Designing supplementation programs for beef cattle fed forage-based diets[1,2]

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Abstract

Reasons for feeding supplements to cattle consuming forage-based diets include conservation of forage, improvement of animal performance, increasing economic return, and(or) managing cattle behavior. This review focuses on identifying the limiting nutrients, effects of source of carbohydrates in energy supplements, feed additives, and feeding systems. The first step in designing a supplement is to determine nutrients that limit utilization of forage energy. Although this seems simplistic, grazing cattle select their diet, and nutrient composition of consumed forage often is unknown. Blood urea nitrogen and fecal analysis offer point-in-time indicators of protein-energy balance of the diet. Energy supplements (balanced with protein, vitamins, and minerals) are often needed to meet desired performance. Several experiments indicate that when nonstructural carbohydrates (NSC) in supplements are offered above .4% of BW, forage intake and digestibility are reduced. In this situation, choosing a highly digestible supplement low in NSC gives 15 to 30% better performance per unit of supplemental TDN. Several antibiotics increase gain and efficiency of growing cattle fed forage diets. Supplementing approved levels of ionophores or bambermycins has improved gains .07 to .11 kg/d, an increase similar to feeding an additional .45 kg of TDN/d. Other antibiotics and feed additives that control diseases, bloat, and parasites may increase net returns in selected situations. Supplementing cattle on low-quality forages with cottonseed meal (7 kg/wk or less) three times or once each week usually gives similar performance compared to daily feeding. Infrequent, compared with daily, supplementation with low-protein grain usually results in lower performance for cattle on low-quality forages, but supplements with moderate protein levels may be successfully fed infrequently. Formulating self-fed supplements that are consumed at desired amounts reduces feeding costs, but challenges for the nutritionist include variation in consumption across situations, variation in consumption amount and frequency within the herd, and availability of reasonable cost intake limiters that do not cause management or disease problems. Salt has been a reliable intake limiter.

Key Words: Supplements, Cattle, Nutrient Improvement, Additives, Supplementary Feeds

Introduction

Reasons for feeding supplements to cattle consuming forage-based diets include correcting nutrient deficiencies, conserving forage, improving forage utilization, improving animal performance, increasing economic return, and(or) managing cattle behavior. The challenge to nutritionists and cattle producers is to determine the ingredients, additives, feed processing, and delivery system that will improve performance and(or) efficiency of cattle and improve forage utilization in a cost-effective manner for a specific situation. This review focuses on identifying the limiting nutrients, feeding level, and sources of carbohydrates in energy supplements, feed additives, and feeding systems.

Limiting Nutrients

Cattle have nutrient requirements that vary with weight, production level, environmental condition, and genetics; much of the current scientific knowledge has been integrated and documented in *Nutrient Requirements of Beef Cattle* (NRC, 1996). Conceptually, a nutritionist can determine the nutrient requirements for a specific beef animal, determine the nutrients in the forage, and design a supplement that provides nutrients deficient in the forage. Grazing cattle present a challenge because they selectively consume different plants when available and(or) parts of plants that differ in nutrient concentration. The nutrient concentration of the consumed forage is often not known and must be estimated. Individual animals in the same pasture have different levels of production and, therefore, have different nutrient requirements. Each animal is likely consuming different forages when available, providing a range of nutrient intake. Cattle may consume different quantities of the supplement and supplement composition may not be uniform. Consequently, the level of each nutrient included in the supplement may require some judgment using estimates of these variations, cost of the nutrients, and the reduction in performance associated with a deficiency.

An approach often followed for supplementing cattle fed forage diets is to provide sufficient protein, minerals, and vitamins to balance deficiencies in the forage then provide supplemental energy if it will provide a return over cost. An example of supplementing energy when protein needs were not met was reported by Chase and Hibberd (1987; Table 1). Mature beef cows were fed low-quality native grass hay

(4.3% CP, 52.5 % ADF) and offered supplements containing 0, 1, 2, or 3 kg/d of ground corn. Each of the four supplements provided similar levels of CP (256 g/d) that met the requirements of the cattle (NRC, 1984). Cottonseed meal provided the supplemental CP and was replaced as the corn increased to keep supplemental CP similar for each treatment. Supplementing with 1 kg/d of corn decreased hay intake by 7% compared with the control but increased digestible OM intake by 12% (Table 1). Feeding 2 or 3 kg/d of corn decreased hay intake and digestibility dramatically, and digestible OM intake (hay plus supplement) was 4 to 6% below that of cows fed no corn. The rate and extent of NDF digestion as well as the ruminal ammonia was decreased as corn supplement increased. Ruminal ammonia declined as corn increased and was below the recommended minimum (2 to 5 mg/dL) suggested by Satter and Slyter (1974) for maximum microbial growth. Low ruminal ammonia may have limited microbial growth, fiber digestion, and hay intake and altered ruminal microflora. Cattle consuming forages that are deficient in protein respond to DIP supplementation by increasing forage intake. The amount of increase seems to be associated with the level of protein in the forage as well as the maturity of the forage. If the objective of supplementing corn was to improve performance of the cattle, then it likely would not have been met; however, it would extend the forage supply.

The metabolizable protein system described in *Nutrient Requirements of Beef Cattle* (NRC, 1996) separates ruminal nitrogen needs (degradable intake protein, **DIP**) from the animal's metabolizable protein needs and should predict the DIP deficiency reported by Chase and Hibberd (1987). Determining the balance of protein with energy in the diet for grazing cattle continues to offer challenges, but development of techniques such as fecal analysis by near-infrared spectroscopy (Lyons et al., 1995) and blood urea nitrogen (Hammond et al., 1994) offer point-in-time indicators of protein-energy balance in the diet of healthy cattle.

Feeding Level and Carbohydrate Effects

Energy supplements balanced with other nutrients usually increase the performance of cattle fed forages, and cattle fed lower-quality forage usually show more improvement. However, supplemental energy often decreases (substitution) forage intake and utilization. Moore et al. (1999) reviewed 66 publications to estimate supplementation (protein and energy) effects on nonlactating cattle consuming forage and reported that supplements decreased voluntary forage intake when supplemental TDN intake was > .7% BW, when forage TDN:CP ratio was < 7 (adequate CP), or when voluntary forage intake was > 1.75% BW. Regression equations (R^2 = .84) developed to estimate effects of supplements on voluntary forage intake and total diet TDN included forage intake when fed alone, supplement intake, and CP and TDN concentration in forage and supplement.

Horn and McCollum (1987) reviewed energy supplementation of grazing ruminants and concluded that concentrates can be fed up to .5% of BW without causing large decreases in forage intake. Bowman and Sanson (1996) reviewed literature on types of energy supplements for grazing ruminants and concluded that supplementing grain-based supplements up to .25% BW had minimal effects on forage utilization but above .25% BW negative effects were much larger. A producer can improve the response to energy supplements by feeding a lower level over a longer period of time when a good supply of forage is available, instead of using higher levels after forage supplies are nearly depleted.

Energy supplements reduce forage intake and digestibility, and this substitution is more pronounced at higher levels of feeding (Horn and McCollum, 1987). Supplements high in nonstructural carbohydrates (**NSC**; i.e., starch and sugars) result in lower ruminal pH and reduced growth of fibrolytic bacteria. However, supplementation with fibrous by-product feedstuffs that contain low levels of NSC has been shown to have less negative impact on forage intake and digestibility (Bowman and Sanson, 1996). By-product feeds that have high TDN (> 75% TDN in DM) and low NSC (< 30% NSC in DM) include soybean hulls, wheat middlings, corn gluten feed, beet pulp, citrus pulp, distillers grains, and brewers grains. The first three by-products have been available across much of the United States at reasonable prices and have been evaluated in several research trials during the last 20 yr.

Soyhulls (**SH**), a by-product of soybean processing, are nearly balanced in protein (12 to 14%), calcium (.63%), and phosphorus (.23%) for supplementing beef cattle. They are palatable and the risk of acidosis is low; consequently, this commodity feed is often fed without blending with other ingredients. Several trials evaluated similar quantities of corn balanced with protein and SH supplements on gains of growing cattle, and reported gains were similar for levels ranging from .4 to 1.0% BW (McDonnell et al., 1982; Anderson et al., 1988b; Brown and Weigel, 1993); one trial reported a 10% increase in gains (Anderson et al., 1988b). Two trials evaluated similar levels of supplemental TDN from corn or SH and reported similar cattle gains when levels were below .5% BW, but 10 to 25% improvements in gains when feeding at 1% BW (Heird et al., 1994; Garces-Yepez et al., 1997). Studies comparing corn-protein and SH supplementation effects on forage intake and digestibility suggest advantages for SH, especially when fed at levels above .5% BW.

Wheat middlings (**WM**), a by-product of wheat milling, are high in protein (19%) and phosphorus (1%) but low in calcium (.14%). They are used in many blended supplements and are quite palatable when pelleted. Wheat middlings were compared to corn-soybean meal as an energy supplement and performance of pregnant and lactating beef cows was similar (Heldt et al., 1998; Lusby et al., 1991a,b). Horn et al. (1995) reported that cattle fed a WM supplement had similar gains and stocking rates compared to growing cattle grazing wheat pastures and given a corn-soybean meal supplement. Blasi et al. (1998) found WM had 95% the value of corn-soybean meal for growing cattle when fed sorghum silage diets for ad libitum consumption. Garces-Yepez et al. (1997) reported that WM and corn-soybean meal supplements gave similar performance when fed to growing cattle at .5% BW, but when fed at 1% BW cattle fed WM supplements had 18% (.14 kg/d) higher gains.

Corn gluten feed (**CGF**) is a high-protein (18 to 24%) by-product of wet-milling corn and both wet and dry forms have been fed. Supplementing dry CGF at levels ranging from .4% to 1.2% BW to growing cattle fed alfalfa silage (Hannah et al., 1990) or grazing fescue pasture (Elizalde et al., 1998) resulted in similar performance compared to cattle fed corn-protein. In contrast, Green et al. (1987) summarized several feeding trials with silage-based diets and reported that feeding CGF resulted in 3% lower feed/gain compared to feeding corn-protein at 25 to 30% of the diet and 16% lower feed/gain when fed at 45 to 60% of the diet. Poore (1995) and Poore and Mueller (1996) also reported 13 to 27% lower gains and 16 to 54% reduced feed/gain when dry CGF was substituted for corn-protein in orchardgrass hay- or sorghum silage-based diets fed to growing cattle. Feeding value of CGF can be reduced by overheating during drying, and high sulfur concentration may limit performance and(or) increase problems with polioencephalomalacia (Gould, 1998) in some feeding situations.

Beet pulp and citrus pulp are highly digestible by-products (74 and 82% TDN) with low (less than 30%) NSC levels, and they may also cause less decrease in forage intake and digestion than high-NSC supplements. Sanson (1993) compared beet pulp and corn supplements in sheep fed low-quality hay and reported that DM intake and fiber digestibility were decreased with corn but not with beet pulp supplements at higher feeding levels.

Many research studies have evaluated forage intake, forage digestibility, fiber digestion, and kinetics of digestion with by-product feeds. Bowman and Sanson (1996) reviewed research on grain and by-product feeds and reported that supplemental starch intake and forage crude protein were two characteristics closely related to forage DM intake. Higher forage protein increased forage intake (+ .11% BW for each 1% increase in CP) and higher starch intake decreased (slope = –.62) forage intake (percentage BW). Although research results are variable, several experiments indicate that when the NSC provided by supplements exceeds .4% BW, the forage digestible OM intake is decreased. In these situations, a highly digestible by-product feed low in NSC often gives 10 to 30% more gain per unit of supplemental TDN or an equivalent improvement in efficiency (Garces-Yepez et al., 1997).

Feed Additives

In addition to supplying additional nutrients, supplements for grazing cattle may also be used as carriers for growth and(or) efficiency promotants. The most common products used in this manner are the polyether ionophores monensin and lasalocid. These products facilitate cation transfer across cellular membranes, thus favoring the growth of Gram-negative bacteria in the rumen. Three changes that occur with ionophore use are 1) increased production of propionate and decreased production of methane, 2) decreased protein degradation and amino acid deamination, and 3) decreased production of lactic acid (Huntington, 1997). These changes in fermentation profile and protein breakdown improve efficiency of nutrient use, allowing the animal to capture more dietary nutrients for growth and production.

In a review of 24 grazing trials involving 1,057 steers and heifers, Potter et al. (1986) reported a gain increase of .09 kg/d, or 16.3%, for cattle receiving 200 mg of monensin in the daily supplement compared to control cattle receiving supplement only. Pasture quality varied greatly in these trials, ranging from lush, green, and growing to end-of-season grass and postharvest crop residue. In another summary of 11 grazing trials involving 853 steers and heifers grazing nondormant, growing pastures (Potter et al., 1986), supplementation of 200 mg/d of monensin increased gain by .09 kg/d, or 15.5%, compared to control cattle receiving supplement without monensin. Goodrich et al. (1984) reviewed data from 914 grazing cattle in 24 trials. Cattle receiving an average of 155 mg/d of monensin had .082 kg/d, or 13.5%, increased gain compared with cattle receiving no monensin. These findings are of great practical importance because forage quality and quantity can vary widely depending on location, season, and environmental effects and similar positive effects have been demonstrated under widely varying forage qualities.

Supplement intake, and thus ionophore intake, can vary under grazing conditions. For widespread adoption by producers, ionophores must be efficacious under a range of intakes. Monensin intake at 50 mg/d has increased gain by as much as .18 kg/d (Boling et al., 1977). Gain response to lasalocid supplementation is more variable, although in some cases as little as 100 mg/d has shown a significant response (Table 2) compared to control cattle. This 11-trial summary shows an average gain response of .07 kg/d, or approximately a 10% improvement.

Even with a range of efficacy, an optimum intake for greatest improvement in gain and efficiency exists. In a study by Andrae et al. (1994), steers were offered 1.82 kg of a supplement containing monensin at 198 mg/kg every other day for a limited time. Cattle were divided into low (< than 150 mg/d) or high (≥ 150 mg/d) monensin intake groups. Cattle in the high monensin intake group (161 mg/d average intake) had .09 kg/d higher gain compared with cattle in the low monensin (123 mg/d average intake) group, and this may be related to the reduced intake of both the monensin and the carrier. Supplements must be designed to reduce variation in intake in order to optimize intake of these feed additives.

Daily hand-feeding of supplements requires considerable labor. Feeding monensin at 200 mg daily or 400 mg on alternate days has increased gain of growing cattle on pasture by .077 and .082 kg/d, respectively, compared with cattle fed an unmedicated supplement (Muller et al., 1986). Alternate-day feeding seems to reduce labor costs without a reduction in gain response.

Acute bovine pulmonary edema and emphysema (**ABPE**) can result in severe lung lesions and fatalities in cattle. The naturally occurring disease is associated with sudden transition of cattle from limited grazing to abundant, lush pasture. The malady is caused by the formation, absorption, and lung metabolism of 3-methyl-indole, a product of tryptophan catabolism in the rumen (Carlson and Dickinson, 1978). Monensin and lasalocid fed at levels consistent with gain stimulation will reduce 3-methyl-indole production and prevent clinical signs and pulmonary lesions of ABPE (Carlson et al., 1983; Nocerini et al., 1985).

Bloat in grazing cattle results from the formation of a stable proteinaceous foam in the rumen that traps the gases of fermentation, preventing eructation. The buildup of the gases creates pressure on the heart and lungs that, if severe enough, may result in death of the animal. Monensin is effective in reducing the incidence and severity of bloat in cattle grazing either alfalfa or winter wheat, but lasalocid has not proven as effective (Bartley, et al., 1983; Katz et al., 1986; Branine and Galyean, 1990).

Coccidosis may be a serious problem in young, grazing cattle. Depending on the severity of infection, calves may either gain slowly or lose weight. Fatalities are not usual but may occur. Ionophores are effective in killing the invasive stages of the parasite and controlling infection (Smith et al., 1981).

Both monensin and lasalocid are cleared for use in replacement beef heifers. They do not seem to alter fertility but they decrease age at first estrus (Sprott et al., 1988). With proper diet quality, this should increase the number of heifers conceiving early in the breeding season.

Caution must be exercised when providing ionophores in supplements to grazing cattle. Both products have FDA-approved levels to provide optimal growth and health response. Supplement overconsumption leading to excessive ionophore intake can result in toxicity to cattle (Potter et al., 1984; Galitzer et al., 1986).

Antibiotics that do not exhibit ionophoric properties are also available for use in grazing ruminants. Chlorotetracycline, oxytetracycline, and bambermycin have FDA clearance for use in cattle. Both chlorotetracycline and oxytetracycline have been shown to increase gain and decrease the incidence of eye problems in grazing cattle (Gay et al., 1985; Coffey and Brazle, 1988; Ward, 1989). The most recent antibiotic to receive clearance for use in grazing cattle, including replacement heifers, is bambermycin. Bambermycin exerts an antibacterial effect in the digestive tract, resulting in a selective influence on the growth of ruminal microflora. In an 18-trial summary, cattle fed bambermycin had .077 kg/d, or 10.5%, greater gain compared with unmedicated controls (Hoechst Roussel Vet, 1998). Bambermycin is not absorbed from the digestive tract of cattle, and thus toxicity effects due to overconsumption should not be of concern.

Feeding Systems

Frequency of Supplementation

Protein Supplements. Early studies in Texas, Oklahoma, and New Mexico (McIlvain and Shoop, 1962; Pope et al., 1962; Wallace, 1988) evaluated supplementing cows or yearlings grazing native range or fed low-quality harvested forages with cottonseed meal (3 to 8 kg/wk) at various frequencies. In these studies daily supplementation was compared to thrice-, twice-, or once-weekly supplementation. Frequency of supplementation did not affect cattle performance, although most of these studies were not replicated and did not have an unsupplemented control, and in most studies performance was quite low. McIlvian and Shoop (1962) showed no difference in variation of performance within groups supplemented daily, every third day, or once a week. Melton and Riggs (1965) noted a tendency for better performance with infrequent supplementation, which they suggested might have been due to changes in grazing behavior. They noted that infrequently supplemented cattle seemed to graze less on the day of supplementation but that they were less likely to have their grazing pattern disrupted by the appearance of a truck. Frequently supplemented cattle were observed to follow the truck whenever it appeared.

Coleman and Wyatt (1982) conducted metabolism trials to evaluate the effect of feeding protein supplements daily, on alternate days, or every 4th d. In the first study 2.9 kg/wk of cottonseed meal was fed, steers averaged 308 kg, and the hay contained 7.9% CP. Dry matter intake and digestibility were not influenced by supplementation, but crude protein digestibility was increased. There was no influence of frequency of supplementation and DIP may have been adequate for forage digestion. In a second study, with lower-quality hay (3% CP), animals were supplemented with green-chopped small-grain forage at a rate of 79 kg/wk (fresh basis). Dry matter intake and digestibility was dramatically increased by supplementation, although the effect was somewhat decreased with reduced supplementation frequency. Results of this study supported the use of alternate-day grazing of small-grain forage to supplement low-quality hay.

Hunt et al. (1989) evaluated supplementing low-quality grass hay (6.6% CP) with cottonseed meal fed either at 12-, 24-, or 48-h intervals and compared this to an unsupplemented control. The study included a trial with ruminally cannulated steers and a performance trial with lighter (297 kg) growing cattle. Supplementation with protein improved in situ digestibility of hay, but there was no clear influence of supplementation frequency. Increased ruminal ammonia concentrations were noted shortly following supplementation, especially for the 24- and 48-h feeding intervals, but overall mean levels were not greatly affected. Total VFA levels and pattern were influenced by supplementation, but there was little effect of supplementation frequency. In the performance trial, digestible DM intake was increased by supplementation but was not influenced by supplementation frequency. Gain was increased from 0.74 kg/d to 0.94 kg/d by supplementation and was greater for calves supplemented at 12-h (0.96 kg/d) and 48-h (0.99 kg/d) intervals than for those supplemented at a 24-h (0.88 kg/d) interval.

Bishop et al. (1992) measured blood metabolites when steers fed low-quality hay were supplemented with cottonseed meal daily compared to every 4th d (6.4 kg weekly). They found that steers fed cottonseed meal daily had greater hay intake than steers fed at 4-d intervals, and that steers fed daily tended to have greater blood glucose than steers fed at

4-d intervals. Steers fed every 4 d had greater blood urea nitrogen the day after supplementation and had greater and more variable NEFA levels in blood than the steers fed daily. This led them to question whether these changes in blood metabolites might have an impact on reproduction in some cases.

Wettemann and Lusby (1994) supplemented range cows with a protein supplement (40% CP) either three or six times/week at a level of approximately 10 kg/wk. There were no differences in BW change, body condition scores, or conception rates between the two treatments, but they still hesitated to recommend infrequent supplementation after calving and during the breeding season because of their earlier (Bishop et al., 1992) findings.

Huston et al. (1995, 1999) reported studies from the Edwards Plateau of Texas in which range cows were individually supplemented using Calan (American Calan, Northwood, NH) gates. All studies had an unsupplemented control. In two trials (consecutive years), cows were supplemented with cottonseed meal at 6.2 kg/wk with supplement given seven times, three times, or once a week. In both years, supplementation reduced BW and body condition loss, but there was no effect of frequency on those variables. Weaning weights were not improved by supplementation, but, surprisingly, weaning weights were 25 kg higher for cows supplemented weekly than for those supplemented daily.

In a recent study designed to determine the effect of supplementation frequency on nutrient absorption, Krehbiel et al. (1998) evaluated the hepatic flux of nutrients in ewes fed low-quality bromegrass hay (7.5% CP) supplemented with soybean meal at 24- or 72-h intervals. Although the pattern of net nutrient absorption was influenced by supplementation frequency, the net absorption of nutrients was similar to the negative control.

Grain-Based Supplements. Chase and Hibberd (1989) evaluated supplementation of low-quality native grass hay (5.0% CP) with two levels of a corn-based supplement (0.8 or 1.7 kg corn/d) on a daily or alternate-day schedule without an unsupplemented control. Supplements were formulated to provide approximately 250 g of CP daily for both the high and low levels. Digestibility and DM intake were lower for the higher supplement level, but they were not significantly influenced by frequency of supplementation. A tendency for reduced DM digestibility, however, resulted in a slight (4%) but significant decrease in digestible OM intake when the supplement was fed on alternate days. Measurements in ruminally cannulated animals showed that ruminal pH was lower on the day of supplementation, but it was higher on the next day for the alternate-day treatment. Ruminal ammonia for all treatments was quite low and was probably responsible for the decreased digestion that occurred when the higher level of supplement was fed.

Wallace (1988) compared supplementing developing heifers on native range with 5.7 kg/wk of a low-protein grain cube (9.4% CP) either fed daily or twice weekly to 6.4 kg/wk cottonseed meal fed twice weekly. Heifers on the grain cube gained less weight than those fed cottonseed cake, but there was little difference in weight gain as a result of frequency of grain feeding. Heifers fed the grain supplement twice weekly seemed to have a lower conception rate than those fed the grain cube daily.

Kartchner and Adams (1982) evaluated supplementing 1.5 kg/d corn with either a daily or alternate-day frequency to nonlactating cows grazing dormant range (4.5% CP and 57% IVDMD) in Montana during the winter. Cows supplemented daily gained more weight (65 vs 31 kg over the 10 wk trial) and were in better body condition at the end of the trial. Grazing time was recorded, but no difference between treatments was observed. Ruminal samples were also taken from cannulated steers that grazed with the cows and showed that ruminal pH was lower, and total VFA was higher, in animals supplemented on alternate days (ruminal ammonia was not reported). The authors suggested that higher fiber digestion may have been responsible for the improved performance in cows supplemented daily.

Beaty et al. (1994) explored the importance of protein concentration in supplements fed daily or three times each week. Mature steers fed wheat straw and cows grazing native range were supplemented with sorghum grain/soybean meal mixtures containing 12, 20, 30, or 39% CP, either daily or three times weekly (14 kg/wk). Reducing supplementation frequency reduced straw intake, increased DM digestibility, and reduced digestible DMI by 9% in the steers, with no interaction of protein level and frequency of feeding. In cows grazing native range, small effects of frequency were noted; weight and body condition loss were slightly greater with less-frequent supplementation. Again, there were no interactions between frequency and protein level. Frequency of supplementation did not influence cow grazing behavior or calf performance. In a third experiment, cows were fed corn- or sorghum grain-based supplements with 20% CP offered daily or three times/week (14.8 kg/wk) for 111 d. Slightly more weight and body condition score loss were reported with less-frequent supplementation during some periods, but overall effects were minor. Frequency of supplementation tended to alter grazing behavior; cows supplemented less frequently spent less time grazing, and more cows were found close to the supplementation area.

Huston et al. (1995, 1999) reported studies in which range cows were supplemented with cottonseed meal or a 20% CP grain-based supplement using Calan gates. During the first study, there was a negative control, and cows were supplemented three times a week or three times each 2 wk. Cottonseed meal was given at 6.4 kg/wk, and the grain-based supplement was fed at 5.7 kg/wk (similar TDN from supplements) or at 13.6 kg/wk (similar CP from supplements). Supplementation did not improve weight or body condition loss compared to unsupplemented cows. However, there was a tendency for the low level of grain-based supplement to result in more weight loss than the other two supplement treatments. There was no effect of feeding frequency for any of the treatments. In the 2nd yr, treatments and supplementation levels were similar, but supplements were fed once vs three times per week. Supplementation reduced loss of BW and condition. The low level of the grain-based supplement was clearly inferior to the cottonseed meal or high level of grain-based supplement. There was no effect of feeding frequency, and, surprisingly, there were no digestive problems noted when 13.6 kg of the grain-based supplement was fed once weekly.

Supplementation frequency has been most often studied in gestating beef cows consuming low-quality hay or grazing dormant range supplemented with cottonseed meal. Despite the limitation that most studies have not included unsupplemented control groups, it seems that the practice of supplementing protein (cottonseed meal) at levels of up to 7 kg/wk as infrequently as once a week results in performance nearly comparable to daily supplementation. No reports of digestive upsets with infrequent supplementation were noted, although the pattern of absorption varies between days and some blood metabolites may be influenced.

Infrequent feeding of low-protein grain mixes has been less effective when cattle are fed low-quality forages, probably due to disruption of ruminal function resulting in decreased forage intake. Grain-based supplements with intermediate protein levels (i.e. 20% CP) fed at higher levels (14 kg/wk) have been fed infrequently with no (or only slight) reductions in performance; this practice needs further work.

No reports were found in which higher-quality forages such as those found in temperate regions were fed, nor were there studies evaluating infrequent supplementation with low-starch energy supplements. Although reports are conflicting, several authors have noted changes in animal behavior as a result of supplementation frequency, but most studies did not monitor these effects. Evaluations of supplementation frequency of cattle grazing higher-quality pastures or fed medium-quality or high-quality hay are needed, and a better understanding of supplementation frequency effects on animal behavior would be helpful.

Although there are very few reports in the literature, time of feeding supplements may affect performance of grazing animals. Adams (1985) noted that when steers were fed a corn supplement in the morning they gained substantially less (.18 kg/d) than when they were supplemented in the afternoon. This was apparently due to a disruption in their normal grazing behavior. More work is needed to determine optimal time of day for supplementation under different conditions.

Supplement Intake Limiters

The high cost and(or) lack of labor has increased interest in using self-fed supplements. The perception that self-feeding allows timid and slow-eating animals to receive their share of supplement may be exaggerated because of the abundance of intake data based on group averages. Bowman and Sowell (1997), in reviewing delivery methods and supplement consumption by grazing sheep and cattle, found greater variation in individual intake and a higher incidence of nonfeeders than the commercial feed industry commonly acknowledges. Supplemental vitamin A, minerals, and feed additives are commonly included along with protein and(or) energy in self-limiting supplements. Concentrations are added with the assumption that animal consumption will be fairly uniform and near target levels. The commercial feed industry commonly uses physical form (blocks, tubs, and liquids) as well as intake-limiting compounds to control supplement consumption. Commercial supplements commonly employ multiple limiters in combination with physical factors for control of intake. It is commonly accepted, with little evidence, that a combination of compounds will provide more specific control than the use of a single compound (e.g., including a phosphorus supplement and magnesium oxide, at levels on the high side of that needed by the animal being supplemented, with a limiter such as salt). However, Paisley et al. (1997) observed no change in the consumption of a self-fed supplement containing energy, mineral, salt, and monensin for stockers on wheat pasture, due to addition of .25, .75, 1.25, or 1.75% magnesium oxide.

The effects of delivery method, mainly meals, blocks, and liquids, were recently reviewed by Bowman and Sowell (1997). Some of the more commonly used compounds for limiting supplement intake will be reviewed here, especially those that are effective as the sole limiter in the mix. Cattle producers are more likely to use simpler approaches for on-farm mixing. It cannot be overemphasized that adequate forage and good water should be available and self-limiting supplements should be present for animals at all times, not on an erratic basis.

Salt. Sodium chloride is the most common intake limiter used, because it is readily available and generally safe. Nelson et al. (1951), Archer et al. (1952), and Riggs et al. (1953) all reported that salt was an effective limiter of cottonseed meal for beef cows grazing dry winter ranges. Cows receiving salt-limited (from 25 to 35% salt) supplements performed similar to those being hand-fed equivalent levels of protein supplement, and no problems were reported. Harvey et al. (1986) reported that a salt-limited protein and energy supplement reduced daily gain of cattle on corn silage by 24% but not that of cattle receiving fescue hay. In a second trial, no reduction of gain was observed for cattle on either type of diet. Chicco et al. (1971) reported similar gains for cattle receiving salt-limited supplements while grazing under tropical conditions. Meyer et al. (1955) observed nearly equal gains for fattening lambs receiving total diets containing .7, 4.8, 9.4, or 12.8% salt. The same was true of steers receiving a basal diet or one containing 9.33% salt. Weir and Miller (1953) and Weir and Torell (1953) reported that 25% salt mixed with 75% cottonseed meal was a satisfactory supplement for self-feeding sheep.

Although Riggs et al. (1953) reported that a salt-limited cottonseed meal supplement improved digestibility of dietary protein, nitrogen-free extract, and crude fiber, most reports (Cardon, 1953; Meyer et al., 1955; Nelson et al., 1955) indicate no practical effects of salt on the digestibility of dietary components. Nelson et al. (1955) and Chicco et al. (1971) reported slight decreases in nitrogen retention, but Meyer et al. (1955) observed no change due to additional salt.

There are numerous reports indicating that the use of salt increases water intake, although many are subjective observations. Meyer et al. (1955) reported that fattening steers consuming 0.77 kg of salt, or 9% of their diet, consumed 35% more water. Other reports were cited that indicated each additional gram of salt intake required from 35 to additional gram of salt intake required from 35 to 54 mL of additional water.

Harvey et al. (1986) reported an increased rate of fluid passage from the rumen with added salt, but not for solids, not even fine particle matter. Hemsley et al. (1975) reported that 28% salt in the diet of sheep increased the escape of nonprotein OM by 15% and of protein by 5%, the former thought to be negative and the latter to be positive for the overall nutrition of the animal. Overall OM digestion was reduced, so this excessive level of salt produced no practical benefit from the additional escape protein.

Brandyberry et al. (1991) reported that season, summer vs winter, had more effect on fluid, DM fill, and digestion of OM by steers grazing range forage than did the salt limiting of supplements. There was no difference in grazing time or distance traveled by steers offered hand-fed or salt-limited supplements. Steers consumed most of their salt-limited supplement around 1200 during periods of less grazing activity and visited feeders only once or twice daily.

Animal health has always been a concern with salt supplementation. Riggs et al. (1953) and Meyer et al. (1955) reported no abnormal kidney pathology, although the latter found additional salt increased kidney weight. Chicco et al. (1971) reported that additional salt caused enlarged kidneys showing an osmotic nephritis. Although such reports exist, it seems that salt must be reasonably safe when considering the years of use and the limited number of negative findings. Increased dietary levels of salt produce little or no change in blood Na, slight increases in blood K, and moderate to large changes in blood Cl (Archer et al., 1952; Hemsley et al., 1975; Harvey et al., 1986). Hemsley et al. (1975) reported similar trends for Na, K, and Cl in the saliva of sheep.

Cattle normally consume salt at a rate of .05 to .15% BW when salt is used as a limiter. Producers should assume .1% BW initially, monitor intake, and make necessary adjustments. Hentges et al. (1967) cautioned that the high variability of salt intake among steers should be kept in mind as supplement formulations are recommended. Succulent, moist feeds tend to increase salt intake, and dry, coarse feeds lower it. Pelleting decreases the effectiveness of salt as a limiter. Only plain salt should be used as the limiter, but trace mineral salt can be added as part of the total supplement to furnish trace minerals. Recommendations to hand-feed high-grain, 10% salt supplements the first few days, or increase salt levels to prevent overeating, are probably not necessary with high-salt (25 to 35%) protein supplements, especially if feeding is started before the cattle are severely deficient. Cattle tend to increase salt intake over time, so the amount of salt in the supplement may need to be increased in order to maintain a constant intake. Damage to plant growth can be a concern when salt intake and stock density are high.

Monensin. The addition of monensin to salt-limiting pasture supplements reduced the level of salt necessary to limit supplement intake by 25 to 50% (Muller et al. 1986). In addition, fewer changes in the level of salt needed to limit intake were required when the supplement contained monensin. Paisley and Horn (1996) observed that the addition of monensin to a self-fed supplement containing 4.4% salt for stocker cattle grazing wheat pasture decreased supplement consumption from 2.28 to .65 kg/d. There was also less variation in daily supplement intake when monensin was included. It is important to check the current Food and Drug Administration regulations before formulating any supplement containing drugs, because individual formulas for self-fed medicated supplements must be approved to ensure intake is consistent with approved feeding levels.

Gypsum. Barrentine and Ruffin (1958) reported that both salt and gypsum were effective in limiting cottonseed meal intake by beef heifers. Less gypsum than salt was required. Wagnon (1960) found that gypsum limited intake of cottonseed meal for heifers and cows when forage was adequate, but, with limited quality and quantity of forage, health problems and death were observed. High sulfur intake can be one of several causes of polioencephalomalacia (**PEM**), as reviewed by Gould (1998). Kroger and Carroll (1964) reported increased plasma sulfate and decreased plasma and urine pH, indicating that the sulfate ion of gypsum was absorbed. In preparing for this review, D. B. Herd found that many Extension Beef Specialists no longer recommend gypsum as a limiter because of its high sulfur content and observed PEM signs, especially blindness. Usually it only takes half as much gypsum as salt to limit intake, and some producers continue to use it without ill effect. When water quality is high, forage is plentiful and low in sulfur, and gypsum is only consumed in quantities that do not raise total dietary sulfur over .4%, there is less risk, but safety cannot be ensured.

Calcium Chloride. Calcium chloride has been used as a limiter, and smaller amounts, compared to salt, are required to be effective. As little as 2.5 to 5% has been reported to limit supplement intake to 1% BW. Calcium chloride has the disadvantage of being corrosive and supplying extra calcium, which may become a problem with high-calcium forages and(or) water.

Fats and Oils. Wise et al. (1965) reported that 10% fat limited ground corn intake, including the fat, to 1.0% BW in steers being finished on pasture. In a second trial, 7 to 10% salt limited supplemental feed intake to .86% BW, and 10% fat limited intake to .79% BW. Cattle receiving fat gained 7% faster (1.16 vs 1.08 kg/d). Ten percent fat, a mixture of hydrolyzed animal and vegetable fat combined with 90% ground shelled corn, only limited supplement intake to approximately 1.5% BW in a 2-yr study with cattle grazing orchardgrass (Hart et al., 1971).

Compared to minerals, fats supply energy that can increase gains, but they have the disadvantage of increased cost and handling problems in cold weather. Too much fat intake can decrease digestion and cause scouring. Fats and oils will probably be used mostly by commercial supplement and feed manufacturers. Problems with imprecise intake control remain, and overconsumption of such supplements is very expensive compared to lower-cost limiters. Fats and oils seem to be more useful for holding grain intake to 1 to 2% BW in cattle than for holding protein or energy supplements under 1 kg/d.

Phosphoric Acid. Phosphoric acid is commonly used to limit consumption of liquid supplements and supplies phosphorus in the process. Phosphoric acid had to be increased from 3 to 5% of the mix to limit the intake of ground corn to less than 2 kg/d by steers grazing irrigated pastures (Jensen, 1979). This acid also helps to maintain molasses in its liquid state during cold weather. The expense and necessary handling equipment keep phosphoric acid from being practical on most farms.

Other Compounds. Jensen (1979) observed that dehydrated potatoes, cornstarch, animal fat, sodium tripolyphosphate, dicalcium chloride, magnesium sulfate, and calcium carbonate failed to limit supplement intake to their goal of less than 1.82 kg/d for steers grazing irrigated pastures. Sodium hydroxide was a consistent and effective limiter, but its physical properties kept it from being recommended. Ammonium chloride was effective but too much (12 to 14% of the supplement) was required to be practical. Although aluminum sulfate was acceptable from several perspectives, its use in a pasture supplement for grazing steers decreased gains and, thus, limited its recommendation.

Implications

Supplements may be used to correct specific nutrient deficiencies, extend forage supplies, carry feed additives, or alter animal behavior. Nutritionists should have a clear goal in mind when designing supplements, and an economic benefit should be realized. One supplement should be developed to deliver all nutrients needed in a given situation. Feed additives including the approved ionophores and antibiotics will often give economic responses for grazing cattle. Infrequent supplementation and self-fed supplements may reduce labor requirements and generally give good results. However, more research is needed to develop strategies that result in uniform supplement consumption.

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Notes

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Table 1. Intake and digestibility of low-quality grass hay by mature beef cows supplemented with increasing quantities of corn[a]

	Supplemental corn, kg/d				
	0	1	2	3	SE
Daily hay intake, % BW	2.30	2.14	1.66	1.32	.072
Total DM, g/d	9,484	9,580	8,467	7,809	276.4
Digestible OM, g/d	3,425	3,809	3,228	3,299	113.1
Digestibility, %					
Apparent OM	39.5	43.1	41.4	46.0	1.05
Neutral detergent fiber	39.6	38.5	29.9	25.6	1.42
Digestible NDF disappearance, %/h	3.9	3.3	2.1	1.4	.54
Ruminal ammonia-N, mg/dL	2.20	1.12	.88	.61	.33

[a]Chase and Hibberd, 1987.

Table 2. Effect of lasalocid on gain of cattle grazing pasture

				Supplement			
Reference	Pasture	Sex[a]	Lasalocid, mg/(animal•d)	Amount, kg	Type	Gain above control, kg (%)	*P*-value
Worrell et al.	Fall rye	S	150	.45	CSM[b]	.02 (1.2)	NS
(1990)	Spring rye	S	150	.45	CSM[b]	.25 (21.5)	< .05
Andersen and Horn	Wheat	H	100	1.06	Corn based	0.0 (0.0)	NS
(1987)			200			.11 (10.6)	< .05
Spears and Harvey	Cool-season grass	S	200	.90	Corn	.10 (20)	< .05
(1984)			300			.07 (14)	< .05
Rush et al. (1996)	Range	S	200	1.0	Corn	.11 (17.8)	< .10
Gill et al. (1982)	Range	S	100	.90	Corn-Milo	.07 (7.8)	< .05
Rode (1987)	Cool-season grass	S	.75 mg/kg of BW	.50	Barley	.15 (17.2)	< .01
Rode et al. (1994)	Cool-season grass	H	114 mg average	Free Choice	Mineral	.05 (14.2)	< .05
	Cool-season grass	H	186 mg average	Free Choice	Mineral	.02 (3.3)	NS
Tanner et al.	Oat	H	50	.45	Milo	.13 (25.9)	NA
(1982)			100			.077 (15.2)	NA
			200			.072 (14.3)	NA
			300			.095 (18.8)	NA
Valdes et al. (1988)	African stargrass	S	122 mg average	Free Choice	Mineral	.08 (12.9)	< .01
DelCurto et al.	NA	S	168 mg average	Free Choice	Mineral	.05 (4.0)	NS
(1989)			200	.45	Corn	.12 (10.7)	< .10
Horton et al.	Bahiagrass	H	50	.90	Corn	-.05 (-14.2)	NS
(1992)			100			.11 (31.4)	< .01
			200			-.03 (-8.5)	NS
			300			.02 (5.7)	NS
	Stargrass	H	50	.90	Corn	.03 (5.2)	NS
			100			.04 (7.0)	NS
			200			.01 (1.7)	NS
			300			.03 (5.2)	NS

[a]S = steers, H = heifers.

[b]Cottonseed meal.

