added advantage because it is easily transported and handled by beef producers, whereas oilseed and byproduct supplements may require additional equipment such as feed bunks and storage bins. While alfalfa can effectively meet CP requirements in rations with low-quality roughages, alfalfa does not have the caloric density of most other feedstuffs commonly used as sources of supplemental CP.

Sources of NPN are attractive as CP supplements because of their high concentration of nitrogen (i.e., urea is 46.6 percent nitrogen) and relatively low-cost when compared per unit of nitrogen. However, concerns associated with the use of NPN include the potential inefficient use of nitrogen, toxicity issues, and reduced intake due to poor palatability.

Natural vs. NPN Supplementation

An obvious advantage of NPN sources over natural proteins is cost. Sources of NPN are usually less expensive than sources of natural protein (on a CP basis). Ruminal microorganisms can effectively use NPN as a nitrogen source in the production of microbial protein, which is the principle source of protein for ruminants consuming forage-based diets; however, when microbial protein production is not limited by ruminal nitrogen availability, sources of natural protein are superior to sources of NPN as a CP supplement.

Research with growing ruminants has demonstrated that NPN, primarily urea, is not as effective as natural protein when used as a CP supplement if the protein requirement for expected gains exceeds the RDP requirement (Raleigh and Wallace 1963; Pate et al. 1995). Nevertheless, most data indicate that mature ruminants consuming low-quality forage (< 7% CP) can use NPN as effectively as sources of natural protein (Farmer et al. 2004; Cooke and Arthington 2008) as long as the proportion of NPN does not exceed 30 percent of the supplemental CP. More specific information on using NPN in supplements for ruminants can be found in fact sheet 322.

Intake Response

The most consistent response to protein supplementation of low-quality forages is increased intake—frequently by as much as 40 percent or more (Mathis and Sawyer 2007). In addition, protein supplementation either slightly increases or maintains the digestibility of low-quality (<7% CP) forages. As a result, the total quantity of digestible nutrients available to the animal for maintenance, reproduction, lactation, and growth is increased. This is based on the premise that forage quantity is not limiting, thereby, allowing the animal to increase forage intake.

Nevertheless, most if not all of the research used in developing the aforementioned recommendations was conducted with low-quality, warm-season (C4) forages. Despite agronomic research evaluating physiological differences between C4 and cool-season (C3) grasses, and nutritional research demonstrating the advantages of CP supplementation of ruminants consuming low-quality forage, data comparing utilization of low-quality C3 and C4 grasses by ruminants is limited. The research that is available suggests that CP supplementation of ruminants consuming low-quality C3 forages does not increase forage DMI in a manner similar to that observed with C4 forages (Mathis et al. 2000; Bohnert et al. 2002a,b).

Recent work (Bohnert et al. 2011) implies that, before supplementation, intake of C3 forages is greater than C4 forages and the forage intake increase in response to CP supplementation is minimal, if at all, with C3 compared to an increase of 40 percent or more with C4. This is most likely because of increased RDP and digestibility for low-quality C3 compared with C4 forages of similar CP concentration (Bohnert et al. 2011).

This research, however, should not be construed to mean that CP supplementation of low-quality C3 forages is not beneficial. Cow performance is still improved with CP supplementation of C3 forages compared with non-supplemented controls (Bohnert et al. 2002b).

Performance Response

Protein supplementation of beef cattle consuming low-quality forage normally results in increased performance. Mature cows lose less weight and/or body condition during the winter grazing or feeding period when supplemented compared with those not receiving a CP supplement (Clanton and Zimmerman 1970). As a result, protein supplementation tends to promote greater reproductive efficiency (Sasser et al. 1988). In addition, CP supplementation of growing cattle consuming low-quality forage routinely improves weight gain compared with non-supplemented controls (Bodine et al. 2001).

Supplement Delivery Method

Critical to the success of a supplemental feeding program is selecting a delivery method that will provide a desired amount of feed to the herd while minimizing the variability in supplement intake among individuals within the herd. Therefore, choosing a delivery method is an important consideration in developing an effective supplementation program. The time and labor available to the beef producer, as well as pasture size, pasture topography, distance to the pasture, number of animals, and management objectives must also be considered when selecting a delivery method. For this discussion, supplement delivery methods are classified as either hand-fed or self-fed.

Hand-Fed—Hand feeding allows the beef producer to control the amount of supplement provided to the cattle. However, there is little control over individual supplement intake. Hand feeding daily allows aggressive animals (usually older and more dominant) to consume disproportionately greater amounts of supplement compared with those that are more submissive. Data indicate that providing approximately 3 feet of trough or feeding space per animal can minimize the effects of dominant animals. Less space excludes some animals from consuming supplement and more space appears to increase the impact of aggressive animals (Wagnon 1965). These authors noted that when more than 3 feet of feeding space per cow was allowed, dominate cows fought and chased sub-dominate cows away from the trough and spent less time eating.

Self-Fed—The primary advantages of self-fed supplements (such as liquid, blocks, and tubs) include ease of application, minimal investment in equipment, and a relatively low labor requirement. Self-fed allows continuous access by animals to supplement, thereby decreasing competition and potentially the number of non-consumers. However, variation in supplement intake can be as great, or greater than, with hand-fed supplements.

Research with self-fed supplements has demonstrated a large degree of variation in individual animal intake (Bowman et al. 1999). In addition, most self-fed supplements are more expensive than hand-fed supplements when expressed per pound of supplemental CP. Consequently, the "cost of convenience" should be calculated and considered when deciding to use self-fed or hand-fed supplements.

The cost per pound of CP for each supplement should be calculated in addition to the cost of associated delivery equipment. The resulting monetary difference between self-fed and hand-fed supplements can be considered the "cost of convenience."

Hand-Fed vs. Self-Fed—Pasture size and accessibility, number of animals in the herd, and the available time, labor, and equipment will dictate which supplement delivery method is most appropriate for an individual program. Delivery method is not as important in small pastures or holding facilities as in extensive situations. This is because pasture topography and site of supplementation have less effect on grazing distribution and grazing time.

Daily hand feeding, however, may affect grazing activity by decreasing grazing time and impairing the ability to uniformly graze the entire pasture. Either self-feeding or infrequent hand feeding may reduce the anticipation of being fed and encourage longer grazing times, thereby improving livestock distribution and forage utilization. Additionally, research has shown cattle can be lured to areas of underutilized rangeland by strategic placement of self-fed supplements.

Frequency of Supplementation

Supplementation of CP to beef cattle consuming low-quality forage is an accepted practice, however, the labor involved in dispensing the supplement can be a major expense. A means of decreasing these labor costs is infrequent supplementation (Table 1). This normally does not mean less of a nutrient is supplemented; the total quantity of nutrient supplemented each week should remain the same.

Daily protein supplementation of cattle grazing low-quality forage is an effective means of improving for-

Table 1. Estimated fuel and labor costs associated with daily, alternate-day, once every 3 days, and once every 7 days supplement feeding for a 30-day interval.

	Supplementation interval			
Item	**Daily**	**2 days**	**3 days**	**7 days**
Fuel cost[a]	$360	$180	$120	$51
Labor cost[b]	$630	$315	$210	$90
Total costs	$990	$495	$330	$141
Cost reduction	--	50%	67%	86%
Benefit	--	$495	$660	$849

[a]Fuel costs calculated as 3 gallons/supplementation day at $4/gallon.

[b]Labor calculated as 2.5 hours/supplementation day at $8.40/hour.

age utilization and animal productivity. However, because ruminants have the ability to "recycle" absorbed nitrogen back to the rumen, infrequent CP supplementation is an option to consider when designing a CP supplementation program. Research has demonstrated that supplementing as infrequently as once every 7 days can be an effective means of providing protein to ruminants without adversely affecting animal performance (Huston et al. 1999; Bohnert et al. 2002b; Schauer et al. 2005).

Other studies have shown less variation in animal weight change and supplement intake with less frequent supplementation. These effects are attributed to less competition for the supplement when greater quantities are provided in a single feeding (Huston et al. 1999).

Infrequent feeding of a CP supplement can be an acceptable and safe practice. However, extreme caution should be used with infrequent supplementation of NPN (e.g., urea) due to a lack of related research and the problems associated with overfeeding non-protein nitrogen (urea toxicity).

Supplementation to Modify Grazing Distribution

In certain situations, the primary role of a CP supplement is not to improve animal performance. For example, strategic placement of a CP supplement can lure cattle to areas of a pasture infrequently grazed, thus potentially improving grazing distribution. One study evaluated the ability of strategically placed low-moisture molasses blocks (30% CP) to attract cows to underutilized rangeland and improve grazing distribution (Bailey and Welling 1999). Molasses blocks were moved every 7 to 10 days to areas normally not grazed because of rough terrain and/or distance from water. Grass utilization within 200 yards of supplement was increased by up to 20 percent compared with the same area before supplement placement. In contrast, areas of similar terrain and distance from water, with no molasses block present, were found to have no evidence of grazing after a similar period of time.

Other studies by the same research group demonstrated that strategic placement of low-moisture blocks could lure cattle to higher elevations and cause them to cover more pasture each day, resulting in more activity (less time resting; suggesting increased grazing time) compared to cattle not receiving low-moisture blocks (Bailey et al. 2008).

Supplement placement can also entice cattle to move from riparian areas to uplands, which can help improve grazing distribution and conserve riparian vegetation (George et al. 2008). Consequently, strategic placement of a CP supplement is an effective method to attract cattle to typically non- or under-utilized locations within a pasture, thereby increasing the total usable area of rangeland pastures. This potentially increases AUMs available to the beef producer while improving pasture utilization, grazing management, and minimizing the environmental impact of grazing in pastures with riparian areas.

Energy Supplementation

Supplemental energy is required when energy availability from grazed forages is inadequate for expected performance. Also, energy-based supplements containing sufficient amounts of protein have been shown to improve the performance and reproductive efficiency of mature cows and developing heifers (Mass 1987). Similar to protein sources, there are numerous energy ingredients that can be supplemented to beef cattle.

This fact sheet will discuss energy-dense feedstuffs that yield different ruminal volatile fatty acid profiles, more specifically ingredients that favor propionate synthesis (starch-based; corn, wheat, barley, etc.) compared to those that favor either acetate of butyrate (fiber-based; beet pulp, soy hulls, distillers grains, wheat mids, etc.). This is of extreme importance given that propionate synthesis is directly associated with circulating levels of glucose, insulin, and IGF-I in beef cattle, each being imperative for optimal reproductive function of beef females (Wettemann et al. 2003).

One research group reported that replacement beef heifers offered diets based on starch (favors propionate synthesis in the rumen) had hastened puberty attainment compared to cohorts fed diets based on digestible fiber (favors acetate synthesis in the rumen) (Ciccioli et al. 2005). Therefore, when supplemental energy is required, ingredients that promote rumen propionate synthesis should be considered to optimize reproductive performance. However, caution should be adopted to prevent ruminal disorders and potential decreases in forage intake/utilization when feeding supplemental energy to cattle, particularly with feeds containing elevated starch and/or fat.

Frequency of Supplementation

In contrast to protein supplements, decreasing the supplementation frequency of energy-based feeds to cattle consuming low-quality forages has been shown to be detrimental to animal performance (Kunkle et al. 2000). With high-starch supplements, forage-fed cattle supplemented daily experience improved performance compared to cohorts supplemented infrequently, mainly due to improved ruminal function and forage intake by daily-fed cattle. The same rationale can be applied to energy supplements containing high concentrations of fats (Cooke et al. 2011)

High-starch supplements, provided at greater than 0.5 percent of body weight, can have negative effects on rumen health and forage intake and digestibility in cattle consuming low-quality forages even if offered daily (Bowman and Sanson 1996). This negative im-

pact is associated with decreased ruminal pH and activity of cellulolytic enzymes, impaired bacterial attachment to fibrous material, and an increase in lag time for digestion. In contrast, energy supplements based on low-starch ingredients, such as fibrous by-products, can be fed up to 0.8 percent of body weight without negatively affecting ruminal fermentation and forage intake (Garcés-Yépez et al. 1997).

A recent study demonstrated that forage-fed heifers offered supplements based on distillers grains daily or on alternate days had similar forage intake, rumen pH, and in situ NDF disappearance (Loy et al. 2007). These authors concluded that low-starch energy supplements can be offered infrequently to cattle without impairing forage intake and digestibility. However, other research with replacement heifers consuming low-quality forage and provided an energy supplement (soybean hulls-based; weaning until the end of the first breeding season) daily had improved growth rates, hastened puberty attainment, and greater pregnancy rates compared to cohorts supplemented three times weekly (Fig. 1) (Cooke et al. 2008). Therefore, energy supplements, independent of the ingredients used (starch, digestible fiber, or fat sources), should be offered daily in order to optimize performance and reproductive efficiency of beef females consuming low-quality forages.

Rumen Fermentation Modifiers

Rumen fermentation modifiers, as the name implies, alter microbial fermentation in the rumen. Their primary purpose is to increase the quantity of energy obtained from feed consumed by cattle. Products currently approved for use in beef cattle consuming a forage diet include Rumensin® (monensin), Bovatec® (lasalocid), and GAINPRO™ (bambermycin). Each of these products is commonly used to improve the feed efficiency (normally 15 to 20 percent) and/or weight gain of cattle. Gain of steers and heifers on pasture has been improved by approximately 0.15 to 0.20 pound per head daily when one of the ruminal fermentation modifiers mentioned above is included in a supplement.

Each of the products is considered a medicated feed with specific feeding clearances and regulations administered by the FDA. In addition, each has various label claims and is available in different forms of feed. Therefore, the cattle producer who uses these products has the responsibility of using them properly. This includes (1) using the feed additive for its intended purpose, (2) following the feeding guidelines and any warning statement on the label, and (3) storing the feed properly.

Vitamins, Minerals, and Fats

Specific information concerning vitamin (381), mineral (315 and 327), and fat (325) supplementation is available in other fact sheets within the Cattle Producer's Handbook.

Conclusion

Numerous supplementation strategies are available to increase animal performance and improve the utilization of forages. The "ideal" supplement is one that best fits the target animals' nutritional needs, is easiest to handle and present to the target animals, and is the most economical to purchase and feed. However, no specific supplementation program is perfect for everyone.

Supplementation strategies will vary from one operation to the next depending on the quantity of forage available, the availability of feedstuffs, labor and equipment, the size, extent, and type of operation, and the desired goals of the beef operation. Thus, a supplementation program should be tailored to the conditions of a particular ranch for a particular year with careful consideration of the desired goals and objectives.

The success of a supplementation program will be influenced by variation in supplement intake, how well overall supplement intake meets projected supplement consumption, and the costs of supplementation (e.g.,

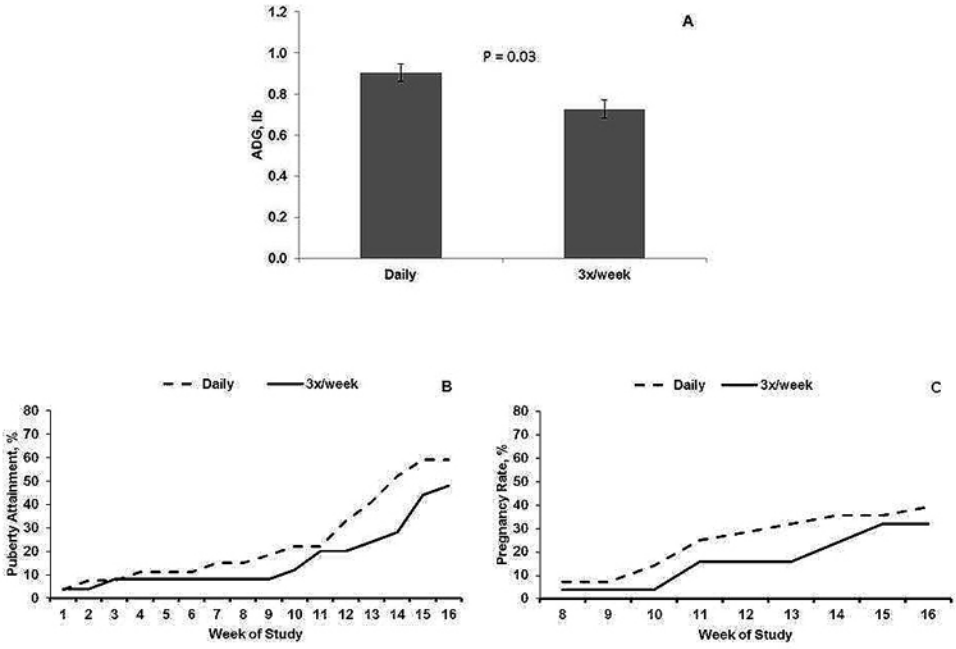

Fig. 1. Average daily gain (A), puberty (B), and pregnancy attainment during the breeding season (C) in heifers consuming low-quality forages as supplemented daily or three times weekly with an energy supplement based on soybean hulls (adapted from Cooke et al. 2008)**.**

labor and special equipment). A successful supplementation program should take advantage of the operation's available resources, with major emphasis on long-term management and economics. Therefore, efficient and economical production, rather than maximal animal productivity, should determine the most appropriate supplementation strategy.

Literature Cited

Bailey, D. W., H. C. VanWagoner, R. Weinmeister, and D. Jensen. 2008. Comparison of low-moisture blocks and salt for manipulating grazing patterns of beef cows. J. Anim. Sci. 86:1271-1277.

Bailey, D. W., and G. R. Welling. 1999. Modification of cattle grazing distribution with dehydrated molasses supplement. J. Range Manage. 52:575-582.

Bodine, T. N., H. T. Purvis II, and D. L. Lalman. 2001. Effects of supplement type on animal performance, forage intake, digestion, and ruminal measurements of growing beef cattle. J. Anim. Sci. 79:1041-1051.

Bohnert, D. W., A. A. Clark, M. L. Merrill, T. DelCurto, S. J. Falck, and D. L. Harmon. 2011. Protein supplementation of low-quality cool- and warm-season forage: Intake, digestibility, and efficacy of nitrogen use in ruminants. J. Anim. Sci. 89:3707-3717.

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

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

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

Bowman, J. G. P., B. F. Sowell, D. L. Boss, and H. Sherwood. 1999. Influence of liquid supplement delivery method on forage and supplement intake by grazing beef cows. Anim. Feed Sci. Technol. 78: 273-285.

Ciccioli, N. H., S. L. Charles-Edwards, C. Floyd, R. P. Wettemann, H. T. Purvis, K. S. Lusby, G. W. Horn, and D. L. Lalman. 2005. Incidence of puberty in beef heifers fed high or low-starch diets for different periods before breeding. J. Anim. Sci. 83:2653-2662.

Clanton, D. C., and D. R. Zimmerman. 1970. Symposium on pasture methods for maximum production of beef cattle: Protein and energy requirements for female beef cattle. J. Anim. Sci. 30:122-132.

Cooke, R. F., and J. D. Arthington. 2008. Case study: Effects of protein sources added to molasses-based supplements on performance of range cows. J. Anim. Sci. 24:264-268.

Cooke, R. F., J. D. Arthington, D. B. Araujo, G. C. Lamb, and A. D. Ealy. 2008. Effects of supplementation frequency on performance, reproductive, and metabolic responses of Brahman-crossbred females. J. Anim. Sci. 86:2296-2309.

Cooke, R. F., D. W. Bohnert, P. Moriel, B. W. Hess, and R. R. Mills. 2011. Effects of polyunsaturated fatty acid supplementation on ruminal in situ forage degradability, performance, and physiological responses of feeder cattle. J. Anim. Sci. 89:3677-3689.

Farmer, C. G., B. C. Woods, R. C. Cochran, J. S. Heldt, C. P. Mathis, K. C. Olson, E. C. Titgemeyer, and T. A. Wickersham. 2004. Effect of supplementation frequency and supplemental urea level on dormant tall-grass prairie hay intake and digestion by beef steers and prepartum performance of beef cows grazing dormant tallgrass-prairie. J. Anim. Sci. 82:884-894.

Garcés-Yépez, P., W. E. Kunkle, D. B. Bates, J. E. Moore, W. W. Thatcher, and L. E. Sollenberger. Effects of supplemental energy source and amount on forage intake and performance by steers and intake and diet digestibility by sheep. J. Anim. Sc. 75:1918-1925.

George, M. R., N. K. McDougald, W. A. Jensen, R. E. Larsen, D. C. Cao, and N. R. Harris. 2008. Effectiveness of nutrient supplement placement for changing beef cow distribution. J. Soil Water Conserv. 63:11-17.

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

Kunkle, W. E., J. T. Johns, M. H. Poore, and D. B. Herd. 2000. Designing supplementation programs for beef cattle fed forage-based diets. In Proc. Am. Soc. Anim. Sci. Available at http://www.asas.org/jas/symposia/proceedings/0912.pdf. Accessed Oct. 27, 2007.

Loy, T. W., J. C. MacDonald, T. J. Klopfenstein, and G. E. Erickson. 2007. Effect of distillers grains or corn supplementation frequency on forage intake and digestibility. J. Anim. Sci. 85:2625-2630.

Mass, J. 1987. Relationship between nutrition and reproduction in beef cattle. Vet. Clin. N. Amer. Food Anim. Pract. 3:633-646.

Mathis, C. P., R. C. Cochran, J. S. Heldt, B. C. Woods, I. E. O. Abdelgadir, K. C. Olson, E. C. Titgemeyer, and E. S. Vanzant. 2000. Effects of supplemental degradable intake protein on utilization of medium- to low-quality forages. J. Anim. Sci. 78: 224-232.

Mathis, C. P., and J. E. Sawyer. 2007. Nutritional management of grazing beef cows. Veterinary Clinics of North America-Food Animal Practice. 23:1-19.

NRC. 1976. Use of urea as a protein replacement for ruminants. *In* Urea and other nonprotein nitrogen compounds in animal nutrition. National Academy of Sciences, Washington, DC.

Raleigh, R. J., and J. D. Wallace. 1963. Effect of urea at different nitrogen levels on performance of growing steers fed low-quality flood meadow roughage. J. Anim. Sci. 22:330-334.

Sasser, R. G., R. J. Williams, R. C. Bull, C. A. Ruder, and D. G. Falk. 1988. Postpartum reproductive performance in crude protein-restricted beef cows: Return to estrus and conception. J. Anim. Sci. 66:3033-3039.

Schauer, C. S., D. W. Bohnert, D. C. Ganskopp, C. J. Richards, and S. J. Falck. 2005. Influence of protein supplementation frequency on cows consuming low-quality forage: Performance, grazing behavior, and variation in supplement intake. J. Anim. Sci. 83:1715-1725.

Wagnon, K. A. 1965. Social dominance in range cows and its effect on supplemental feeding. Calif. Ag Exp. Sta. Bull. 819. pp 1-32.

Wettemann, R. P., C. A. Lents, N. H. Ciccioli, F. J. White, and I. Rubio. 2003. Nutritional- and suckling-mediated anovulation in beef cows. J. Anim. Sci. 81(E. Suppl. 2):E48-E59.

Issued in furtherance of cooperative extension work in agriculture and home economics, Acts of May 8 and June 30, 1914, by the Cooperative Extension Systems at the University of Arizona, University of California, Colorado State University, University of Hawaii, University of Idaho, Montana State University, University of Nevada/Reno, New Mexico State University, Oregon State University, Utah State University, Washington State University and University of Wyoming, and the U.S. Department of Agriculture cooperating. The Cooperative Extension System provides equal opportunity in education and employment on the basis of race, color, religion, national origin, gender, age, disability, or status as a Vietnam-era veteran, as required by state and federal laws.

Fourth edition; December 2016 Reprint