

EFFECTS OF CARBOHYDRATE SOURCE, FEED ADDITIVES AND FEEDING SYSTEMS ON RESPONSE TO SUPPLEMENTS FOR CATTLE FED FORAGE BASED DIETS

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INTRODUCTION

Reasons for feeding supplements to cattle consuming forage-based diets include; correct nutrient deficiencies, conserve forage, improve forage utilization, improve animal performance, increase economic return, and(or) manage cattle behavior. The challenge to nutritionists and cattlemen 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 will focus on identifying the effects of feeding level and sources of carbohydrates in energy supplements, feed additives and feeding systems.

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 once 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 byproduct feedstuffs that contain high levels of NSC has been shown to have less negative impact on forage intake and digestibility (Bowman and Sanson, 1996). Byproduct 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 byproducts have been available across much of the U. S. at reasonable prices and have been evaluated in several research trials during the last 20 years.

Soyhulls (SH), a byproduct 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 (Anderson et al., 1988b; McDonnell et al., 1982; Brown and Weigel, 1993; Horn et al., 1995); one trial reported a 10% increase in gains (Anderson et al., 1988a). 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 (Garces-Yepez et al., 1997, Heird et al., 1994). Studies comparing corn-protein and SH effects on forage intake and digestibility suggest advantages for SH, especially when fed at levels above .5% BW.

Wheat middlings (WM), a byproduct 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; Lusby et al., 1991b). Horn et al., (1995) reported cattle fed a WM supplement had similar gains and stocking rates compared to a corn-soybean meal supplement for growing cattle grazing wheat pastures. Blasi et al. (1998) found WM had 95% the value of corn-soybean meal for growing cattle when fed sorghum silage diets offered ad libitum. Garces-Yepez et al. (1997) reported 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 (18-24%) byproduct of wet-milling corn and both wet and dry forms have been fed. Supplementing dry CGF at levels for .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 corn-protein. In contrast, Green et al. (1987) summarized several feeding trials with silage based diets and reported that CGF had 3% lower feed/gain when compared to corn-protein when fed 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 byproducts (74 and 82% TDN) with low NSC levels, and may also cause less depression in forage intake and digestion than high NSC supplements. Sanson (1993) compared beet pulp and corn supplements in sheep fed low quality hay. He reported DM intake and fiber digestibility were depressed 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 byproduct feeds. Bowman and Sanson, (1996) reviewed research on grain and byproduct 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 (% 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 depressed. In these situations, a highly digestible byproduct 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) increase 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 1057 steers and heifers (Table 1), Potter et al., 1986, reported an average daily gain increase of .09 kg 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 post-harvest crop residue. In another summary of 11 grazing trials involving 853 steers and heifers grazing non-dormant growing pastures (Potter et al., 1986), supplementation of 200 mg/d of monensin increased daily gain by .09 kg or 15.5% compared to control cattle receiving supplement without monensin. Goodrich et al., 1984 reviewed data from 914 grazing cattle in 24 trials (Table 2). Cattle receiving an average of 155 mg/d of monensin had .082 kg or 13.5% increased daily 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 daily gain by as much as .18 kg (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 3) compared to control cattle. The 11 trial summary shown in Table 3 shows an average gain response of .07 kg/d or about 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 (\geq 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 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 (Table 4; Muller et al., 1986). Alternate day feeding appears 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 (Table 5; Carlson et al., 1983; Nocerini et al., 1985).

Bloat in grazing cattle results from the formation of a stable proteinaceous foam in the rumen which traps the gases of fermentation preventing eructation. The buildup of the gases creates pressure on the heart and lungs which, 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).

Coccidiosis 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 appear not to alter fertility but will 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 over-consumption 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 bambermycins 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 (Corah et al., 1983; 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 bambermycins. In an 18 trial summary, cattle fed bambermycins had .077 kg/d or 10.5 % greater gain compared with non-medicated controls (Hoechst Roussel Vet, 1998). Bambermycins are not absorbed from the digestive tract of cattle, thus toxicity effects due to over-consumption should not be of concern.

FEEDING SYSTEMS

Frequency of supplementation.

Protein Supplements. Early studies in Texas, Oklahoma and New Mexico (McIlvian and Shoop, 1962; Pope et al., 1962; Melton and Riggs, 1965; Wallace, 1988) evaluated supplementing cows or yearlings grazing native range or fed low quality harvested forages with cottonseed meal (3 to 8 kg/week) at various frequencies. In these studies daily supplementation was compared to three, two or even 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 appeared 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 fourth day. 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/week (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 hour intervals and compared this to an unsupplemented control. The study included a trial with ruminally cannulated steers and a performance trial with lighter weight (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 hr feeding intervals, but overall mean levels were not greatly effected. 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. Daily gain was increased from 0.74 kg/d to 0.94 kg/d by supplementation, and interestingly, was greater for calves supplemented at 12 hr (0.96 kg/d) and 48 hr (0.99 kg/d) intervals as compared to the 24 hr (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 fourth day (6.4 kg weekly). They found that steers fed cottonseed meal daily had greater hay intake than steers fed at 4 day intervals, and that steers fed daily tended to have greater blood glucose than steers fed at four day intervals. Steers fed every four days had greater blood urea nitrogen the day after supplementation, and had higher 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 3 or 6 times/wk 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, 1996) reported studies from the Edwards Plateau of Texas in which range cows were individually supplemented using Calan® 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 higher by 25 kg for the weekly than for the daily supplemented cows.

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 hour intervals. Supplementation increased the net absorption of nutrients, and while the pattern of net absorption was influenced by supplementation frequency, total net absorption was not different for 24 or 72 hour supplementation intervals.

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/d corn) 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 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 alternative days. Measurements in ruminally cannulated animals showed that ruminal pH was lower on the day of supplementation, but 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 appeared 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 dry 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 alternate day supplemented animals (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, with weight and body condition loss being 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/wk (14.8 kg/wk) for 111 days.

Slightly more weight and body condition score loss was reported with less frequent supplementation during some periods, but overall effects were minor. Frequency of supplementation tended to alter grazing behavior with cows supplemented less frequently spending less time grazing, and with more cows found close to the supplementation area.

Huston et al. (1995, 1996) 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 two weeks. 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 give more weight loss than the other two supplement treatments. There was no effect of feeding frequency for any of the treatments. In the second year, 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 appears that the practice of supplementing protein (cottonseed meal) at levels of up to 7 kg/wk as infrequently as once a week will result 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 and this practice needs further work.

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

While there are very few reports in the literature, it has been observed that time

of feeding supplements may impact 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 non-feeders 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 added assume 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 like 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 the 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 which are effective as the sole limiter in the mix. Cattlemen are more likely to use simpler approaches for on-farm mixing. It can not 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 as it is readily available and generally safe. Archer et al. (1952), Nelson et al. (1951) 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 for cattle receiving fescue hay. In a second trial, no reduction of gain was observed for cattle on either type 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 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 the use of salt will increase water intake, though many are subjective observations. Meyer et al. (1955) reported that fattening steers consuming 1.7 pounds of salt, or 9% of their diet consumed 35% more water. Other reports were cited that indicated each additional g 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 non-protein OM by 15% and 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 versus winter, had more effect on fluid and 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 h 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 additional salt caused enlarged kidneys showing an osmotic nephritis. Though 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 will 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 while dry coarse feeds lower it. Pelleting will decrease 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 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 where 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, as individual formulas for self-fed medicated supplements must be approved to insure intake is consistent with approved feeding levels.

Gypsum. Barrentine and Ruffin (1958) reported both salt and gypsum were effective in limiting cottonseed meal intake by beef heifers. Less gypsum than salt was required. Wagon (1960) found gypsum limited intake of cottonseed meal for heifers and cows where 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 the sulfate ion of gypsum was absorbed. In preparing for this review, D.B. Herd (personal communication) found many Extension Beef Specialists no longer recommend gypsum as a limiter because of its high sulfur content and observed PEM symptoms, 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. Where 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 can not be assured.

Calcium chloride. Calcium chloride has been used as a limiter with smaller amounts, compared to salt, being 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 10% fat to limit 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 while 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 two-year study with cattle grazing orchardgrass (Hart et al., 1971).

Compared to minerals, fats supply energy which can increase gains, but 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 over consumption 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 one 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, corn starch, 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 was required. Although aluminum sulfate was acceptable from several perspectives, its use in a pasture supplement for grazing steers depressed gains and thus limited its recommendation.

SUMMARY

Supplements may be used to correct specific nutrient deficiencies, stretch forage supplies, improve forage utilization, carry feed additives or alter animal behavior. The nutritionist should have a clear goal in mind when designing supplements, and an economic benefit should be realized. 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/day. Other antibiotics and feed additives that control diseases, bloat, and parasites may increase net returns in selected situations. Feed additives including the approved ionophores and antibiotics will often give economic responses for grazing cattle. 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 moderate protein level supplements 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. One supplement should be developed to deliver all nutrients needed in a given situation. Infrequent supplementation, and self-fed supplements, have potential to reduce labor requirements and generally give good results. However, more research is needed to develop strategies that result in uniform supplement consumption.

LITERATURE CITED

- Adams, D.C. 1985. Effect of time of supplementation on performance, forage intake and behavior of yearling beef steers grazing Russian Wild Ryegrass in the fall. *J. Anim. Sci.* 61:1037-1042.
- Andersen, M. A., and G. W. Horn. 1987. Effect of lasalocid on weight gains, ruminal fermentation and forage intake of stocker cattle grazing winter wheat pasture. *J. Anim. Sci.* 65:865-871.
- Anderson, S. J., J. K. Merrill, M. L. McDonnell, and T. J. Klopfenstein. 1988b. Digestibility and utilization of mechanically processed soybean hulls by lambs and steers. *J. Anim. Sci.* 66:2965-2967.
- Anderson, S. J., J. K. Merrill, M. L. McDonnell, and T. J. Klopfenstein. 1988a. Soybean hulls as an energy supplement for the grazing ruminant. *J. Anim. Sci.* 66:2959-2964.
- Andrae, J. G., G. W. Horn, and G. Lowrey. 1994. Effect of alternate-day feeding of a monensin containing energy supplement on weight gains and variation in supplement intake by wheat pasture stocker cattle. In: *Anim. Sci. Res. Rept.* P-939, pp 158-161, Agric. Exp. Sta., Oklahoma State Univ., Stillwater.
- Archer, Jr., W., A. B. Nelson, R. MacVicar, and A. E. Darlow. 1952. Salt as a regulator of cottonseed meal consumption by beef cattle. *J. Anim. Sci.* 11(Suppl. 1):755.(Abstr.)
- Barrentine, B. F., and B. G. Ruffin. 1958. Salt and gypsum as regulators of cottonseed meal intake. In: *Agr. Exp. Sta. Information Sheet* 587:1, Mississippi State Univ., Starkeville.
- Bartley, E. E., T. G. Nagaraja, E. S. Pressman, A. D. Dayton, M. P. Katz, and L. R. Fina. 1983. Effects of lasalocid or monensin on legume or grain (feedlot) bloat. *J. Anim. Sci.* 56:1400-1406.
- Beaty, J. L., R. C. Cochran, B. A. Lintzenich, E. S. Vanzant, J. L. Morrill, R. T. Brandt, Jr., and D. E. Johnson. 1994. Effect of frequency of supplementation and protein concentration in supplements on performance and digestion characteristics of beef

cattle consuming low-quality forages. *J. Anim. Sci.* 72:2475-2486.

Bishop, D. K., R. P. Wettemann, and J. A. Vizcarra. 1992. Blood Metabolites in steers fed protein supplement daily or at 4-day intervals. In: *Anim. Sci. Res. Rep.* MP-136. pp 245-250. Agric. Exp. Sta., Oklahoma State Univ., Stillwater.

Blasi, D. A., J. S. Drouillard, G. L. Kuhl, and R. H. Wessels. 1998. Wheat middlings in roughage-based or limit-fed, high-concentrate diets for growing calves. In: 1998 Cattleman's Day, Report of Progress 804. pp 56-59. Kansas State Univ., Manhattan.

Boling, J. A., N. W. Bradley, and L. D. Campbell. 1977. Monensin levels for steer calves grazing pasture. In: *Beef Cattle Res. Rept., Prog. Rept.* 227, pp 11-12, Univ. of Kentucky, Lexington.

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

Bowman, J. G. P., and B. F. Sowell. 1997. Delivery method and supplement consumption by grazing ruminants: A review. *J. Anim. Sci.* 75:543-550.

Brandyberry, S. D., R. C. Cochran, E. S. Vanzant, T. DelCurto, and L. R. Corah. 1991. Influence of supplementation method on forage use and grazing behavior by beef cattle grazing bluestem range. *J. Anim. Sci.* 69:4128-4136.

Branine, M. E. and M. L. Galyean. 1990. Influence of grain and monensin supplementation on ruminal fermentation, intake, digesta kinetics, and incidence and severity of frothy bloat in steers grazing winter wheat pasture. *J. Anim. Sci.* 68:1139-1150.

Brown, W. F., and J. Weigel. 1993. Utilization of soybean hulls in supplemental programs for beef cattle. In: *Proc. 4th Annual Florida Ruminant Nutr. Symp.*, pp 76-89, Univ. of Florida, Gainesville.

Cardon, B. P. 1953. Influence of a high salt intake on cellulose digestion. *J. Anim. Sci.* 12:536-540.

Carlson, J. R., and E. O. Dickinson. 1978. Tryptophan-induced pulmonary edema and emphysema in ruminants. In: R. F. Keeler, K. R. Van Kampen and L. F. James (Ed.) *Effects of Poisonous Plants on Livestock.* pp 261-272. Academic Press, New York.

Carlson, J. R., A. C. Hammond, R. G. Breeze, M. J. Potchoiba, and W. W. Heinemann. 1983. Effect of monensin on bovine ruminal 3-methylindole production after abrupt change to lush pasture. *Am. J. Vet. Res.* 44:118-120.

Chase, C. C., Jr., and C. A. Hibberd. 1989. Effect of level and frequency of maize supplementation on the utilization of low-quality grass hay by beef cows. *Anim. Feed Sci. and Technol.* 24:129-139.

- Chicco, C. F., T. A. Shultz, J. Rios, D. Plasse, and M. Burguera. 1971. Self-feeding salt-supplement to grazing steers under tropical conditions. *J. Anim. Sci.* 33:142-146.
- Coffey, K., and F. Brazle. 1988. Performance of stocker heifers and steers grazing high endophyte fescue and offered oxytetracycline in a mineral mixture. In: *Kansas Beef Res. Rept., Rept. of Prog. 539*, pp 42-46, Kansas State Univ., Manhattan.
- Coleman, S. W, and R. D. Wyatt. 1982. Cottonseed meal or small grain forages as protein supplements fed at different intervals. *J. Anim. Sci.* 55:11-17.
- Corah, L., J. Riley, S. O'Neill and R. Pope. 1983. Effect of aureomycin, injectable tramisol and ectrin fly control ear tags on grazing steer performance. In: *Kansas Beef Res. Rept.*, pp 114-117, Kansas State Univ., Manhattan.
- DelCurto, T., D. W. Weber and A. M. Craig. 1989. Administration of lasalocid in a self-fed mineral carrier or hand-fed three times weekly to stocker cattle on pasture. *Nut. Rep. Int.* 39:773-780.
- Elizalde, J. C., J. D. Cremin, Jr., D. B. Faulkner, and N. R. Merchen. 1998. Performance and digestion by steers grazing tall fescue and supplemented with energy and protein. *J. Anim. Sci.* 76:1691-1701.
- Galitzer, S. J., F. W. Oehme, E. E. Bartly, and A. D. Dayton. 1986. Lasalocid toxicity in cattle: Acute clinicopathological changes. *J. Anim. Sci.* 62:1308-1316.
- Garces-Yepez, P., W. E. Kunkle, D. B. Bates, J. E. Moore, W. W. Thatcher, and L. E. Sollenberger. 1997. Effects of supplemental energy source and amount on forage intake and performance by steers and intake and diet digestibility by sheep. *J. Anim. Sci.* 75:1918-1925.
- Gay, N., D. H. Seman, J. A. Boling, N. W. Bradley, and E. D. Miksch. 1985. Management practices for beef cow herd productivity. In: *Kentucky Beef Res. Rept., Prog. Rept. 291*, pp 5-6, Univ. of Kentucky, Lexington.
- Gill, D. R., E. J. Richey, F. N. Owens, and K. S. Lusby. 1982. Effect of lasalocid on weight gains of stocker steers. In: *Anim. Sci. Res. Rept.*, MP-112, pp 85-86, Oklahoma State Univ., Stillwater.
- Goodrich, R. D., J. E. Garrett, D. R. Gast, M. A. Kirick, D. A. Larson, and J. C. Meiske. 1984. Influence of monensin on the performance of cattle. *J. Anim. Sci.* 58:1484-1498.
- Gould, D. H. 1998. Polioencephalomalacia. *J. Anim. Sci.* 76:309-314.
- Green, D., R. Stock, and T. Klopfenstein. 1987. Corn gluten feed - A review. In: *Nebraska Beef Cattle Report MP 52*: pp 16-18. Univ. of Nebraska, Lincoln.
- Hammond, A. C., J. R. Carlson and R. G. Breeze. 1980. Prevention of tryptophan-induced acute bovine pulmonary oedema and emphysema (Fog Fever). *Vet. Rec.* 107:322-325.

Hannah, S. M., J. A. Paterson, J. E. Williams, and M. S. Kerley. 1990. Effects of corn vs corn gluten feed on site, extent and ruminal rate of forage digestion and on rate and efficiency of gain. *J. Anim. Sci.* 68:2536-2545.

Hart, R. H., J. Bond, G. E. Carlson, and T. R. Ramsey. 1971. Feeding corn or molasses to cattle on orchardgrass pasture. *Agron. J.* 63:397-401.

Harvey, R. W., W. J. Croom, Jr., Pond, B. W., Hogarth, and E. S. Leonard. 1986. High levels of sodium chloride in supplements for growing cattle. *Can. J. Anim. Sci.* 66:423-429.

Heird, C. E., A. L. Goetsh, A. H. Brown, Jr., P. K. Lewis, and Z. B. Johnson. 1994. Different supplements for steers consuming low-quality forage. *Prof. Anim. Sci.* 10:112-117.

Heldt, J. S., R. J. Pruitt, C. P. Birkelo, P. S. Johnson, and Z. W. Wicks III. 1998. Evaluation of wheat middlings as a supplement for beef cows grazing native winter range with differing forage availabilities. *J. Anim. Sci.* 76:378-387.

Hemsley, J. A., J. P. Hogan, and R. H. Weston. 1975. Effect of high intakes of sodium chloride on the utilization of a protein concentrate by sheep. II Digestion and absorption of organic matter and electrolytes. *Aust. J. Agric. Res.* 26:715-727.

Hentges, J. F., Jr., J. R. Adams, J. E. Moore, and R. R. Oltjen. 1967. Control of beef cattle forage supplement intake. *J. Anim. Sci.* 26(Suppl. 1):208 (Abstr.).

Hoechst Roussel Vet. 1998. GainPro Technical Manual. Hoechst Roussel Vet, Warren, NJ.

Horn, G. W., M. D. Cravey, F. T. McCollum, C. A. Strasia, E. G. Krenzer, Jr., and P. L. Claypool. 1995. Influence of high-starch vs high-fiber energy supplements on performance of stocker cattle grazing wheat pasture and subsequent feedlot performance. *J. Anim. Sci.* 73:45-54.

Horn, G. W., and F. T. McCollum. 1987. Energy supplementation of grazing ruminants. In: M. Judkins (Ed.) *Proc. Grazing Livestock Nutrition Conf.* pp 125-136. Jackson, WY.

Horton, G. M. J., P. Mislevy and W. D. Pitman. 1992. Ionophore effects on performance of heifers grazing subtropical grass pasture. *J. Prod. Agric.* 5:77-80.

Hunt, C. W., J. F. Parkinson, R. A. Roeder, and D. G. Falk. 1989. The delivery of cottonseed meal at three different time intervals to steers fed low-quality grass hay: effects on digestion and performance. *J. Anim. Sci.* 67:1360-1366.

Huntington, G. B. 1997. Use of ionophores in grazing ruminants. *Proc. Am. Assoc. Bovine Prac.* 30:104-109.

Huston, J. E., K. W. Bales, R. K. Dusek, P. V. Thompson, and D. W. Spiller. 1996. Winter losses in body weight and condition score of range cows fed supplements at different intervals. In: *Beef Cattle Research in Texas*, Texas A & M Univ., College

- Huston, J. E., K. W. Bales, R. K. Dusek, and P. V. Thompson. 1995. The importance of frequency of supplemental feeding in adult beef cows on rangeland. In: Texas Agric. Exp. Sta. Consol. Prog. Rep. 5256, pp 92-97, Texas A & M Univ., College Station.
- Jensen, J. E. 1979. Restricting intake of energy supplements fed to yearling steers grazing irrigated pasture. M.S. thesis. Univ. of Nebraska, North Platte.
- Kartchner, R. J., and D. C. Adams. 1982. Effects of daily and alternate day feeding of grain supplements to cows grazing fall-winter range. Proc. West. Sect. Am. Soc. Anim. Sci. 33:308-311.
- Katz, M. P., T. G. Nagaraja, and L. R. Fina. 1986. Ruminal changes in monensin and lasalocid fed cattle grazing bloat provocative alfalfa pasture. J. Anim. Sci. 63:1246-1257.
- Krehbiel, C. R., C. L. Ferrell, and H. C. Freetly. 1998. Effects of frequency of supplementation on dry matter intake and net portal and hepatic flux of nutrients in mature ewes that consume low-quality forage. J. Anim. Sci. 76:2464-2473.
- Kroger, D., and F. D. Carroll. 1964. Possible mechanism of agricultural gypsum in regulating appetite. J. Anim. Sci. 23:1011-1015.
- Lusby, K. S., R. P. Wettemann, K. H. Ovenell, and D. A. Cox. 1991a. The value of wheat middlings in winter supplements for beef cows. Prof. Anim. Sci. 7:24-29.
- Lusby, K. S., R. P. Wettemann, K. H. Ovenell, and D. A. Cox. 1991b. Effects of lactation on performance of grazing beef cows wintered with supplements containing soybean meal, wheat middlings, or soybean meal-wheat middlings mixtures. Prof. Anim. Sci. 7:30-34.
- McDonnell, M. L., T. J. Klopfenstein, and J. K. Merrill. 1982. Soybean hulls as energy source for ruminants. In: Nebraska Beef Cattle Rep. MP-43, pp 54-56, Univ. of Nebraska, Lincoln.
- McIlvain, E. H., and M. C. Shoop. 1962. Daily versus every third-day versus weekly feeding of cottonseed cake to beef steers on winter range. J. Range Manage. 15:143-146.
- Melton, A. A., and J. K. Riggs. 1965. Frequency of feeding protein supplement to range cattle. In: Agric. Exp. Sta. Bul. 1025, Texas A & M Univ., College Station.
- Meyer, J. H., W.C. Weir, N. R. Ittner, and J. D. Smith. 1955. The influence of high sodium chloride intakes by fattening sheep and cattle. J. Anim. Sci. 14:412-418.
- Moore, J. E., M. H. Brant, W. E. Kunkle, and D. I. Hopkins. 1999. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. J. Anim. Sci. 77: In Press.

- Muller, R. D., E. L. Potter, M. I. Wray, L. F. Richardson, and H. P. Grueter. 1986. Administration of monensin in self-fed (salt limiting) dry supplements or on an alternate-day feeding schedule. *J. Anim. Sci.* 62:593-600.
- Nelson, A. B., R. W. MacVicar, W. Archer, Jr., and J. C. Meiske. 1955. Effect of a high salt intake on the digestibility of ration constituents and on nitrogen, sodium and chloride retention by steers and wethers. *J. Anim. Sci.* 14:825-830.
- Nelson, A. B., R. W. MacVicar, W. J. Van Arsdale, and A. E. Darlow. 1951. Salt as a means of regulating consumption of cottonseed meal by beef cattle. *J. Anim. Sci.* (Suppl 1) 10:1058 (Abstr.).
- Nocerini, M. R., D. C. Honeyfield, J. R. Carlson, and R. G. Breeze. 1985. Reduction of 3-methylindole production and prevention of acute bovine pulmonary edema and emphysema with lasalocid. *J. Anim. Sci.* 60:232-238.
- Paisley, S. I., and G. W. Horn. 1996. Effects of monensin on intake of a self-limited energy supplement for growing steers grazing winter wheat pasture. In: *Anim. Sci. Res. Rep.* P-951. pp 218-223. Agric. Exp. Sta., Oklahoma State Univ., Stillwater.
- Paisley, S. I., C. J. Ackerman, and G. W. Horn. 1997. Effect of increasing levels of magnesium oxide on intake of a self-limited energy supplement for growing steers grazing winter wheat. In: *Anim. Sci. Res. Rep.* P-958, pp 85-89. Agric. Exp. Sta., Oklahoma State Univ., Stillwater.
- Poore, M. H.. 1995. Alternative sources of energy and protein in sorghum silage-based diets for beef heifers. *J. Anim. Sci.* 73 (Suppl.1):280 (Abstr.).
- Poore, M. H., and J. P. Mueller. 1996. Dried corn gluten feed as a source of supplemental concentrate for growing steers fed orchardgrass hay free choice. *J. Anim. Sci.* 74(Suppl. 1):4 (Abstr.).
- Pope, L. S., A. B. Nelson, and W. D. Campbell. 1962. Feeding protein supplements to range beef cows at 2, 4 or 6 day intervals. In: *Anim. Sci. Res. Rep.* MP-70. pp 49-51. Agric. Exp. Sta., Oklahoma State Univ., Stillwater.
- Potter, E. L., R. D. Muller, M. I. Wray, L. H. Carroll, and R. M. Meyer. 1986. Effect of monensin on the performance of cattle on pasture or fed harvested forages in confinement. *J. Anim. Sci.* 62:583-592.
- Potter, E. L., R. L. Van Duyn, and C. O. Cooley. 1984. Monensin toxicity in cattle. *J. Anim. Sci.* 58:1499-1511.
- Riggs, J. K., R. W. Colby, and L. V. Sells. 1953. The effect of self-feeding salt-cottonseed meal mixtures to beef cows. *J. Anim. Sci.* 12:379-393.
- Rode, L. M. 1987. Effect of anabolic implant and ionophore on the performance of grazing steers. *Can. J. Anim. Sci.* 67:461-467.
- Rode, L. M., T. J. Lysyk and K. A. Beauchemin. 1994. Intake of lasalocid-containing

mineral supplements by grazing beef heifers. *Can. J. Anim. Sci.* 74:77-82.

Rush, I. G., B. A. Weichenthal and B. Van-Pelt. 1996. Effects of Bovatec, Rumensin and GainPro fed to yearling summer grazing steers. In: 1996 Nebraska Beef Cattle Report. Agricultural Research Division, Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln. MP 66-A:69-70.

Sanson, D. W. 1993. Effects of increasing levels of corn or beet pulp on utilization of low-quality crested wheatgrass hay by lambs and in vitro dry matter disappearance of forages. *J. Anim. Sci.* 71:1615-1622.

Smith, C. K., II, R. B. Galloway, and S. L. White. 1981. Effect of ionophores on survival, penetration and development of *Eimeria tenella* sporozoites in vitro. *J. Parasitol.* 67:511-516.

Spears, J.W. and R.W. Harvey. 1984. Performance, Ruminal and Serum Characteristics of Steers Fed Lasalocid on Pasture. *J. of Anim. Sci.* 58:460-464.

Sprott, L. R., T. B. Goehring, J. R. Beverly, and L. R. Corah. 1988. Effects of ionophores on cow herd production: A review. *J. Anim. Sci.* 66:1340-1346.

Tanner, J. W. , F. M. Byers, L. M. Schake, W. C. Ellis, T. T. Schelling, C. R. Long and R. May. 1982. Ionophore effects on growth rates of grazing stocker cattle. *J. Anim. Sci.* 55 (Suppl 1):469 (abstr).

Valdes, J. L., L. R. McDowell and N. Wilkinson. 1988. Lasalocid for grazing steers administered in a free-choice mineral mix. *Nutr. Rep. Int.* 38:1-8.

Wagnon, K. A. 1960. Agricultural gypsum as a regulator for self-feeding cottonseed meal to cattle on the range. *J. Range Manage.* 13:279-283.

Wallace, J. D. 1988. Supplemental feeding options to improve livestock efficiency on rangelands In: R. S. White and R. E. Short (Eds.). *Achieving efficient use of rangeland resources*, Proc. of Fort Keogh Res. Sym., pp 92-100, Sept. 1987, Miles City, MT. Montana Agr. Exp. Sta., Bozeman.

Ward, J. K. 1989. Antibiotic-mineral mixture for grazing cow-calf pairs and yearlings. In: Nebraska Beef Res. Rept. MP-54, p16, Univ. of Nebraska, Lincoln.

Weir, W. C., and R. F. Miller, Jr. 1953. The use of salt as a regulator of protein supplement intake by breeding ewes. *J. Anim. Sci.* 12:218-225.

Weir, W. C., and D. T. Torell. 1953. Salt-cottonseed meal mixture as a supplement for breeding ewes on the range. *J. Anim. Sci.* 12:353-358.

Wettemann, R. P., and K. S. Lusby. 1994. Influence of interval of feeding protein supplement to spring calving beef cows on body weight and body condition score during the winter. In: *Anim. Sci. Res. Rep.* P-939. pp 123-125. Agric. Exp. Sta., Oklahoma State Univ., Stillwater.

Wise, M. B., E. R. Barrick, and T. N. Blumer. 1965. Finishing steers with grain on pasture. Agric. Exp. Sta. Bull. 425, North Carolina State Univ., Raleigh.

Worrell, M. A., D. J. Undersander, C. E. Thompson, and W. C. Bridges. 1990. Effects of time of season and cottonseed meal and lasalocid supplementation on steer grazing rye pasture. J. Anim. Sci. 68:1151-1157.

Table 1. Performance of Pasture Cattle Fed Monensin (Potter et al., 1986)

Series One: 24 Trial Summary

	Supplement Only	Supplement + Monensin
Daily gain, kg	.56 ^a	.65 ^b
Difference, kg (%)		+.09 (+16.3%)

Series Two: 11 Trial Summary

	No Supplement	Supplement Only	Supplement + Monensin
Daily gain, kg	.50	.59	.68
Difference, kg		+.09 ^c	+.18 ^d

^{a,b}P < .01;^cSupplement vs No Supplement;^dSupplement + Monensin vs No Supplement, Difference between indicated treatments P < .01

Table 2. Performance of Pasture Cattle Fed Monensin (Goodrich et al., 1984).

Item	Control	Monensin ^a
Number of cattle	456	458
Daily gain, kg	.609 ^b	.691 ^c
Difference, kg		+.082

^aAverage monensin intake = 155 mg/d^{b,c}P < .01

Table 3. Effect of Lasalocid on Gain of Cattle Grazing Pasture

Reference	Pasture	Sex ^a	Lasalocid ,mg/(h•d)	Supplement		Gain > control, kg (%)	P Value
				Amount , kg	Type		
Worrell et al. (1990)	Fall Rye	S	150	.45	CSM ^a	.02 (1.2)	NS
	Spring Rye	S	150	.45	CSM ^a	.25 (21.5)	P < .05
Andersen and Horn (1987)	Wheat	H	100	1.06	Corn based	0.0 (0.0)	NS
			200			.11 (10.6)	P < .05
Spears and Harvey (1984)	Cool Season Grass	S	200	.90	Corn	.10 (20)	P < .05
			300			.07 (14)	P < .05
Rush et al. (1996)	Range	S	200	1.0	Corn	.11 (17.8)	P < .10
Gill et al. (1982)	Range	S	100	.90	Corn- Milo	.07 (7.8)	P < .05
Rode (1987)	Cool Season Grass	S	.75mg/kg of BW	.50	Barley	.15 (17.2)	P < .01
Rode et al. (1994)	Cool Season Grass	H	114 mg average	Free Choice	Mineral	.05 (14.2)	P < .05
	Cool Season Grass	H	186 mg average	Free Choice	Mineral	.02 (3.3)	NS
Tanner et al. (1982)	Oat	H	50	.45	Milo	.13 (25.9)	NA
			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)	P < .01
DelCurto et al. (1989)	NA	S	168 mg average	Free Choice	Mineral	.05 (4.0)	NS
			200	.45	Corn	.12 (10.7)	P < .10
Horton et al. (1992)	Bahia grass	H	50	.90	Corn	-.05 (-14.2)	NS
			100			.11 (31.4)	P < .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)	N

^aCottonseed meal.

Table 4. Daily or Alternate Day Feeding of Monensin to Pasture Cattle - 5 Trial Summary (Muller et al., 1986)

	Control	Daily Feeding Monensin	Alternate Day Feeding Monensin
Daily gain, kg	.544 ^a	.621 ^b	.626 ^b

^{a,b}P < .008

Table 5. Effect of Monensin and Lasalocid on Prevention of ABPE^a

Treatment	Dose	Lung Lesions	Mortality
Trial 1			
Control	No Medication	4 of 4	1 of 4
Monensin, twice/d	100 mg	0 of 4	0 of 4
Monensin, once/d	200 mg	0 of 4	0 of 4
Lasalocid, twice/d	100 mg	4 of 4	1 of 4
Trial 2			
Control	No Medication	5 of 5	3 of 5
Lasalocid, once/d	200 mg	0 of 5	0 of 5

^aAcute bovine pulmonary edema and emphysema, adapted from Hammond et al., 1980 (Trial 1) and Nocerini et al., 1985 (Trial 2)