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Strategic Supplementation of Beef Cattle Consuming Low-Quality Roughages in the Western United States



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Cover Photo: Individually fed beef cows at the USDA/ARS Northern Great Basin Experimental Range (NGBER) located about 35 miles west of Burns, Oregon. (Photo by Tim DelCurto)

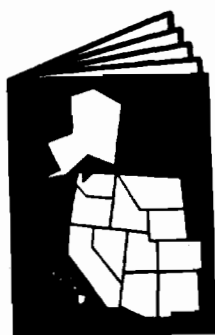
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Improving Ruminant Use of Forages in Sustainable Production Systems for the Western United States

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In cooperation with

USDA-ARS, Fort Keogh LARRL, Miles City, MT 59301; Texas Agricultural Experiment Station,
Texas A&M University, San Angelo, TX 76901; and Rosepine Research Station, Louisiana State University,
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Chapter 1. Introduction

SUPPLEMENTAL FEEDING OF RANGE LIVESTOCK: AN INTRODUCTION

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Sustainable livestock production utilizing rangelands requires knowledge of the nutritional value of available forage and experience with the probable responses by livestock to the quality and availability of that forage. These predicted responses are compared to the desired productivity of the grazing animal. If the predicted animal response is less than the desired productivity, then supplementation is considered. Supplementation research that started over 50 years ago has attempted to develop a predictive tool that could be used by ranchers. However, industry and nutritionists are still unclear on what type, amount, and duration of supplement is needed for optimum profitability of grazing animals.

Under extensive livestock management, systems comprised of management expertise, fences, water, and white salt, livestock give birth and reproduce during the periods of available green vegetation. These animals go through cycles, within a year, of using stored body nutrients and then replacing those nutrients. Not every animal is reproductively successful each year. Those that do reproduce every year are suited to their nutritional environment because they can synchronize their high nutritional demands and replenishment of body energy reserves to occur when abundant, high quality forage is available. This particular scenario, although low cost, may not optimize profitability. Therefore, to enhance profitability, our nutritional management is planned around an optimal marketing scheme, and the nutritional

environment is altered (by supplementation) to best fit the marketing decisions.

In range operations, the ranch is the energy or nutrient supply for the livestock. Energy is the constituent of the diet that is needed in the largest quantity. When range and grazing management are planned simultaneously with animal energy needs, dietary energy rarely should be supplemented. As long as livestock can consume herbage to their appetite every day, the livestock manager has made the greatest and usually lowest cost impact on nutrient intake. At times when energy demand by the animal exceeds energy intake (snow cover or other environmental effects that reduce forage availability, cold stress, lactation, and late pregnancy), deposited body energy reserves can be used to meet the animal's needs.

Protein is the nutrient needed in the second greatest amount. To utilize forage energy efficiently, there must be a balance with protein. In most situations when livestock are grazing or browsing dormant, non-green herbage, the balance of protein to energy is insufficient. Under these conditions, a protein supplement can improve forage digestibility and intake. By meeting the nutrient needs of the microorganisms that degrade fiber in the rumen, the net effect is more protein and energy available to the animal. Sometimes microbial protein is not sufficient to meet the animal's needs. Then, a protein can be fed to complement the protein derived by the microbes. In this situation, bypass protein may be used effectively to meet requirements during lactation, weight loss, antibody production, or

wool growth. The challenge at this point is the delivery of a protein supplement. The following questions may need to be resolved: How much protein? What sources will be used economically? Should it be fed as a 20, 32, or 40 percent crude protein (CP) supplement? Fed for what period of time? Should it be fed every day, every other day, or once a week? Can it be fed as a liquid, cubes, cake, or in blocks? Should younger or thinner animals receive more per day or for a longer period? We need to know what is the least amount of supplement, fed in the simplest method, which will allow for accomplishment of production goals.

Minerals and vitamins are required in the third and fourth largest quantity. They are important for animal structure, enhancing metabolism and immune function, and maintaining electrolyte balance, and are found in all parts of the body. Some can be stored and used over long periods, while others are needed on a daily basis. The most common method to supplement minerals and vitamins is through salt mineral mixes, using livestock's attraction to salt as a mechanism to entice mineral consumption. Because of yearly variation and normal production fluctuation, it is difficult for most ranchers to assess the effectiveness of any supplementation program, especially with minerals, in any one year.

Any nutrient not consumed in the necessary amount or balance to other nutrients compromises animal metabolism and production. It is important to establish which nutrient is most limiting or out of balance and supply that nutrient first. Observation of cattle and forage conditions, along with experience, can be used to assess the first limiting nutrient. Other methods that have been used with little or limited success are: clipped forage samples along with a forage analysis, analysis of blood urea nitrogen concentration or collecting fecal samples, and using prediction equations to determine limiting nutrients. Especially with sheep, clipped forage samples are not indicative of the quality of the diet that animals are capable of consuming. In fact, the limitation in

the diet may change between years, so that in some years an energy supplement is most effective, some years a protein, and in other years no supplement is the best choice for the lowest unit cost of production. Even within a range livestock operation that has not changed genetic potential of the grazing animal, supplement needs, if any (type, quantity, time, duration, etc.), can change from year to year because of changes such as environmental conditions that impact forage availability and quality, and factors that effect body condition of animals as they enter traditional supplementation periods.

Additional burdens to range animal nutritionists are the seasonal changes in forage quality and availability. With good moisture and moderate temperatures, forages are succulent and contain high nutrient density. As the season progresses, forages become coarser, drier, and lower in nutrient density. By mid-winter, these dormant forages contain 30 percent of their original protein, are 50 percent lower in digestibility, and almost all high quality soluble nutrients have been leached away. As forage quality changes during the year, livestock protein requirements double, and energy requirements increase 50 percent. This creates a situation in which important criteria for supplementation decisions are constantly changing.

Finally, evaluation of the success of a nutritional management plan is difficult. On the ranch, it is important to have good records and then to make comparisons over years to determine the optimal nutritional management plan for improved productivity and profitability. Even better, but more difficult, is to use ranch-based experiments and assess different nutritional programs. The complexity of supplementation decisions (i.e., forage conditions, forage availability, animal condition, that which might be the lowest cost management plan in one year may negatively impact replacement rates long term) can be beyond the typical ranch manager's experience. Decision aids are what is needed, to take into account all of the factors simultaneously, to

produce choices with the highest probability of long-term success.

As production costs rise and societal views of food safety and confinement meat production become more critical, meat production from extensive grazing operations may be positioned well to increase market share of meat consumption in the 21st century. However, meat and protein production rapidly is becoming a world market. U.S. producers, even for domestic consumption, must be competitive with other meat producing countries. Nutritional costs represent both the highest variable cost in the form of feeds and the highest fixed cost in the form of land purchases. The key to the lowest unit cost of production is grazing the reproductive female as long as possible. Strategic supplementation of the grazing female needs to balance low unit cost of production with long term reproductive performance to yield a sustainable production system.

The goal of this publication is to expand on a scheme called Strategic Supplementation. By using this process, livestock are supplemented only during the most effective period, with the minimum potent amount, and in a practical delivery system.

Hopefully, this publication will assist range livestock managers and nutritionists in making these supplementation decisions.



Cattle grazing at EOARC Hall Ranch

CHARACTERISTICS AND CHALLENGES OF SUSTAINABLE BEEF PRODUCTION IN THE WESTERN U.S.

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Introduction

Beef cattle producers in the Western U.S. are faced with the dilemmas of maintaining economic viability during times of low market values and, more recently, increased public criticism of beef product quality and industry compatibility with the environment. Unlike other meat animal industries, such as swine and poultry, the beef industry in the western United States is very dynamic. It must adapt constantly to changing arid environments and subsequent effects on forage quality and quantity, and associated relationships with beef cattle nutritional requirements. As a result, the Western beef cattle industry is very extensive, with optimal production being a function of the resources each ranching unit has available and how successfully the manager can match the type of cow and (or) production expectations to those resources. Successful beef producers are not necessarily the ones who wean the heaviest calves, obtain 95 percent conception, or provide the most optimal winter nutrition. Instead, the successful producers are dynamic and adaptive to economic and public pressures that challenge the industry.

Rangeland Forage Resources

The western United States has several unique geographic features that shape and influence

the beef cattle industry. Much of the land area fits the general classification of "rangeland"; hence, it is not suitable for tillage due to arid environments, shallow/rocky soils, high elevations, and short growing seasons. From arid rangelands in the Northern Great Basin (cold desert) to arid rangelands in southern New Mexico, ranchers are faced with limited forage resources and challenging nutritional calendars. Arid/high elevation rangelands also are characterized by dynamic, highly variable climates that change drastically from season to season and year to year. For example, the crude protein (CP) content of diets selected by cattle in the Northern Great Basin differs dramatically across seasons and years (Figure 1).

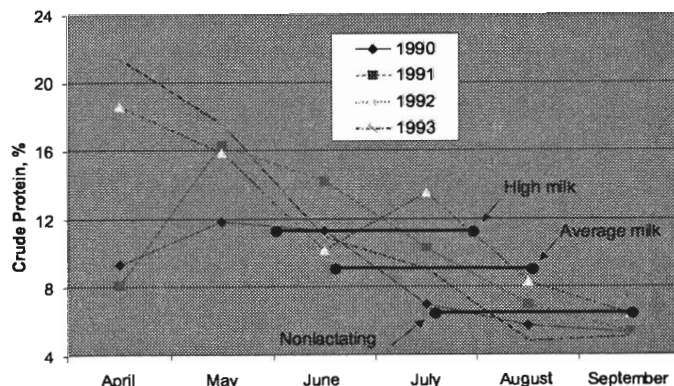


Figure 1. Crude protein content of diets selected by cattle grazing Northern Great Basin native rangelands. Crude protein requirements (NRC, 1984) are indicated for a high milking (20 lbs/day), average milking (10 lbs/day) and nonlactating gestating beef cow (1100 lbs).

The extremes in CP content in this data set are, in turn, related to wide ranges in crop year precipitation averaging 158, 246, 231, and 524 mm for 1990, 1991, 1992, and 1993, respectively (40-year average = 277 mm). The extreme fluctuations in precipitation also had significant affects on forage availability, with 1990 to 1992 averaging 240 kg/ha, whereas 1993 forage availability was 580 kg/ha. The beef manager must be aware of these changes and be able to adapt to wide ranges in forage quality and quantity.

The dynamic nature of arid/high elevation rangelands, in terms of forage quality, forage availability, and environmental extremes (snow cover, precipitation, temperature, etc.) results in seasonal cattle body weight and condition changes that mimic those observed with forage quality and availability. This has been illustrated in many winter grazing supplementation studies. DelCurto and coworkers (1991) supplemented cows grazing sagebrush steppe rangelands during the winter with graded levels of alfalfa and reported dramatic differences in cow weight and body condition change compared across years (Figure 2). Specifically, the magnitude of response was dramatically different between consecutive years due to observed changes in forage quality, forage availability, and environmental stress imposed on the grazing cattle. Likewise, other researchers in the western U.S. have indicated variable results when supplementing free-ranging beef cattle consuming stockpiled forage. While this does not adequately describe all the considerations needed for supplementing grazing livestock, it does point out some of the complexities in achieving optimal response to supplementation strategies in arid environments. Obviously, further research is needed to describe the interaction of environment, forage quality/quantity, and livestock nutrient demands so that optimal use of the forage resources, minimal use of supplements, and acceptable levels of beef cattle production can be obtained.

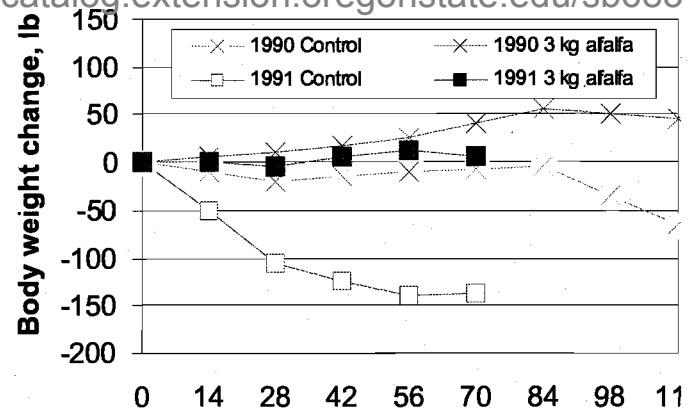


Figure 2. Body weight changes of beef cows winter grazing intermountain rangelands and supplemented with alfalfa (1990 and 1991).

Winter Feed Needs

Perhaps the greatest challenge to Western beef producers relates to the need for supplemental feed. Seasonal deficiencies of nutrients (protein/energy) are usually extreme in arid and high elevation rangelands. Consequently, producers dependent on rangeland forage resources must develop strategies to maximize the use of the forage resources and minimize supplemental inputs while maintaining acceptable levels of beef cattle production. Likewise, high-elevation and high latitude beef cattle operations are likely to have significant periods of snow accumulation, which necessitate feeding of harvested forages. In the Pacific Northwest and Intermountain West, many producers feed 1,500 to 3,000 kg of hay to their mature cows during the winter feeding period. This represents costs of \$75 to \$150 per cow per year and may be greater than 50 percent of the input costs per cow per year. Obviously, our ability to compete with other regions of North America may depend on how effectively we can reduce winter-feed costs, yet still maintain acceptable levels of beef cattle production.

The success of producers in the western United States may depend on their ability to find economical alternatives to winter-feeding of hay, such as stockpiled forages and crop residues. However, like dormant range forages, stockpiled forage and crop residues are low-

quality roughages that require nutritional inputs for optimal use. What follows is a general discussion of potential management strategies that may offer economic advantages to Western range livestock producers. Many scenarios or strategies may not be appropriate for your environment or production goals. Instead, most of the following information should be considered potential management alternatives that **may** offer economic advantages by decreasing input costs per cow.

Management to Reduce Nutritional Inputs and Costs

One of the most fundamental objectives of economically sustainable livestock production is to not provide nutritional inputs such as harvested feeds and (or) supplements unless it is necessary. Therefore, the first goal of a manager should be to match the biological cycle and nutritional demands of the cowherd with the forage resources available.

When is the best time to calve? One of the most fundamental management decisions that has profound effects on beef cattle nutritional requirements is calving date. Calving date sets the biological cycle, which, in turn, determines the nutritional cycle of the cowherd and the associated relationship to ranch resources. The Western beef cattle industry is dominated by spring-calving cattle. In addition, time of calving generally has been related to the “55 days to grass” philosophy. This traditional management strategy has gained popularity for a variety of reasons. First, gestation length in beef cattle is approximately 284 days. Therefore, if your cowherd calves approximately 55 days before the onset of green forage, the cows will be exposed to green, highly nutritious forage for approximately 25 days before they must conceive to stay on a 365-day calving interval. In a sense, the 25 days of high quality forage is a natural “flushing” mechanism that normally prompts a cow to begin cycling, provided she was in adequate body condition initially. Obviously, if your goal is to match the cows’

nutritional requirements with available forage quality, as a producer you might coincide calving with the onset of green forage (McInnis and Vavra, 1997). However, the “55 days to grass” philosophy has another advantage: the calf. A typical beef calf does not develop a fully functioning rumen until approximately 90 to 120 days of age. This normally coincides with the time a cow has passed its peak lactation period (day 70 to 90); and, as a result, calf performance will depend largely on the quality of available forage. Thus, a calf born March 1 effectively utilizes the high quality forage available in June. In contrast, a calf born May 1 does not utilize forage resources effectively until August, when forage quality is normally low in the Intermountain region. Because of the vast difference in calf nutrition from day 90 to weaning, the earlier born calf will have weaning weight advantages that greatly outweigh the 60-day difference in age. If higher weaning weights are a measure of economic importance (you market calves in the fall), then the “55 days to grass” philosophy may be the best approach.

Are weaning weights really important? The beef cattle industry in the United States has seen dramatic changes in production efficiencies over the last 30 years. In particular, weaning weights have increased from approximately 400 pounds in 1967 to greater than 600 pounds in 1997. The increase in weaning weights is related to increased use of continental breeds, greater selection for growth traits, and general improvements in management efficiency. Heavier weaning weights could increase the potential for profit if the producer’s goal is to market calves in the spring. This scenario would only be true if the increased income of heavier weaning weights outweighs the added cost of attaining that increase in weight.

However, the increase in weaning weights is an improvement in production efficiency that has some indirect problems. First, the target slaughter weight of market cattle has not changed dramatically during this period. As a result, the opportunities to put on post-weaning

weight have become limited with the heavier weaning weight cattle. For example, if a spring-calving cow/calf producer weans his cattle in late October at 600 pounds, he/she may choose to sell in the fall market or retain calves over the winter feeding period. However, because of the bigger calves, his/her options are reduced. With only marginal gains of 1 to 1.5 pounds per head per day, this producer will come out of the winter feeding period (120 to 150 days) with 700 to 800 pound yearlings. The opportunities to place these animals on spring grass have now become very restricted. To fit market standards, yearlings need to be placed in the feedlot (avg. 90 days) with an expected gain of 300 to 350 pounds in order to meet a target end weight of 1,200 to 1,300 pounds. Therefore, heavy-weaning, spring-born calves have limited opportunities as stocker cattle on grass markets.

Another change in the beef cattle industry in recent years is the trend toward retained ownership and (or) branded markets. These changes indirectly have led producers to reevaluate weaning weight goals because of opportunities to capture weight gains on yearlings and the need to provide cattle at finished weights on a yearly time frame. For producers who wish to retain ownership of cattle after weaning, weaning weight takes on less significance. In fact, these producers are the ones who should consider calving dates strongly. If a producer wishes to decrease costs per cow, moving the calving date to synchronize cow nutrient demands with range/pasture forage quality may effectively reduce costs associated with supplementing cows during nutrient deficiencies. Weaning weight advantages are reduced, but the producer has more opportunities to capture gains in the stocker, backgrounding, and finishing phases.

Preparing the Cow-Herd for the Winter Period

Because the winter period represents a time of high feed costs for beef cow-calf production,

management strategies should emphasize decreasing the inputs. Getting your cowherd in good fleshy condition going into the winter period should be a year-round management goal. Obviously, this involves monitoring your range and (or) pasture forage conditions with particular attention to the quantity and quality of late summer and early fall forage (Figure 1). Forage resources in the Pacific Northwest are influenced strongly by the Mediterranean climate and, as a result, are dominated by cool season forages. The majority of precipitation comes in the winter months, while summers are relatively dry. As a result, forage quality and quantity may be limited and, at the very least, highly variable during late summer and fall.

A manager should monitor cow body condition and calf performance in late summer. When cows start losing body condition and (or) calf performance begins to decline, the producer should consider nutritional management strategies to optimize cow condition going into the winter period. A cow in good condition (5 or better) going into the winter period is easier to feed and can lose some body condition without adversely effecting subsequent calving and rebreeding potential.

Early weaning as a management tool.

Traditionally, beef producers in the Great Basin region have weaned calves at approximately 7 months of age, which is usually late October or November for spring-calving herds. However, gains of both calves and cows are often poor by late August, particularly during years of poor forage quality/quantity. Early removal of calves allows the producer to provide them higher quality sources of feed and potentially greater gains at a similar cost to later weaning. The cows can be left on the range and, due to the removal of the nutrient demands of lactation, do well on range forage during the fall; without a suckling calf, the cows will come into winter in better condition. Improved body condition, in turn, translates into a cow that is easier to maintain during the winter period and has a higher chance of breeding

back and maintaining a 365-day calving interval.

Figure 3 presents some early weaning data from the Eastern Oregon Agricultural Research Center herd (Turner and DelCurto, 1991). Early-weaned calves were removed from their dams on September 12 and put on meadow aftermath and regrowth supplemented with 2 pounds of barley and 1 pound of cottonseed meal. Late-weaned calves remained on range with their dams until October 12 and then were managed with the early-weaned calves. Beginning on November 12, all calves were provided meadow hay, 2 pounds of barley, and 1 pound of cottonseed meal daily throughout the winter. Early-weaned calves gained more weight than late-weaned calves by 20 pounds from September 12 to October 12 despite going through the stress of weaning and adjusting to new feed. During the next period, October 12 to November 12, the early-weaned calves out-gained late-weaned calves by an additional 31 pounds and were now 51 pounds heavier. Late-weaned calves compensated somewhat over the remainder of the winter, but they were still 24 pounds lighter on April 12.

A number of factors must be considered when deciding if early weaning is appropriate. First, forage quality must be limiting to the point that calf gain will be reduced and cows are likely to lose body condition from late August to the October or November weaning date. If forage quality and (or) quantity are not limiting, there is really no advantage to early weaning. The real advantage of early weaning is to improve the weight and body condition of the cows from late summer to the beginning of the winter feeding period. In addition, the producer must provide adequate forage/nutrition to the early-weaned calf. For producers with limited nutritional options during the late summer and fall period, however, early weaning may provide an alternative that allows greater efficiency in the management of mature cows' body condition. In turn, improved body condition of cattle going into the winter period facilitates reduced

supplemental feed requirements during the winter period.

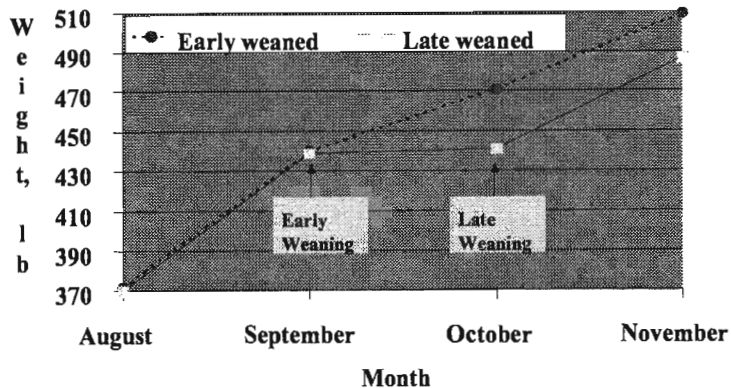


Figure 3. Influence of weaning date on calf weights (Turner and DelCurto, 1991).

Alternative Nutritional Management Strategies

Rake-bunch hay. The Eastern Oregon Agricultural Research Center conducted approximately 10 years of research evaluating rake-bunch hay as an alternative to traditional winter management. With this system, hay is cut, then raked into small piles (80 to 120 pounds) with a bunch rake, and left in the field. The forage then is strip-grazed, using New Zealand type electric fences, throughout the winter. A general summary of 10 years of data demonstrated that cows wintered on rake-bunch hay came out of the winter period in better condition than traditionally fed cows and did not require supplements or additional hay. Likewise, conception rates, calving interval, weaning weights, and attrition rates were equal between traditionally fed and treatment groups. In addition, the costs of winter feeding rake-bunch hay has been \$30 to \$40 less per head than the traditional feeding of harvested hay due, in part, to reduced harvest and feeding costs. For additional information relative to rake-bunch hay feeding, please refer to Turner (1987) and Turner and DelCurto (1991).

Winter grazing. Another alternative to traditional winter-feeding is winter grazing of "stockpiled" forage. To use this alternative

effectively in the Intermountain region, the producer must defer grazing of irrigated pasture or native range to the fall or winter months. The range forage base will be dormant and, as a result, is likely to need some level of supplementation depending on quality of selected diets, body condition status of mature cows, and stage of gestation. Brandyberry et al. 1994 offers more thorough discussions of winter grazing are available.

Similar to rake-bunch hay, winter grazing may decrease winter feed cost by \$20 to \$30 per cow during mild to average years (Bates et al., 1990). To winter graze pastures or native rangelands effectively, the land area must have numerous attributes. First, the producer must have access to the animals to accommodate supplementation programs. In addition, water must be available throughout the fall or winter grazing period, although cows can utilize snow effectively. However, the grazing area must be relatively free of snow accumulation during most years.

Indirect benefits of winter grazing relate to the increased management opportunities of traditional hay meadows for spring and early summer grazing. In addition, fall and winter grazing is an alternative use of native rangelands that may provide some significant advantages. First, deferment of grazing to the fall and winter months minimizes potential damage to native plants that are sensitive to early season defoliation, such as bluebunch wheatgrass (*Agropyron spicatum* Pursh; Mueggler, 1975; McLean and Wikeem, 1985); Idaho fescue (*Festuca idahoensis* Elmer; Mueggler, 1975; Jaindl et al., 1994); and Thurber needlegrass (*Stipa thurberiana* Piper; Ganskopp, 1998). Second, the grazing of nonlactating-gestating cows is distributed better over the grazing area, demonstrating greater distance traveled from water, better use of slopes, and more uniform use of the grazed area (Hedrick et al., 1968).

Grass seed residues. Another alternative to traditional winter management is the use of grass seed residues produced as a by-product of

Oregon's Grass Seed Industry. Currently, Oregon's Grass Seed Industry produces over 1 million tons of crop residues. While only 50 percent of these residues appear to be a viable livestock feed resource due to quality and (or) anti-quality factors, there are a number of reasons producers should consider these feeds as winter alternatives. First, many of the grass species are perennial forages (Kentucky bluegrass, tall fescue, perennial ryegrass, bentgrass, etc.) and, as a result, are substantially better than annual cereal grain straws. Second, burning, which traditionally was used as a tool to sanitize fields and remove residues, has been eliminated as the primary tool for grass seed producers. As a result, there is a critical need to find an effective use for these residues. Third, the Japanese export market has become "soft" in recent years, making delivery of grass seed residues to the eastern portions of Oregon more economically viable.

In most cases, grass seed residues should not be considered a complete feed for wintering mature beef cows. Instead, the nutritive quality of grass seed straws should be tested and supplements formulated to meet nutritional requirements while maximizing the use of the low-quality roughage. A more thorough review of grass seed residues and associated supplementation are available from Chamberlain and DelCurto (1991) and Turner et al. (1995). Currently, grass seed straw is being delivered to Eastern Oregon for approximately \$40 to \$50 per ton. The economic practicality of this feed resource should not only be compared with the costs associated with meadow hay production, but also with other potential benefits. First, feeding grass straw frees up meadows traditionally used to produce hay for grazing and (or) other uses. Second, grass seed residues represent a clean feed with limited weeds, with the exception of the seeds from the residue itself. On introduced/improved pastures, germination of perennial seeds from perennial ryegrass, tall fescue and (or) bluegrass may be beneficial to winter-feeding sites. Third, feeding residues on winter-feed grounds or traditional hay

meadows represents an increase in nutrients added to the site. Decreased fertilizer costs and improved organic matter of the soil may result from long-term feeding of grass seed residues.

Strategic supplementation. Management practices such as water development, salting, fencing, fertilization, and herding have been successful in improving forage and pasture utilization by cattle (Cook, 1966; Kauffman and Krueger, 1984; Bailey and Rittenhouse, 1989). However, implementation has been minimal over extensive locations and environments, primarily due to impracticality and (or) costs involved. In contrast, strategic supplementation has potential as a reasonable economic alternative to the aforementioned practices.

Recent work has demonstrated that strategic placement of supplement can lure cattle effectively to ungrazed or under-utilized areas, thereby improving animal disbursement and pasture utilization, even in moderate and difficult terrain (Bailey and Welling, 1999). These workers used dehydrated molasses supplement blocks as a management tool to alter cattle location and pasture utilization. They reported that supplementation increased grass utilization (within 200 m of supplement location) compared with non-supplemented areas by approximately 24 and 12 percent for moderate and difficult terrain, respectively.

Intensive management of native flood meadow.

Most native flood meadows are privately owned. They often produce up to 10 times more forage compared with sagebrush-bunchgrass range (Angell, 1997) due to increased water availability in the spring and early summer from annual runoff of high elevation snow pack. In general, 1 ha of native flood meadow frees 10 ha or more of typical sagebrush-bunchgrass range (Angell, 1997).

Traditional management of native flood meadows in the Intermountain West (1,618,800 ha; Gomm, 1979) involves haying in the summer and grazing aftermath and regrowth in the fall. However, control of water is minimal

and results in uncontrolled flooding (duration and amount). This normally prevents haying until the forage has become mature. As a result, hay quality is low, with CP concentration often less than 7 percent and total digestible nutrients (TDN) less than 50 percent. In addition, cattle are brought to the meadows from summer range in order to wean spring-born calves, winter the cowherd, and calve. As a result, beef cattle routinely spend half of the year on native flood meadows grazing residual forage or being fed hay harvested from the meadows. Consequently, many traditional beef cattle producers work within a management system that has developed around the annual production cycle of native hay meadows.

These highly productive meadows provide several alternatives to traditional hay-only management. Cattle can gain in excess of 2 pounds per day while grazing these meadows in the spring and summer, with no supplementation (Figure 4; Angell, 1997). This provides the benefit of added pounds of gain as well as deferring native range for late-season use. In addition, these cattle are in better condition going into the winter and require less feed to maintain acceptable performance. A second option is using meadow regrowth, harvest aftermath, or stockpiled forage, in conjunction with an early-weaning program, as a forage resource for calves. A third option is early-season grazing along with haying or late-season grazing.

Irrigated pasture. Irrigated pasture can be an excellent buffer when range forage is limited in quantity and (or) quality. With controlled irrigation and proper management, these pastures can offer high quality forage that can be grazed yearlong, harvested multiple times for hay, or used in combinations of late and (or) early season grazing in addition to hay production. Research has shown that growing cattle can gain well on irrigated pasture, and cows and spring-born calves can be held on pasture in early spring to allow deferment of native range for late-season use and (or) development of plant species sensitive to early-season defoliation (Gomm, 1979). In addition,

irrigated pasture can be used as a supplemental forage source in drought situations. Irrigated pasture can provide all of the management alternatives described previously for native flood meadow, while improving the ability to manage forage production, quality, and availability.

monensin had daily gains 0.2 pounds higher than cows fed meadow hay alone. In studies where cow body weights were kept equal between control cows receiving meadow hay and cows receiving meadow hay plus monensin, hay savings of up to 13 percent were realized. These rumen fermentation modifiers

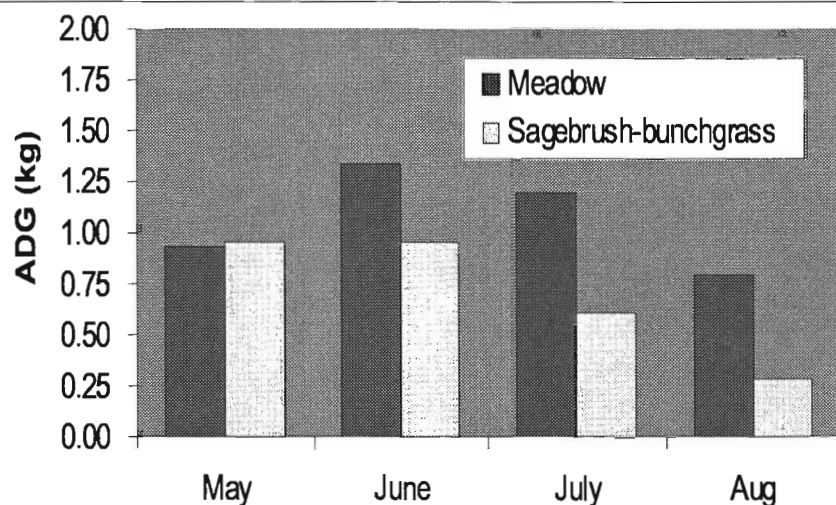


Figure 4. Expected daily gains of yearling cattle grazing either native flood meadow or sagebrush-bunchgrass range from May through August at the Eastern Oregon Agriculture Research Center (adapted from Angell, 1997).

represent another management tool for improving cow condition or reducing feed requirements while maintaining cow condition through the winter feeding period. Each of the products mentioned has various label claims and are available in different forms of feed.

However, the cattle producer who uses these products has the responsibility of using them properly. This includes (1) using it for its intended purpose, (2) following the feeding guidelines and any warning statement on the label, and (3) storing the feed properly.

Rumen fermentation modifiers. Rumen fermentation modifiers alter microbial fermentation in the rumen. Their purpose is to increase the quantity of energy obtained from feed consumed by cattle. Products currently approved for use in beef cattle consuming a forage diet include Rumensin® (monensin), Bovatec® (lasalocid), and GAINPRO™ (bambermycin). Each of these products commonly is used to improve the feed efficiency and (or) weight gain of cattle on pasture. Gain of steers and heifers on pasture has been improved by approximately 0.15 to 0.20 pounds per head daily when one of these products is included in a supplement. In addition, research at the Eastern Oregon Agricultural Research Center has shown that Rumensin can improve winter beef cow performance and (or) reduce winter feed needs (Turner et al., 1977; Turner et al., 1980). Cows fed a diet of meadow hay plus 200 mg of

Alternative Management -- A "Systems" Approach

Beef producers in the Intermountain West are in urgent need of management practices that provide sustainable alternatives to traditional management and are dynamic enough to provide options if government regulations decrease or eliminate public grazing allotments. When developing these strategies, animal scientists and beef cattle producers must contend with the public's preconceived notion that any livestock grazing is bad for the environment and (or) wildlife. In reality, the effect of livestock grazing on an ecosystem depends on a number of variables, including grazing or browsing intensity, the evolutionary history of the ecosystem, and the opportunity for regrowth (Hobbs, 1996). Therefore, the continued use of public and private lands by livestock producers will depend on the ability of animal and range scientists, Extension specialists, and producers to formulate

management systems that help overcome the stigma that livestock grazing is not a sustainable use. This point is illustrated in a survey by Coppock and Birkenfeld (1999). In a poll of 340 livestock producers in Utah ranging from large operators to part time ranchers or "hobbyists," they reported that the greatest perceived threats to the respondent's livelihood were reduced access to public and private lands and lack of applied information and technology for production and management. This demonstrates the need for alternative methods and technologies that can provide management options for Intermountain beef producers. In addition, these technologies must be practical and presented in an understandable format that encourages implementation by cattle producers.

The typical beef cattle operation in the Intermountain West utilizes three broad categories of land. These are sagebrush-bunchgrass communities, coniferous forests, and native flood meadows. Traditional management entails using sagebrush-bunchgrass range for spring and summer grazing and coniferous forests when sagebrush-bunchgrass range is mature and dry. Cattle are moved to native flood meadows in the fall to wean calves, winter the cowherd, and calve. Cattle are able to consume a limited quantity of meadow regrowth and harvest aftermath, and then they are fed hay harvested from the meadows earlier in the summer. Two possible alternative management scenarios using a "whole system" approach are listed below.

One possible management alternative would be to graze native flood meadows in the spring and early summer followed by early weaning. The early-weaned calves would be placed on irrigated pasture and the cows moved to mature native range and strategically supplemented through late winter. Calves would be sold or moved to a feedlot when the irrigated pasture was no longer able to sustain grazing (dependent on calf prices and available feed resources). Cows would be brought back to the native flood meadows approximately 1 to 2 months before calving and fed hay or rake-bunch until they are moved again to mature

native range in late summer. A portion of native flood meadow would be deferred from grazing in the spring and used for harvesting hay and rake-bunch. In addition, the irrigated pasture would be harvested at least once prior to use by early-weaned calves. Care and proper management would be undertaken when grazing late-season native range to ensure that riparian areas are protected and not over-utilized. Harvested hay would be used as emergency forage for cows and (or) sold as a source of additional revenue.

Another potential "systems" approach would be to maintain all animals on native flood meadow yearlong. The meadows would be grazed in the spring and early summer followed by early weaning as described above. However, early-weaned calves would be placed on rake-bunch and supplemented, while the cows would be held on native flood meadow that had been either mechanically harvested or grazed. The cows would be allowed to consume any hay (or rake-bunch not used by the calves) harvested during the summer and then provided grass seed straw and supplemented to meet expected production goals. Cows would be placed on new forage as it became available in the spring. Straw would be purchased and delivered to the ranch. Calf and meadow management would be as described above.

Rapid changes in technology, marketing strategies, and environmental concerns and regulation are challenging severely the managerial abilities of many producers and threatening their livelihood. The primary purpose of this discussion is to prepare cattle producers and managers for the changes that are occurring in the beef industry and to provide them with the ability to understand and respond appropriately. We briefly have outlined two potential management scenarios; however, there are numerous others that can be used by Western beef cattle producers. In addition, no one scenario or strategy is appropriate for all producers. Each producer must evaluate his or her own enterprise and decide which alternative(s) is most suitable. Using alternative management practices in a

“whole system” approach requires increased future planning and adaptability in relation to animal, forage, and land use. However, it will provide economic sustainability and, thereby, help improve the future of beef production in the West.

Summary

The ability of Western beef cattle producers to compete effectively with other regions of North America may depend on management strategies that emphasize profit margins rather than weaning weights. The above information only “scratches the surface” of potential alternative management strategies that may offer economic advantages. Keep in mind, however, that Western beef cattle producers and resources are dynamic, and incorporation of any of these strategies must fit your production philosophy, production goals, and holistic ranch management plan.

Many of the management strategies described in this paper, as well as future opportunities for beef production in the Pacific and Intermountain West, necessarily involve the use of supplementation to utilize low-quality feed resources. Producers must evaluate which supplements are most economically viable in their region, as well as which strategy best fits their needs, nutritional calendar, and management style.

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Chapter 2. Protein/Energy and Physical Form Considerations

ENERGY/PROTEIN SUPPLEMENTATION CONSIDERATIONS FOR GRAZING RUMINANTS

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Introduction

Dormant range forage is usually high in fiber and may be deficient in both protein and energy, especially for cows during late gestation and lactation (Krysl et al., 1987b; Krysl and Hess, 1993). Limited forage quantity or quality may necessitate supplemental feed to maintain reproductive efficiency or to achieve desired levels of production. Unfortunately, when cattle consuming low-quality forages are given traditional concentrate supplements that contain high amounts of non-structural carbohydrates (NSC) such as cereal grains, forage intake and digestibility often are depressed (Chase and Hibberd, 1987; Cordes et al., 1988; Sanson and Clanton, 1989; Sanson et al., 1990). However, supplementation with fibrous by-product feedstuffs that contain high levels of structural carbohydrates, such as soybean hulls and wheat middlings (Chan et al., 1991; Horn et al., 1995), or with higher quality forages, such as alfalfa (Bowman and Asplund, 1988; DelCurto et al., 1990a; DelCurto et al., 1990b; Atwell et al., 1991), has been shown to increase intake and utilization of low-quality forages. This review examines the effects of energy supplements containing starch or fiber on forage intake and utilization by grazing ruminants.

Substitution for Forage vs. Enhancing Forage Quality

The purpose of supplementation of ruminants consuming forages is to make up for limited

forage quantity, where supplement substitutes for forage; or to make up for nutrient deficiencies, where supplement enhances forage quality. Ensminger et al. (1990) defined supplementation as adding feedstuffs to the diet to improve the value of the base feed. By this narrow definition, many of the feedstuffs that are fed with forages are not true supplements, because they do not improve the utilization of the forage. A broader definition of supplements would be feedstuffs added to the base forage to provide nutrients required to support the desired level of production. This definition of supplementation often applies when the desired level of production is significantly above the level provided by the base forage. Although the difference between these two definitions may appear trivial, it becomes important when supplements provide a more economical source of energy than forages. It is also important when substitution for forages is desirable, as when forage availability is limiting or forage supplies need to be stretched.

In the early part of this century, Armsby and Fries (1918) reported that readily fermentable carbohydrates decreased crude fiber digestion; and Morrison (1940) summarized literature in his text that indicated molasses or sugar decreased forage digestibility. Other early supplementation work by Fontenot et al. (1955) and Campbell et al. (1969) indicated that supplements high in NSC interfered with fiber digestibility. In contrast, Johnson et al. (1962) reported that feeding soybean hulls with poor-quality timothy hay increased organic matter (OM), cellulose, and crude fiber digestibility

compared to values predicted from digestibility obtained when either feedstuff was fed alone. Beginning with these early supplementation studies, research indicated that not all energy supplements were equal in their effects on forage utilization.

Carbohydrate Composition of Energy Supplements

Although protein supplements provide energy and may stimulate additional energy intake, generally the term "energy supplement" refers to either cereal grains or by-products of the grain milling industry. Energy supplements can be classified into those high in NSC (starches and sugars) or those high in structural carbohydrates (cellulose and hemicellulose). Examples of energy supplements containing high levels of NSC are corn, barley, and sorghum grains, and molasses-based liquids or blocks. Examples of energy supplements containing high levels of structural carbohydrates are soybean hulls, wheat middlings, beet pulp, and alfalfa hay. It is essential to understand the carbohydrate composition of energy supplements fed with forages, because the type of carbohydrate has a major effect on forage utilization.

Supplementation of forage diets with concentrates containing NSC often decreases fiber digestion and forage intake (Tamminga, 1993). Starch has been shown to have a negative effect on fiber digestion (Mould et al., 1984; Firkins et al., 1991). This depression in fiber digestion may result from the effects of low ruminal pH from increasing volatile fatty acid production on the growth of fibrolytic bacteria (Hiltner and Dehority, 1983; Tamminga and Van Vuuren, 1988), from an increase in lag time for fiber digestion due to preferential use of NSC by fibrolytic bacteria (Mertens and Loftin, 1980; Hoover, 1986), or from competition for nutrients between fibrolytic and amylolytic microorganisms (Mackie et al., 1978; Hoover, 1986). When fiber digestion is depressed, passage rate may

be decreased as well, reducing forage intake (Robinson et al., 1987; Uden, 1988).

By-products of concentrate feeds generally contain more fiber and less starch than the parent feedstuffs. This results in a lower NSC to structural carbohydrate ratio. In addition, by-product fiber or structural carbohydrate is highly digestible (Highfill et al., 1987; Hsu et al., 1987; Anderson et al., 1988b; Nakamura and Owens, 1989) compared with fiber in most forages. As an example, soybean hulls are low in ferulic and para-coumaric acids, non-core lignin phenolics that form covalent crosslinkages between lignin and hemicelluloses and thereby reduce digestibility of the structural carbohydrate fraction (Garleb et al., 1988).

Supplementation of forage diets with by-product feeds usually results in less negative effects on fiber digestion than supplementation with the original grains (Cordes et al., 1988; Garleb et al., 1988). High levels of structural carbohydrates compared to NSC may increase numbers or activity of cellulolytic bacteria (Silva and Ørskov, 1985). By-product concentrates with a high fiber content tend to stabilize rumen fermentation by maintaining a more constant pH, and prevent the negative associative effects of concentrates on forage digestion (Tamminga, 1993). In fact, positive associative effects have resulted from supplementation with soybean hulls to all-forage diets (Johnson et al., 1962; Hintz et al., 1964; Sudweeks, 1977).

Associative Effects of Feeds

Associative effects of feeds usually are ignored when balancing diets for ruminants, and it is assumed that each feed will contribute a given amount of nutrients without interfering with the utilization of the other feeds. This approach does not account for the effects that the supplemental feed may have on fermentation of the basal forage. Associative effects can be negative or positive.

A positive associative effect resulting from supplementation is seen when supplemental protein is provided to animals consuming mature, low-protein forages. Many studies have reported increases in low-quality forage intake and (or) digestibility when supplemental protein was fed (McCollum and Galyean, 1985; Krysl et al., 1987a; Stokes et al., 1988; Sanson et al., 1990). Steers fed mature, low-protein forage had increased ruminal ammonia throughout a 24-h period when a rumen-degradable protein supplement was fed (Sanson et al., 1990). These steers responded to supplemental protein with an increase in diet and forage dry matter intake (DMI). A 22 percent increase in DMI by cattle (Elliott, 1967a) and an 11 percent increase in DMI by sheep (Elliott, 1967b) were reported when peanut meal was fed as a supplement. Other studies have shown increases in intake of mature, low-protein forages by both sheep (Smith and Warren, 1986; Krysl et al., 1987a; Matejovsky and Sanson, 1995) and cattle (McCollum and Galyean, 1985; Smith and Warren, 1986) when rumen-degradable protein was fed. Dry matter digestibility of low-quality forages also has been increased with protein supplementation (Church and Santos, 1981; DelCurto et al., 1990a; Sanson et al., 1990; Gaebe et al., 1994; Matejovsky and Sanson, 1995). The above cited increases in forage intake and digestibility resulted in greater intake of digestible nutrients than would be expected from the nutrient content of the forage and the supplement individually.

A negative associative effect occurs when the supplement suppresses intake or digestibility of the forage so that the intake of digestible nutrients is less than would be expected from the forage and supplement separately. Negative associative effects have been reported when cattle and sheep consuming mature forages were supplemented with corn (Chase and Hibberd, 1987; Sanson and Clanton, 1989; Sanson et al., 1990).

Moore et al. (1995) estimated associative effects between forages and supplements in 113 mixed diets for which digestibility was reported

and observed metabolizable energy (ME; Mcal/kg OM) could be estimated. The expected ME was estimated using forage and supplement intakes and ME concentrations. If the observed ME of the mixed diet was greater than expected, a positive associative effect occurred; and if observed ME was less than expected, a negative associative effect occurred. Both positive and negative associative effects were seen when supplement OM intake was less than 0.8 percent of body weight (BW), but only negative associative effects were seen when supplement intake was greater than 0.8 percent BW. Positive associative effects due to feeding supplements were seen primarily when forages were "unbalanced" (had a deficiency of protein relative to energy) or had a digestible OM (DOM) to CP ratio of greater than 7.

Attempts have been made to estimate forage DM digestibility when supplements are fed by assigning a constant digestibility value (usually the total digestible nutrients [TDN] value) to the supplement, and then correcting the fecal output for the undigested supplement. This approach assumes that all of the negative associative effect that occurs from feeding a supplement is on the forage, and disregards the possibility that the digestibility of both forage and supplement may be affected. Decreases in estimated hay DM digestibility of low-quality forages have been seen with sheep (Sanson, 1993; Matejovsky and Sanson, 1995) and cattle (Sanson and Clanton, 1989; Sanson et al., 1990) supplemented with increasing levels of corn. Chase and Hibberd (1987) reported a cubic decrease in estimated hay DM digestibility when steers consuming a low-quality hay were supplemented with increasing levels of corn. These researchers concluded that a small amount of corn supplement may have little or no effect on hay digestion, whereas higher levels have a negative associative effect.

Level of Supplementation

Limited amounts of NSC may stimulate fiber digestion by increasing microbial activity and attachment to fibrous digesta (Demeyer, 1981; Hiltner and Dehority, 1983); however, increasing amounts of NSC usually depress forage digestion and intake.

Chase and Hibberd (1987) reported that forage and total diet DMI by cows fed mature, low-protein native grass hay decreased linearly as level of supplemental corn increased from 0 to 0.78 percent BW. These supplements were balanced for similar N intake from the supplements, but not for similar N degradability. A cubic response was seen in forage neutral detergent fiber (NDF) digestibility to level of corn supplementation. Little effect on forage NDF digestibility was seen at the first level of corn supplementation; however, a large decrease in digestibility occurred between the first and second level of corn, and then only a small decrease between the second and third level of corn. Diet digestible DMI also responded in a cubic fashion, with intake by cows receiving the highest level of supplementation being 4 percent below that of cows receiving no supplemental corn. Sanson and Clanton (1989) reported linear decreases in intake and digestibility when steers consuming a low-quality meadow hay were supplemented with increasing levels of corn (0, 2.5, 5, or 7.5 g/kg BW). Sanson et al. (1990) reported quadratic responses in intake and digestibility by steers consuming a low-protein meadow hay and unsupplemented or supplemented with protein, or protein plus 2.5 or 5 g/kg BW corn.

Vanzant et al. (1990) supplemented steers consuming bluestem forage (6.1 percent CP) with increasing levels of grain sorghum (0, 1.5, 3.1, or 6.2 g/kg BW). Forage intake and digestible NDF intakes were not affected by increasing level of supplement, whereas total diet DMI was increased linearly by increasing level of supplementation. In contrast, Pordomingo et al. (1991) reported a linear decrease in forage OM intake by steers grazing

blue grama summer rangeland and supplemented with 0, 2, 4, or 6 g/kg BW of corn, with no effect on total OM intake or digestible OM intake. When steers were fed a medium-quality bromegrass hay (9.9 percent CP; 56.2 percent dry matter digestion [DMD]) and supplemented with 6 g/kg BW corn or barley (Carey et al., 1993), diet intake was not affected by supplementation, although forage intake by steers receiving supplements was lower than steers receiving only a protein supplement. Paisley et al. (1994) fed steers native meadow hay (9 percent CP) and 0, 2.5, or 5 g/kg BW of either corn or barley. Forage intake was depressed quadratically by both supplements, whereas diet DMI and digestible DMI were not affected. Sanson (1993) reported lambs consuming low-quality hay and supplemented with increasing levels of corn exhibited a decrease in forage intake when the level of corn reached 0.75 percent BW. Studies with steers fed low-quality forage and supplemented with increasing levels of corn demonstrated a decrease in forage intake when the level of corn reached 0.5 percent BW (Chase and Hibberd, 1987; Sanson and Clanton, 1989; Sanson et al., 1990). These data indicate that the response in forage intake to level of corn supplementation differs between cattle and sheep, with sheep able to consume higher levels of supplemental corn before forage intake is negatively affected.

In the above studies with low-protein, mature forages, supplements containing low levels of NSC tended to affect forage utilization positively, whereas supplements containing high levels of NSC had small to large negative effects, depending on the amount of NSC fed. It appeared that supplements with high levels of NSC, such as feed grains, have minimal negative effects on forage utilization when fed at or less than 0.25 percent BW. At levels above 0.25 percent BW, negative effects were much larger.

We used data from 116 comparisons in the literature that estimated forage DMI with and without supplementation to evaluate the effects of level and composition of supplement on

change in forage intake. Supplement DMI as %BW, supplement %CP, forage %CP, forage DMI as %BW without supplementation, forage DMI as %BW with supplementation, composition of the supplements, and the change in forage DMI as %BW due to supplementation were estimated from the individual research studies. Data from the Cornell net carbohydrate and protein system (Sniffen et al., 1992) were used to estimate supplement NSC intake as %BW, supplement starch intake as %BW, supplement %NSC, supplement % carbohydrate, supplement carbohydrate intake as %BW, supplement sugar intake as %BW, and supplement CP intake as %BW.

Correlations were made between the change in forage DMI (%BW) and all of the forage and supplement characteristics. Results of the correlation analysis are presented in Table 1. The two characteristics that had the greatest individual relationship with the change in forage DMI were forage %CP and supplement starch intake as %BW. Using stepwise regression analysis, forage %CP and supplement starch intake as %BW explained 65 percent of the variation in the change in forage DMI ($P = 0.0001$) and resulted in the prediction equation: $Y = 0.95 - 0.11 (\text{forage \%CP}) - 0.62 (\text{supplement starch intake, \%BW})$. This equation predicts that increasing forage CP content and increasing supplemental starch intake would reduce any positive effect supplementation had on the change in forage DMI. Figure 1 represents this prediction equation, plotting the change in forage DMI versus forage CP content, when defined levels of supplemental starch are fed ranging from 0.15 to 0.75 percent BW. For a 1,200 lb cow, 0.1 percent BW starch intake represents 1.8 lb supplemental corn, and 0.5 percent BW starch intake represents 9.2 lb supplemental corn. Figure 1 indicates that 0.1 percent BW starch can be fed with forages containing up to 8 percent CP without a negative effect on forage intake. However, 0.1 percent BW starch has a negative effect on forage intake when fed with forages containing greater than 8 percent

Table 1. Correlations between changes in forage DMI with supplementation, forage, and supplement characteristics, as calculated for 116 comparisons in the literature.

Item	Change in forage DMI, %BW
Forage CP, %	-0.66
Supplement characteristics	
Intake, %BW	-0.47
CP, %	0.33
NSC, %	-0.27
Carbohydrate, %t	-0.39
NSC intake, %BW	-0.56
Starch intake, %BW	-0.66
Carbohydrate intake, %BW	-0.53
Sugar intake, %BW	-0.41

CP. A level of 0.5 percent BW supplemental starch can be fed with forages containing 6 percent CP or less without negative effects on forage intake.

Substitution Rate

Substitution rate is defined as the change in forage intake in kg DM per kg supplement DM fed. A positive substitution rate indicates that forage intake was reduced by supplement intake "substituting" for forage. A negative substitution rate indicates that forage intake was increased by supplementation.

Goetsch et al. (1991) reviewed 18 studies with steers fed bermudagrass and supplemented with corn at levels from 0 to 1 percent of BW and reported that for each kg of corn, hay DMI decreased by 0.46 kg (substitution rate of 0.46). These hays varied in CP from 8 to 12 percent. In contrast, lambs consuming a medium-quality native hay (10 percent CP) and supplemented with corn had a substitution rate of -0.17, whereas lambs consuming a high-quality hay (14 percent CP) exhibited a substitution rate of -0.02 (Matejovsky and Sanson, 1995). Wide variations in the substitution of supplement for forage have been reported by others. Moore et al. (1995) calculated the substitution rate for 135 comparisons between forage intake alone and when supplement was fed, and found little relationship between substitution rate and forage characteristics or level of supplement intake.

Jones et al. (1988) reported intakes of a warm-season forage (bermudagrass) by steers supplemented with 0.48 percent BW of corn were higher than a cool-season forage (orchardgrass), although calculated substitution rates were similar (0.42 and 0.48 for bermudagrass and orchardgrass, respectively). Pordomingo et al. (1991) observed a linear decrease in forage intake with steers grazing summer blue grama rangeland and supplemented with corn. Calculated substitution rates were -0.95, 1.25, and 1.3 for steers fed 0.2, 0.4, and 0.6 percent BW of corn, respectively. This forage had a mean CP of 10.5 percent and *in vitro* dry matter digestion (IVDMD) of 62 percent. Carey et al. (1993) reported a substitution rate of 0.56 for steers fed a medium-quality forage and supplemented with corn, barley, or beet pulp; whereas, Paisley et al. (1994) observed a substitution rate of 1 for corn and 0.72 for barley with steers fed a medium-quality forage. Chase and Hibberd (1987) reported a substitution rate of 0.56 for steers fed low-quality forage. Dairy cows grazing perennial ryegrass-white clover pastures (17 to 22.8 percent CP) and supplemented with 4 or 8 kg of barley, had substitution rates of 0.64 (Opatpatanakit et al., 1993). The Australian Standard Committee on Agriculture (1990) reported a substitution rate of 1 for high digestibility supplements fed to cows grazing high-quality forage, and a substitution rate of 0.6 for low digestibility supplements. Allden (1981) indicated that forage availability affects substitution rate, with substitution rate increasing linearly with forage availability below 1,500 kg DM/ha.

Broster and Thomas (1981) indicated that substitution rate can be influenced by forage characteristics, level and type of concentrate, and physiological state of the animal. Many researchers found substitution rate increased with increasing level of supplement (Phipps et al., 1988; Faverdin et al., 1991); however, others reported no effect on substitution rate of level of supplementation (Gordon, 1984; Opatpatanakit et al., 1993). Supplements containing high levels of NSC have been shown to have higher substitution rates than

supplements containing lower levels of NSC (Meijs, 1986; Faverdin et al., 1991).

Jarrige et al. (1986) reported that substitution rates vary with forage quality and fill value. These authors presented data that suggest that as fill value increased (forage quality decreased), the substitution rate decreased, or became more negative. The concept appears valid in general; however, when fill values and substitution rates were estimated with sheep, the substitution rates were from 0.2 to 0.4 (Sanson et al., unpublished data), compared to observed substitution rates of 0.8 to 1 with medium- to high-quality forages presented by Jarrige et al. (1986). This points out problems with assigning one substitution rate for all concentrates and all animals.

We made calculations of substitution rate for 116 observations in the literature where estimates of change in forage DMI with supplementation were given. These data are presented in Figure 2, and a strong relationship ($R^2 = 0.51$; $P = 0.0001$; $Y = -1.77 + 0.24 X$) was found between substitution rate and forage percent CP. Substitution rate was zero when forage CP was equal to 7.4 percent, averaged -0.83 for forages below 7.4 percent CP, averaged 0.5 for forages between 7.4 and 12 percent CP, and averaged 2.0 for forages above 12 percent CP. This means that each unit of supplement resulted in a 0.78-unit decrease in forage DMI when forage CP was between 7.4 and 12 percent, and resulted in a 2-unit decrease in forage DMI when forage CP was above 12 percent. A 0.83-unit increase in forage DMI resulted when forage was below 7.4 percent CP. Using stepwise regression, substitution rate was best predicted ($R^2 = 0.60$; $P = 0.0001$) by DMI of the forage without supplementation (DMIF), forage CP%, (FCP), supplement CP% (SCP), and supplement starch intake as %BW (STIBW), resulting in the following prediction equation: $Y = -1.69 + 0.34(\text{DMIF}) + 0.18(\text{FCP}) - 0.02(\text{SCP}) + 0.32(\text{STIBW})$. The substitution rate increased (became more positive, or supplement had a larger depressing effect on forage DMI) as DMI of forage without supplementation, forage CP%, and supplement

starch intake (%BW) increased. Substitution rate decreased (became more negative, or supplement had a less depressing effect on forage DMI) as supplement CP percent increased. As demonstrated in the above calculation of substitution rate, and suggested by Jarrige et al. (1986), the substitution rate of a supplement varies with the characteristics of the forage and the supplement.

Non-Structural Carbohydrate Supplements

Differences may exist in source and amount of NSC, as barley has been shown to have a greater negative effect on fiber digestion compared with corn (DePeters and Taylor, 1985; McCarthy et al., 1989; Herrera-Saldana and Huber, 1989). Others have reported no differences between supplemental grain sources when fed at similar DM levels (Vanzant et al., 1990). Galloway et al. (1993) reported no difference in digestible OM intake by steers fed bermudagrass hay and supplemented with 1 percent BW of ground corn, whole corn, ground grain sorghum, or ground wheat. However, gain was greater for grazing steers supplemented with ground corn, whole corn, or ground sorghum grain, than for those supplemented with barley or wheat. Fredrickson et al. (1993) reported no differences in prairie hay intake when steers were supplemented with 0.25 percent BW starch from barley, corn, grain sorghum, or wheat.

The effect of NSC supplementation on (NDF) digestibility has varied. Chase and Hibberd (1987) reported a decrease in NDF digestion as level of corn fed to steers consuming low-quality hay increased. Neutral detergent fiber digestion was decreased by corn supplementation in sheep (Sanson, 1993) and cattle (Sanson et al., 1990) consuming low-quality forage. Sanson and Clanton (1989) reported a decrease in disappearance of NDF from nylon bags when steers consuming low-quality forage were supplemented with corn. Carey et al. (1993) reported a decrease in NDF digestion by steers receiving a medium-quality

forage and either corn or barley supplement, whereas Paisley et al. (1994) reported no effect of supplemental corn or barley on NDF digestion by steers consuming a medium-quality forage. Krysl et al. (1989) reported no effect on *in situ* NDF disappearance when steers grazing medium-quality rangeland were supplemented with steam-flaked sorghum grain. Vanzant et al. (1990) reported no effect of supplemental grain sorghum on NDF digestion by steers consuming early-growing season, bluestem forage; whereas, Jones et al. (1988) reported a decrease in NDF digestion of steers consuming either orchardgrass or bermudagrass and supplemented with 0.5 percent BW of corn. Galloway et al. (1991) observed no differences in NDF digestion when Holstein steers were fed 0.5 percent BW corn and bermudagrass, yet NDF digestion decreased when ryegrass-wheat hay and 0.5 percent BW corn was fed. With bermudagrass, NDF digestion averaged 10.5 percent lower than ryegrass-wheat NDF digestion. These data indicate a large variation in the effect of cereal grain supplementation on digestion of the NDF fraction by sheep and cattle.

By-product Supplements

Some by-products of the milling industry offer feeds that are low in NSC and contain structural carbohydrates that have high digestibility. Supplementation with fibrous by-product feedstuffs, such as soybean hulls and wheat middlings, has been shown to increase intake and utilization of low-quality forages by cattle (Chan et al., 1991; Horn et al., 1995; Ørskov, 1991). Wheat middlings supplements increased forage intake and fiber digestibility when fed to beef cattle consuming dormant range forage (Sunvold et al., 1991). Martin and Hibberd (1990) reported a quadratic decrease in hay OM intake, a quadratic increase in total diet OM intake, and a linear increase in digestible OM intake and NDF digestibility when cows consuming low-quality grass hay were supplemented with increasing levels of soybean hulls. It should be noted that when evaluating the effects of supplements high in degradable

fiber on diet NDF digestibility, the digestibility value includes the digestibility of the supplement as well as the forage. In this case, actual forage NDF digestibility may have decreased, since it would be expected that the digestibility of the NDF fraction of soybean hulls would be higher than the forage. Sanson (1993) reported diet DM digestibility decreased linearly when lambs consuming mature crested wheatgrass hay were supplemented with increasing levels of corn, whereas supplementation with increasing levels of beet pulp did not affect diet DM digestibility. Supplementation with increasing levels of corn caused a linear decrease in NDF digestibility, while NDF digestibility increased linearly with increasing levels of beet pulp supplementation.

Anderson et al. (1988a) reported steers and heifers grazing smooth brome pastures and heifers grazing corn stalks had similar gains when supplemented with soybean hulls or an equal amount of supplemental DM from corn and gained more than unsupplemented animals. Marston et al. (1992) supplemented gestating cows grazing dormant native prairie with 0.64 kg of protein from supplements containing different combinations of soybean hulls and soybean meal. Cows receiving a supplement containing high levels of soybean hulls consumed less forage but gained more weight than cows receiving a supplement low in soybean hulls.

Forage NDF intake by steers increased with increasing soybean hull supplementation, but decreased when corn was supplemented (Anderson et al., 1988b). Average daily gain and feed conversion were similar in growing calves when they were fed forage diets supplemented with soybean hulls or corn (Anderson et al., 1988b). Stocker cattle grazing wheat pasture had improved gains when fed a soybean hull/wheat middling supplement compared with a corn supplement (Horn et al., 1995).

Ovenell et al. (1989) and Cox et al. (1989) reported experiments where fall- and spring-calving cows grazing dormant native prairie

received supplements containing 0.54 kg CP and 0, 0.36, 1, or 2.2 kg wheat middlings. Spring-calving cows had increased weight gain with increasing level of wheat middlings in the supplement. In contrast, level of wheat middlings in the supplement did not affect weight change of fall-calving cows (lactating); all lost weight during the supplementation period. Any additional energy supplied by the supplement may have increased milk production at the expense of cow weight in the fall-calving cows.

Kunkle et al. (1995) compared supplements of corn, wheat middlings, and soybean hulls fed at 0.5 or 1 percent BW to growing steers consuming high-quality bermudagrass hay. Gain, forage intake and NDF digestibility were similar for all three supplements when fed at 0.5 percent BW. However, when supplements were fed at approximately 1 percent BW, cattle fed corn had lower gains, forage intake and digestibility than those fed soybean hulls. Cattle fed wheat middlings at 1 percent BW had gains intermediate to those fed corn or soybean hulls.

Cows grazing winter range were unsupplemented or supplemented with soybean hulls/soybean meal, wheat middlings, or barley/soybean meal fed to supply equal amounts of DM and CP, but increasing levels of NSC (Surber et al., 1996). Intake and digestibility of forage and total diet DM, OM, and NDF decreased linearly with increasing level of NSC. The lowest NSC supplement, soybean hulls/soybean meal, increased total diet intake of CP. Cow BW change responded quadratically to increasing level of NSC, with the most weight being lost by unsupplemented cows, and those receiving the highest level of NSC, the barley/soybean meal supplement. Carboxymethylcellulase activity of particle-associated microbes attached to forage extrusa ruminally incubated in nylon bags decreased linearly with increasing level of NSC supplementation (Figure 3). Increasing levels of NSC reduced cellulolytic activity of ruminal microbes, resulting in decreased forage digestibility and intake.

High-quality Forage Supplements

High-quality forages also have application as supplements for mature low-quality forages. Judkins et al. (1987) reported that heifers grazing dormant rangeland responded similarly to supplementation with alfalfa hay when fed at an equal level of CP as they did to supplementation with cottonseed meal. High-quality grass forage also can be used as a supplement. Villalobos et al. (1992) reported cows grazing dormant native range and supplemented with 0.31 kg of protein from either high-quality meadow hay or soybean meal gained more weight than cows receiving no supplement.

Bowman and Asplund (1988) reported a 9 percent increase in DMI and a 60 percent increase in ADG when lambs consuming low-quality Caucasian bluestem hay were supplemented with alfalfa hay. When beef cows grazing dormant range forage were supplemented with soybean meal/sorghum grain, alfalfa hay, or dehydrated alfalfa pellets, forage intake was increased over cows not given supplement (DelCurto et al., 1990b). Cows fed alfalfa hay or dehydrated alfalfa pellets had a greater digestible DMI than unsupplemented cows or those supplemented with soybean meal/milo. Forage OM intake and digestibility were increased when steers consuming low-quality range forage were fed supplemental alfalfa at 0.5 percent BW (Lintzenich et al., 1995).

Castrillo et al. (1995) supplemented sheep consuming barley straw with increasing levels of meadow grass hay, beet pulp, or barley. Straw intake decreased linearly with increasing level of all three supplements, but no effect of supplement type was seen.

Vanzant and Cochran (1994) fed beef cows grazing low-quality forage increasing levels of supplemental alfalfa hay (0.48, 0.72, or 0.96 percent BW) during the winter, and found quadratic responses in digestible DMI and estimated ME intake. Cows fed the highest level of alfalfa supplement weaned the heaviest

calves, had the shortest interval to conception, and lost the least amount of weight and body condition.

Forage Quality

In general, forage quality and nutritive value decrease with physiological maturity or growth stage due to increases in the proportion of cellulose, hemicellulose, and lignin, and decreases in CP and NSC content (Nelson and Moser, 1994). The digestibility of structural carbohydrate also decreases as forages mature (Gordon et al., 1983; Nelson, 1988; Shaver et al., 1988). When native meadow forages were harvested at two different maturities, the digestibility of structural carbohydrates was 45 percent for the late-cut or mature forage compared to 60 percent for the early-cut forage (Sanson et al., unpublished).

The decrease in forage digestion seen with NSC supplementation becomes more severe as forage quality declines (Doyle, 1987; Beever et al., 1988). However, the depression of forage DMI by NSC supplementation is greater with high-quality forages than with low-quality forages (Jarrige et al., 1986; Minson, 1990).

In a review of the effects of chemical and physical composition of forage on intake, Minson (1982) reported that intake of forages containing greater than 8 percent CP was not increased by supplemental protein. Forage or diet DMI was not increased by a rumen-degradable protein supplement when lambs consumed a medium- or high-quality forage (Matejovsky and Sanson, 1995).

Moore et al. (1995) reported a relationship between the change in forage DMI when supplements were fed and the ratio of DOM to CP in the forage. When DOM:CP was less than 7 (a balance between energy and protein), the change in forage DMI with supplementation was always negative. When DOM:CP was greater than 12 (very unbalanced for protein relative to energy), the change in forage DMI was always positive, with all types and levels of

supplements increasing forage intake. When DOM:CP was between 7 and 12 (deficient in protein relative to energy) the changes in forage DMI were both positive and negative, with increases in forage intake occurring with low intakes of supplement, and decreases in forage intake occurring with high intakes of supplement.

Forage quality alters the effects that supplements have on forage utilization. Lambs consuming low-quality forage responded to a protein supplement with increased forage DMI, but increasing levels of corn supplement decreased forage DMI (Matejovsky and Sanson, 1995). Total diet DMI was decreased when corn intake was above 0.5 percent BW. In contrast, total diet DMI by lambs fed medium- or high-quality forage was not affected by level of corn supplementation, and forage DMI decreased linearly, implying a 1:1 substitution of the corn for the forage. Diet digestibility increased linearly with increasing supplement level for lambs fed all three forage types.

In a study to evaluate the interaction of forage quality and level of supplementation, lambs were fed low- (5.2 percent CP, 44 percent DMD), medium- (10.2 percent CP, 58 percent DMD) or high-quality (14.2 percent CP, 58 percent DMD) hays and either no supplement or a protein supplement with 0, 2.5, 5, or 7.5 g/kg BW of corn (Sanson et al., unpublished data). Hay DM and NDF intake decreased quadratically with increasing level of corn supplementation. Little effect was seen on forage DMI until 7.5 g/kg BW of corn was supplied, at which time both hay DM and NDF intake were decreased by 20 percent. Total diet DMI increased with increasing level of corn supplementation, until 7.5 g/kg BW of corn was reached, when it was reduced by 7 percent. Digestible diet DMI responded in a similar fashion. In contrast, total diet DMI and total diet digestible DMI by lambs consuming medium- and high-quality forages were not affected by level of supplemental corn, but forage DMI decreased linearly with increasing corn supplementation.

Lake et al. (1974a; 1974b) reported that steers grazing irrigated pasture and supplemented with corn had higher gains than unsupplemented animals. Heifers fed medium-quality (9 percent CP, 56 percent DMD) native meadow hay and supplemented with 0.7 or 1.4 kg of corn or barley gained more weight than unsupplemented heifers (Sanson et al., 1993). As the level of supplement increased, heifer gains increased linearly, with no difference between corn and barley fed in similar amounts. In contrast, cows consuming native meadow hay (7 percent CP, 51 percent IVDMD) and supplemented with 0, 0.9, or 1.8 kg of corn had similar performance, although there was a trend for increase in gains as level of corn supplementation increased (Sanson and Clanton, 1989). These data indicate that responses in forage digestion and intake, and animal gain to supplementation are different for medium-quality forages than low-quality forages (Vanzant et al., 1990; Sanson and Clanton, 1989).

Supplement Energy/Protein Interactions

Classification of supplements as either energy or protein is somewhat confusing, because both types of feeds contain energy and protein. In fact, natural protein supplements usually contain similar energy levels as energy supplements. For example, nutrient composition tables (NRC, 1984) list the TDN content of soybean meal to be 84 to 87 percent, whereas barley and corn contain 84 and 90 percent TDN, respectively. However, the carbohydrate composition of protein and energy supplements may differ substantially. The total carbohydrate contents of barley and corn (82.3 and 84.0 percent, respectively) are approximately twice that of soybean meal (37.4 to 41.3 percent), and the NSC contents are 64.3 and 75.6 percent in barley and corn, respectively, compared to 29.8 to 32.2 percent for soybean meal (Sniffen et al., 1992).

The levels of both energy and protein in supplements are important, and often these interact. With mature forages, there may not be

adequate nitrogen for microbial fermentation of fiber, and additional protein from either a "protein" or an "energy" supplement may result in improved forage utilization. Researchers often try to remove the interaction of protein and energy by attempting to keep the level of one constant while varying the other. The concept is valid, but difficult to accomplish because of differences in protein degradability and carbohydrate content. Creating isonitrogenous or isocaloric supplements does not mean that N or energy from different supplements will be available at the same rate. It becomes more complex when developing isocaloric supplements, because protein and energy feeds both supply energy, yet the effect that energy from amino acids has on microbial fermentation in the rumen may be different than the effect that NSC or structural carbohydrates have on fermentation. When barley and soybean meal are fed at the same level of DM, equal levels of energy would be provided; however, soybean meal provides much less starch than barley. Effects of supplements containing combinations of oil meals and cereal grains on forage utilization have been variable (Williams et al., 1953; Fontenot et al., 1955; Elliott, 1967a, 1967b; Rittenhouse et al., 1970), and performance of animals supplemented with various levels of protein and energy has not been consistent (Norman, 1963; Bellows and Thomas, 1976; Davis et al., 1977; Hennessy et al. 1981; Sanson et al., 1990). The variable results may be due in part to different levels of NSC in supplements that are formulated to be isocaloric.

Another approach that has been used is to feed the supplement in increasing amounts. With this approach, an attempt is made to control the level of either protein or energy and allow the other to increase. However, this results in different amounts of DM being fed, which also may affect the utilization of the basal forage. Because of the interaction between protein and energy in supplements, and its effect on forage utilization, it is important to understand the impact that the design of the supplemental treatments can have on the outcome of the experiment.

Pruitt et al. (1993) supplemented cows grazing native winter range with two levels of protein and energy. Cows received 0.32 kg CP and 3.92 Mcal ME, 0.32 kg CP and 10.64 Mcal ME, 0.64 kg CP and 7.78 Mcal ME, or 0.64 kg CP and 10.91 Mcal ME. Increasing supplemental energy at the low level of CP did not increase cow weight gains. However, increasing supplemental energy at the higher level of CP increased weight gain by 9.5 kg.

Cattle grazing dormant native winter range were fed supplements containing 0.13 kg CP and 1.18 kg TDN, 0.28 kg CP and 1.18 kg TDN, or 0.28 kg CP and 0.72 kg TDN during the last third of gestation (Sanson et al., 1990). Cows receiving 0.28 kg CP and 0.72 kg TDN gained 4 kg during this period, cows receiving 0.28 kg CP and 1.18 kg TDN lost 18 kg, and cows receiving 0.13 kg CP and 1.18 kg TDN lost 55 kg. An interaction between supplemental protein and energy was seen in this study, with cows receiving low CP and high TDN losing the most weight, cows receiving high CP and low TDN gaining weight, and cows receiving high CP and high TDN losing an intermediate amount of weight. Differences in the degradability of the protein sources may explain some of the interactions.

Summary

Despite the negative effects on forage digestion and intake that can result, energy supplementation of forage diets can increase animal performance due to an increase in digestible OM intake, a shift in rumen fermentation pattern to a greater proportion of propionate, and an increase in the flow of undigested feed and microbial protein to the intestine (Galyean and Goetsch, 1993).

Data in this paper indicate that the effect an energy supplement has on the utilization of forage is dependent on the composition of the supplement, the level at which it is fed, and the quality of the forage. Supplements high in NSC may have a negative effect on utilization of mature, low-quality forage; the amount of

negative effect depends on forage quality, amount of supplement fed, and the grazing conditions. In contrast, supplements low in NSC have a positive associative effect on low-quality forages and may increase forage intake and digestibility, along with the energy value of the forage. Associative effects of energy supplements (both high and low NSC) on medium- and high-quality forages appear to be more negative compared with their effects on low-quality forages, and often result in a depression of forage intake.

This paper does not suggest that feed grains or other high-NSC supplements should never be fed with low-quality forages. In situations where forage is in short supply, it may be more economical to discount the energy value of the forage and to use grain to provide the additional required energy. Using traditional methods to calculate energy intake, and not correcting for associative effects between forages and supplements by adjusting energy value and intake of the forage, may result in over- or under-estimation of energy intake.

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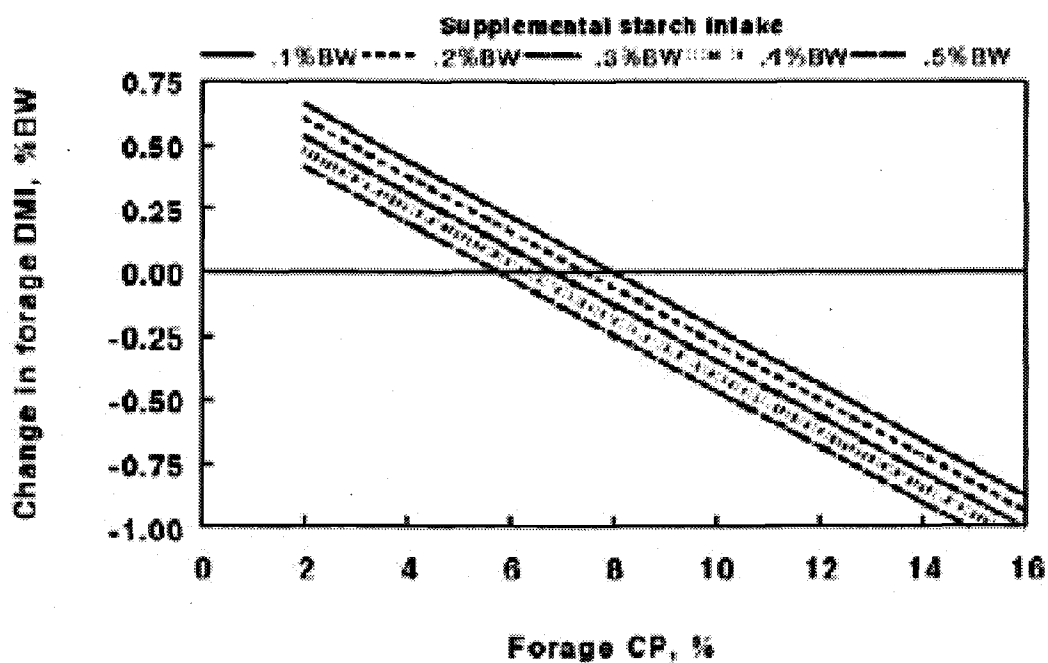


Figure 1. Predicted change in DMI with increasing forage CP and levels of supplemental starch ranging from 0.1 to 0.5% BW.

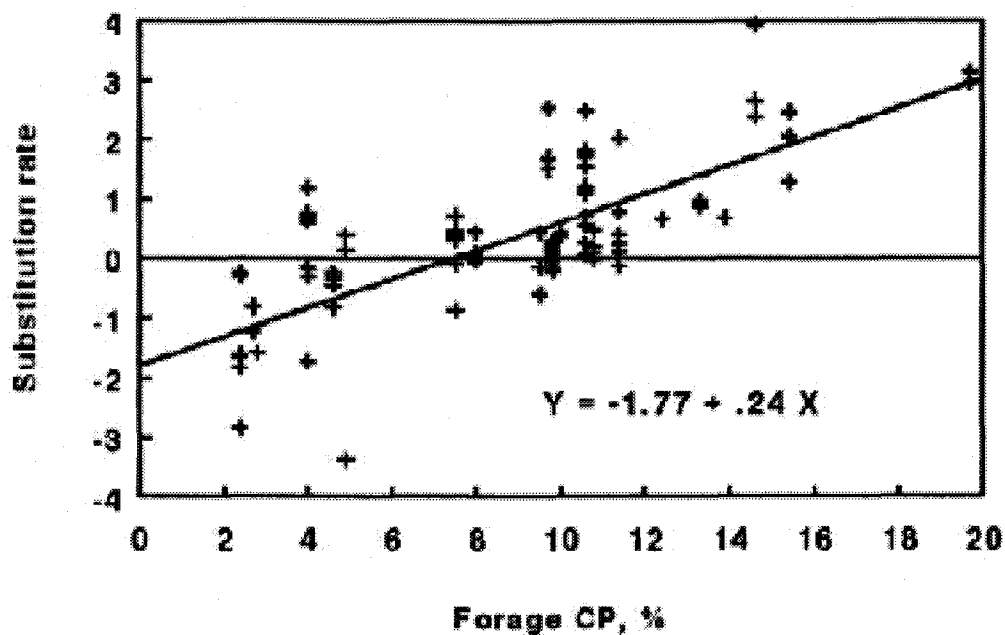


Figure 2. Relationship between substitution rate and forage CP. Data based on 116 observations in literature ($R^2 = 0.51$, $P < 0.01$).

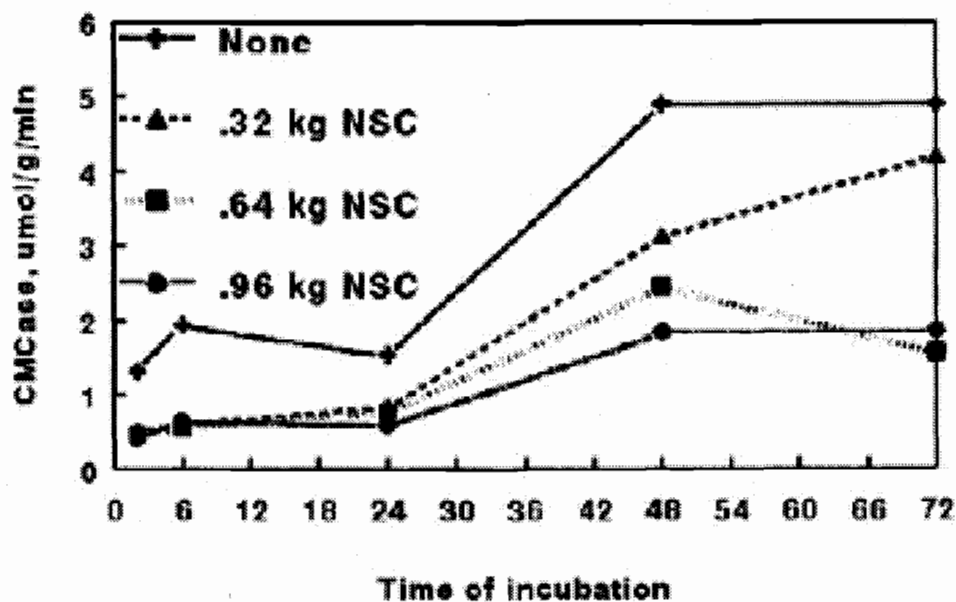


Figure 3. Influence of increasing amounts of supplement non-structural carbohydrates (NSC) and time of incubation on carboxymethylcellulose activity (Surber, et al., 1996).

PHYSICAL FORM OF CRUDE PROTEIN FOR SUPPLEMENTATION OF LOW-QUALITY ROUGHAGES.

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Introduction.

What Supplement is Best?

To this juncture, this publication has addressed the concept of supplementation, protein and (or) energy considerations, and mineral and vitamin supplementation of low-quality roughages. This chapter will focus on protein supplementation building on previous chapters and will begin to address the simple question of "what supplement is best?" Unfortunately, like most simple questions, the answers are not straightforward. In fact, evaluating various supplements is an ongoing process for ranchers and university faculty who focus on supplementation strategies. There are numerous types or "physical forms" of supplemental protein available. In addition, the Beef NRC (1996) has promoted a more detailed evaluation of protein requirements and feed characteristics to achieve optimal production. This improvement in protein characterization has, in turn, inadvertently promoted increased interest in finding the ideal supplement. The influence of supplemental degradable (DIP) versus undegradable intake protein (UIP) on utilization of low-quality roughages is currently being evaluated. What fits a given production scenario will depend on a number of factors, including cost of the protein, ease and practicality of feeding the supplement, as well as productive stage and nutritional status of the animal.

Physical Form of Supplemental Protein.

There is limited information available concerning the efficacy of various types of feeds that might be used as sources of supplemental protein. The most common supplemental protein feed sources are derived from oilseed byproducts such as soybean meal and cottonseed meal (Table 1). These sources of supplemental protein offer several advantages, including high concentrations of crude protein (i.e., soybean and cottonseed meal consistently have at least 50 and 45 percent CP, respectively) and energy densities similar to cereal grains. Thus, we usually consider these supplements as protein sources, they also provide significant energy contributions. However, these feed sources are sometimes expensive. As a result, identifying less expensive alternative feed sources that provide supplemental protein would be beneficial to ruminant livestock producers.

Other potential oilseed supplements include canola meal, sunflower meal, rapeseed meal, and crambe meal. However, little research has been conducted to evaluate their value as supplements to low quality forages for beef cattle. Seoane et al. (1992) supplemented steers receiving a medium-quality grass hay (15.8 percent CP) with canola meal and found that ADG was improved by 60 percent and hay intake was improved by 8 percent. Total diet dry matter digestibility was unaffected, but fiber digestion was decreased by canola meal. Coombe et al. (1987) evaluated rapeseed or sunflower meals as supplements for growing sheep grazing low-quality grass pastures. Sheep

receiving no supplement or a urea supplement lost weight, whereas sheep receiving sunflower meal gained weight. Intake of rapeseed meal was low and variable, and resultant sheep performance was also variable and intermediate to performance of control and sunflower-meal supplemented sheep. Crambe seed is another oilseed that provides a high-protein meal after oil extraction. Caton et al. (1994) compared crambe meal to soybean meal, and found that OM and fiber digestion were similar, but N digestion was greater for crambe meal indicating that it may have higher DIP than soybean meal.

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

In the Pacific Northwest and Intermountain West, alfalfa hay or cubes are often the supplement of choice because of competitive pricing and easy accessibility to the supplements. Studies comparing alfalfa and alfalfa products to oilseed-based supplements have yielded variable results. Work from eastern Montana (Cochran et al., 1986) and New Mexico (Judkins et al., 1987) have indicated that alfalfa pellets or cubes are as effective as cottonseed cake when fed on an equal protein basis (Table 3). DelCurto and coworkers (1990c) found that sun-cured alfalfa pellets promoted higher forage intake and better maintenance of mature cow weight and body condition compared to long-stem alfalfa hay or soybean meal/sorghum grain supplements. Increasing levels of supplemental alfalfa often cause a quadratic effect on intake

of low-quality forages (DelCurto et al., 1991; Vanzant and Cochran, 1994). Thus, total rations should be balanced, but exceeding the CP requirements with increased supplemental alfalfa will result in substitution for potential intake of low-quality forage. In general, these results suggest that alfalfa provides the same benefits as other protein supplements when fed on an equal crude protein basis (Table 1). Alfalfa hay may have an added advantage because it is easily transported and handled by ranchers, whereas oilseed supplements may require additional equipment such as feed bunks and storage bins. Furthermore, alfalfa hay has been shown to be comparable to alfalfa pellets whether fed daily or on an alternate day basis (Brandyberry et al., 1994).

While alfalfa is a very versatile protein supplement with easy application to many beef production scenarios, producers should be careful to make sure the energy requirements are met and body condition reserves are adequate during winter feeding periods. Alfalfa can effectively meet CP requirements in rations with low-quality roughages; however, alfalfa does not have the caloric density of the oilseed meals or other byproduct feeds (Table 1). In fact, alfalfa is similar to moderate to high quality grass hay in terms of energy density. Thus, if cows are energy deficient and marginal in body condition (fat reserves), supplements with higher energy density may be more appropriate.

Another potential supplement for low-quality forages is high-quality grass hay. Horney et al (1996) suggested that high-quality fescue hay (11.9 percent CP) supplementation of grass straw (4.1 percent CP) yielded beef cattle performance that was similar to or better than that of cows receiving alfalfa hay supplements (19 percent CP). Likewise, Villalobos et al. (1997) evaluated cow performance and steer digestion responses to supplementation with a 15 percent CP grass compared to a soybean meal and wheat grain mixture while consuming dormant Nebraska Sandhills range forage. Both supplements improved cow performance by a similar amount over control cattle not receiving

supplements. Forage intake was unaffected, but both supplements slightly depressed forage digestibility. These studies suggest that higher quality grass hays are adequate supplements for low-quality roughages.

Use of feeds with high UIP or "bypass" protein is generally not a preferred strategy to supplement low-quality roughages. The optimal time to use low-quality roughages is during the last half of pregnancy. During this time (after weaning), cows are most suited to utilize cheap, low-quality roughage resources because they are not lactating and thus, are at the lowest nutrient requirements of their annual production cycle. Also during this time, amino acid requirements of the cow are adequately met by microbial cell protein reaching the lower gut. Thus, feeds with high levels of UIP such as feather meal, corn gluten meal, blood meal, and other "bypass" supplements can be used (Alawa et al., 1986; Fleck et al., 1988), but they do not offer an advantage over less expensive feeds with high levels of DIP (Table 1). In fact, the Beef NRC (1996) equations generally underscore that DIP is the critical protein fraction to supplement with low-quality roughages. The relative successes of the numerous supplements described above illustrate the need to provide supplemental protein to beef cattle consuming low-quality, nitrogen-deficient diets. However, the general success of all supplements suggests that site of protein degradation (ruminal versus intestinal) is not a major consideration with the mature, non-lactating beef cow.

Optimal Protein Concentration

Numerous researchers have evaluated differing protein concentrations as well as protein to energy ratios with variable results in terms of providing consistent recommendations. DelCurto et al. (1990a,b) suggested that a 26 percent CP soybean meal-sorghum grain supplement was an optimal concentration for low-quality tallgrass prairie forage when compared with 13 and 39 percent CP supplements. In these studies, all supplements

provided the same amount of energy, but were somewhat confounded by source of energy with high starch content in the low protein supplements. Likewise, in a study evaluating wheat middlings in 15, 20, and 25 percent CP supplements, Sunvold et al. (1991) suggested that 20 percent was best for enhancement of forage intake whereas reduced benefits were reported at the 25 percent CP level. Both researchers indicated negative effects of low protein concentrations, including reduced intake and digestibility, which was presumably due to the high starch content of the low protein supplements.

Optimal protein concentration of forage supplements is less easily defined. Horney et al. (1996) found that high-quality meadow hay (11.9 percent CP) was comparable to alfalfa hay (19.0 percent CP) when used as a supplement to tall fescue straw (4.1 percent CP). In fact, cows supplemented with meadow hay gained more weight and tended to lose less body condition than alfalfa hay-supplemented cows; presumably due to the greater quantity of meadow hay fed to provide similar protein levels. Likewise, Weder et al. (1998) conducted a series of experiments evaluating the influence of alfalfa hay quality on intake, forage use, and subsequent performance by beef cattle consuming low-quality roughages. Alfalfa hays ranging in quality from 15 to 21 percent CP did not influence intake and digestibility of the low-quality basal diets nor dramatically alter beef cattle weight and body condition status when fed to provide equal amounts of protein. Therefore, in an alfalfa hay market that places a premium on CP concentration, beef cattle producers should look at feeder quality alfalfa as a viable supplement to low-quality roughages.

Use of NPN Supplements

Nonprotein nitrogen (NPN) supplements are commonly used in both hand-fed and self-fed supplements. Compared to natural protein supplements, NPN sources are usually substantially cheaper. Therefore, the use of

NPN ingredients yields a substantial economic advantage. However, NPN has not been as effective as natural protein sources when supplemented to cattle consuming low-quality roughages. Summarizing six experiments evaluating the efficacy of urea and feed-grade biuret in supplements fed to cattle on winter range, Clanton (1978) reported decreased performance with supplements containing greater than 3 percent urea or 6 percent biuret as compared to cattle receiving all natural protein supplements. Likewise, Rush and Totusek (1976) found that cows maintained on winter range forage lost less weight when a natural protein supplement was fed compared to isonitrogenous supplements containing urea and biuret. Numerous other researchers have also observed depressions in expected beef cow performance when NPN is substituted for a portion of a natural protein in a supplement (Raleigh and Turner, 1968; Williams et al., 1969; Oltjen et al., 1974). Köster et al. (1997) substituted graded levels of urea for sodium caseinate so all supplement treatments were based entirely on DIP and were isonitrogenous, but differed in ratio of NPN to true protein. Intake of dormant tallgrass prairie forage (2.4 percent CP) was unaffected by treatment, but ruminal and total tract digestibility of OM and NDF, as well as digestible OM intake, all declined quadratically, with the rate of decline increasing as urea content increased. It should be noted that in all the above performance studies, special attention was devoted to assuring proper sulfur to nitrogen ratios in the NPN supplements. Likewise, while the NPN supplements did not yield equal responses to natural protein supplements, positive responses to the improved N status were observed.

Many potential explanations exist regarding why NPN is limited in potential as a source of N for ruminants consuming low-quality roughages. One of the major problems associated with efficient utilization of urea, the most common NPN source, is the rapid release of ammonia. Bloomfield et al. (1960) indicated that urea hydrolysis occurred four times faster than uptake of the liberated ammonia, which in turn, increases the passive transport gradient

and pH, thus making conditions optimal for absorption of ammonia into the blood (Bloomfield et al., 1963). As a result, much of the ammonia released from urea is absorbed before the ruminal bacteria can efficiently utilize it. Additionally, Chalupa (1968) suggested that assimilation of ammonia by ruminal bacteria might also be limited by availability of carbon skeletons, such as branch-chain VFA, and other nutrients. Sulfur is a common nutrient suggested to impact the utilization of ruminal nitrogen due to their interrelated role in microbial cell protein synthesis. The advantage of natural protein sources, in this scenario, is that degradable proteins that are broken down and deaminated provide carbon skeletons and other essential nutrients for microbial cell protein assimilation. These results indicate that NPN might be a more viable supplement if the availability of ammonia was more closely synchronized with fermentative processes and essential nutrients for bacterial growth.

Summary and Implications

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

In general, natural protein appears to be the most beneficial supplement for high-fiber, low-quality roughages in ruminant diets.

Nonprotein nitrogen does not appear to be as beneficial as natural protein supplementation. However, the differences in response can be minimized and NPN can offer economic advantages over natural protein. Furthermore, feeding of slowly degraded or bypass protein,

as well as potentially “rate limiting” amino acids appear to show inconsistent responses and do not appear to show any substantial improvements over traditional supplemental protein sources used with mature, nonlactating beef cows consuming low-quality roughages.

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

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

¹ Adapted for the National Research Council Nutrient Requirements of Beef Cattle (1996).

Table 2. A Summary Of Investigations Comparing Supplementation Strategies With Low Quality Roughages. Effect On Beef Cattle Weight Change, Body Condition Change And Reproductive Efficiency.^{a,b}

Reference	Forage or substrate	Supplement Treatments	Class of livestock	BW Change, kg	BC Change	Supplementary information
Cochran et al., 1986	Dormant mixed grass prairie forage 3.0-6.5 % CP Feeding period: -84 d, year 1 -98 d, year 2	1) Control, no supple. 2) Alfalfa cubes, 16.5 % CP 3) Cottonseed meal/barley cake, 21.6	517 kg pregnant cows (151 hd)	-0.11 24 14	-0.5 0.5 0	Quantities of supplement provided were adjusted to insure equal portions of CP
DelCurto et al., 1990b	Dormant tallprairie forage Feeding period: -Mid November to early February (84 d)	1) 13 % CP supple. fed @ 0.5 % BW 2) 26 % CP supple. fed @ 0.5 % BW 3) 39 % CP supple. fed @ 0.5 % BW	454 kg pregnant cows (99 hd)	-11 12 17	-0.7 -0.4 -0.2	Supplements were isocaloric mixtures of soybean meal and sorghum grains. Tendency for increased birth weights and calf ADG with dams who received high concentrations of supplemental protein
DelCurto et al., 1990c	Dormant tallprairie forage Feeding period: -Mid November to early February (84 d)	4) 25 % CP SBM/sorghum supple. @ 0.48 % BW 5) 17 % CP alfalfa hay fed @ 0.7 % BW 6) 17 % CP dehydrated alfalfa pellets fed @ 0.7 % BW	488 kg pregnant cows (84 hd)	-3 2 19	-0.4 -0.5 -0.3	Quantity of supplements provided were adjusted to insure isonitrogenous treatments. No reproductive differences were observed.
Judkins et al., 1987	Dormant Blue Grama range -11.5 % CP feeding: -Mid February to late April (104 d)	1) Control, no supple. 2) Cottonseed meal (47 %) fed alternate days @ 1.7 kg/hd 3) Alfalfa hay (17.5 % CP) fed alternate days @ 3.6 kg/hd	241 kg heifers	-3 25 24	- - -	Quantity of supplements provided were adjusted to insure isonitrogenous treatments.
Wallace, 1987	Dormant Blue Grama range -9.6 % CP. Feeding Period: -Mid December to mid May (150 d)	1) Cottonseed cake (41 % CP): 3.2 kg 2 x weekly 2) Corn grain cube (9.4 % CP): 2.91 kg 2 x weekly 3) Corn grain cube (9.4 % CP): 83 kg daily	227 kg heifers	34 -2 10	- - -	Heifers receiving cottonseed cake were heavier at breeding and had greater conception rates.
DelCurto et al., 1991	Dormant sagebrush-steppe rangelands: -Year 1 -6.8 to 5.4 % CP 48 hd - 112 d feeding period	1) Control, no supple. 2) 1.5 kg alfalfa/hd/d 3) 3.0 kg alfalfa/hd/d 4) 4.5 kg alfalfa/hd/d	463 kg pregnant cows (5.3 BC)	-30 9 30 44	-1.2 -1.2 -0.1 0.2	Calf ADG and birth weight tend to increase with increasing levels of supplementation. Calving interval declined with increasing level of dam's nutrition. All cows were individually fed supplements during 112 d feeding period.
	-Year 2 -4.2 to 4.8 % CP -72 hd -70 d feeding period.	1) Control, no supple. 2) 1.5 kg alfalfa/hd/d 3) 3.0 kg alfalfa/hd/d 4) 4.5 kg alfalfa/hd/d	471 kg pregnant cows (5.3 BC)	-62 -15 5 11	-2.1 -0.8 -0.2 0.2	Calf ADG and birth weight were increased with 3.0 and 4.5 kg supple. Treatments. All cows were individually fed supplements during 70 d feeding period.

^aSummary is not all inclusive, but lists studies with differing forage bases, treatment structures and productive classes of livestock.^bDefinition of abbreviations: BW = body weight, BC = body condition (1-9 scale), CP = crude Protein, ADG = average daily gains

Table 3. A Summary Of Investigations Comparing Supplementation Strategies With Low Quality Roughages: Effect On Intake And Digestion

Reference	Forage or substrate	Supplement Treatments	Class of livestock	Dry matter intake, % BW		Forage digestion		Supplementary information
				Forage	Total	DM	NDF	
A. Protein levels and protein/energy ratios:								
Church and Santos, 1981	3.8 % CP wheat straw	1) 0 g/kg BW. ⁷⁵ protein 2) 1 g/kg BW. ⁷⁵ protein 3) 2 g/kg BW. ⁷⁵ protein 4) 3 g/kg BW. ⁷⁵ protein 5) 4 g/kg BW. ⁷⁵ protein	270 kg heifers	1.32 1.56 1.72 1.79 1.74	1.32 1.64 1.84 1.94 1.91	47.1 55.8 49.0 48.6 51.9	- - - - -	Increasing levels of protein were achieved by supplementing increasing quantities of soybean meal.
DeIurto et al., 1990a	Dormant tallgrass prairie hay (2.9 % CP)	1) Control, no suppl. 2) 13 % CP suppl. 3) 26 % CP suppl. 4) 39 % CP suppl.	242 kg steers	0.87 0.85 1.36 1.21	0.87 1.27 1.76 1.62	35.5 44.8 48.4 48.8	37.9 29.9 39.9 38.6	Isocaloric supplement fed at .4 % BW
Sanson et al., 1990	Sanhills meadow hay (4.3 % CP)	1) Control, no suppl. 2) 48.5 % CP suppl. 3) 24.5 % CP suppl. 4) 16.0 % CP suppl.	550 kg steers	1.8 2.1 2.0 1.6	1.8 2.3 2.4 2.2	49.5 56.7 59.2 60.0	50.0 52.7 51.1 49.5	Supplements were isonitrogenous with increasing level of corn as CP concentration decreased.
Sunvold et al., 1991	Dormant tallgrass prairie hay (2.0 % CP)	1) Control, no suppl. 2) 15 % CP suppl. 3) 20 % CP suppl. 4) 25 % CP suppl.	422 kg steers	1.03 1.12 1.62 1.70	1.03 1.49 1.99 1.07	34.7 49.3 48.8 49.8	46.2 51.2 53.2 55.5	Supplements were isocaloric mixtures of 40 % wheat middlings and mixtures of soybean meal and sorghum grain.
DeIurto et al., 1990a	Dormant tallgrass prairie hay (2.6 % CP)	1) 22 % CP suppl. fed @ 0.3 % BW 2) 11 % CP suppl. fed @ 0.6 % BW 3) 44 % CP suppl. fed @ 0.3 % BW 4) 22 % CP suppl. fed @ 0.6 % BW	332 kg steers	1.21 0.82 1.07 1.51	1.51 1.42 1.37 1.75	39.1 46.1 45.9 47.5	49.2 44.3 50.9 48.0	2x2 factorial contrasting high and low levels of crude protein (treatments 1 & 2 vs 3 & 4 (with high and low levels of supplemental energy (treatments 1 & 3 vs 2 & 4).
		1) 22 % CP suppl. fed @ 0.3 % BW 2) 11 % CP suppl. fed @ 0.6 % BW 3) 44 % CP suppl. fed @ 0.3 % BW 4) 22 % CP suppl. fed @ 0.6 % BW	401 kg steers	1.30 1.17 1.71 1.49	1.60 1.77 2.01 1.09	- - - -	- - - -	
McCollom and Galyean, 1985	6.1 % CP prairie hay	1) Control, no suppl. 2) Cottonseed meal, 0.8 kg/d (0.37 % BW)	214 kg steers	1.69 2.15	1.69 2.52	49.9 53.5	- -	Early rates of in vitro digestion were improved with supplementation. Digesta kinetics was increased with supplementation.

Table 3. A Summary Of Investigations Comparing Supplementation Strategies With Low Quality Roughages: Effect On Intake And Digestion.^{a, b} (Continued)

Reference	Forage or substrate	Supplement Treatments	Class of livestock	Dry matter intake, % BW		Forage digestion		Supplementary information
				Forage	Total	DM	NDF	
B. Physical Form of Supplemental Protein								
DelCurto et al., 1990c	Dormant tallgrass prairie hay (2.6 % CP)	1) Control, no supple.	259 kg steers	0.49	0.49	42.7	57.3	Supplemental treatments provided equal quantities of ME and crude protein.
		2) Soybean meal/sorghum grain fed at 0.48 % BW.		1.07	1.55	46.3	48.5	
		3) 17 % CP alfalfa hay fed at 0.7 % BW		1.05	1.75	49.6	52.6	
		4) 17.4 % CP dehydrated alfalfa pellets fed at 0.68 % BW		1.21	1.88	44.2	458	
Judkins et al., 1987	Blue grama range (11.5 %)	1) Control, no supple.	230 kg steers	1.08	1.08	-	-	Quantities of supplemented feed were adjusted to be isonitrogenous.
		2) 23 % CP alfalfa pellets		0.77	1.41	-	-	
		3) 47.7 % CP cottonseed cake		0.96	1.29	-	-	
Sunvold et al., 1991	Dormant tallgrass prairie hay (2.4 % CP)	1) Control, no supple.	374 kg steers	0.87	0.87	43.9	54.3	Treatments 2 & 3 provide equal energy levels.
		2) Soybean meal/sorghum grain fed at 0.32 % BW		1.07	1.39	49.4	51.2	
		3) Wheat middlings fed at 0.39 % BW		0.99	1.38	50.6	54.1	
		4) Wheat middlings fed at 0.77 % BW.		1.15	1.92	50.4	49.8	
C. Supplementation Under Grazing Conditions:								
Caton et al., 1988	Blue grama rangelands 8.1 % CP (OM basis)	1) Control, no supple.	Hereford x Angus	0.93	0.93	46.7	3.0	Initial rate of digestion was improved but evened out in later <i>in situ</i> periods
		2) Cottonseed meal, 0.83 kg/d (0.18 % BW)	454 kg steers	1.16	1.34	49.6	%/h 3.4 %/h	
Judkins et al., 1987	Blue grama range (11.5 %)	1) Control, no supple.	230 kg steers	1.08	1.08	-	-	Quantities of supplemented feed were adjusted to be isonitrogenous
		2) 23 % CP alfalfa pellets		0.77	1.41	-	-	
		3) 47.7 % CP cottonseed cake		0.96	1.29	-	-	
Kartchner, 1981	Winter range forage: Blue grama range 6.0 % CP – Year 1	1) Control, no supple.	458 kg dry pregnant	1.89	1.89	54.9	54.9	Differences between years 1 and 2 were attributed to severity of weather and limited availability of forage in year 2.
		2) 1.5 kg cottonseed meal fed on alternate days	Herford cows	1.78	1.94	53.2	52.9	
		3) 1.4 kg barley fed alternate days		1.71	1.86	54.2	51.7	
	Blue gama range 8.1 % CP – Year 2	1) Control, no supple.	497 kg dry pregnant	1.37	1.37	40.6	40.6	
		2) 1.5, 1.5 and 2 kg SBM fed Monday, Wednesday and Friday, respectively	Herford cows	1.61	1.75	46.4	48.6	
		3) 1.3, 1.3 and 2 kg barley		1.27	1.40	38.8	34.3	

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

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

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Chapter 3. Mineral/Vitamin Supplementation

MACROMINERAL NUTRITION OF GRAZING RUMINANTS: LEVELS IN FORAGES GROWN IN THE WESTERN U.S., AND EFFICACY OF SUPPLEMENTATION

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Introduction

Maintenance of production suitable to today's agricultural industry may require supplementation of mineral nutrients to ruminant livestock. Under natural situations, animals make use of salt licks and, at times, bone chewing and other forms of pica to supplement their diets with minerals. In production situations, minerals may be supplied to livestock in several forms, and knowledge of mineral levels and bioavailability in feedstuffs are important to optimize mineral supplementation economically with animal performance.

In 1804, Theodore de Saussure made the first analysis of the ash of herbage. From his experiments, he concluded that plants do not absorb minerals in the same proportion in which they occur in the soil; different soil types have a profound influence upon the concentration of minerals in the same species of plants; the different plant parts differ in their mineral concentration; and the percentage of ash reaches its maximum before flowering in herbaceous plants and then declines (Beeson, 1941). More recent literature has dealt with the different elements separately, but these four conclusions generally hold true.

Changes in forage maturity affect both forage mineral level and bioavailability. For an element to be biologically useful to an animal, it must first be absorbed, and then it must be present at its site of action when needed. The latter requirement might be affected by the chemical form in which the element is found in the body, the ability of the body to store an element and mobilize it when needed, and the

amount of excretion of the element from the body. Both absorptive efficiency and the ability of an animal to store and use an element may vary with the animal's age, nutritional state, and reproductive status. A large volume of research has been devoted to determining biological availability of supplementary minerals (see Ammerman et al., 1995, for a review), however, much less is known about the availability of macrominerals from forages and factors affecting that bioavailability.

Phosphorus

Phosphorus is commonly deficient for livestock on Western rangelands. Deficiencies in phosphorus result in depressed feed intake, growth, lowered reproductive performance, and milk yield. The NRC (1996) lists the phosphorus maintenance requirement of cattle to be 16 mg P/kg body weight. This requirement increases with pregnancy, growth, and lactation. Phosphorus is necessary for proper bone development, absorption of carbohydrates from the intestine, and for energy transfer within cells. A very marked secretion of phosphorus occurs through the saliva in ruminants (Ben-Ghedalia et al., 1975), most of which is reabsorbed while passing through the intestine, so it is not entirely lost from the body. This can be of significance in ruminants whose natural feeds are often deficient in phosphorus.

Phosphorus in forages. Phosphorus has an important function in plants as an energy carrier and is found in sugar phosphates, coenzymes, nucleic acids, and phospholipids. Phosphorus decreases in concentration as plants

mature (McMillen et al., 1943; Rauzi et al., 1969). Declining phosphorus concentrations are related primarily to decreases in the amount of live tissue as plants age. Phosphorus content of dead tissue remains relatively constant and low, whereas live tissue phosphorus is high in young tissue and decreases as the growing season progresses (Greene et al., 1987; Grings et al., 1996). Live:dead ratios of available forage may be a good indicator of phosphorus levels in the diet. Livestock do select a diet higher in phosphorus than the average of what is available, and this does need to be considered in evaluating phosphorus needs. In addition to lowered concentrations in the forage, phosphorus absorption and retention have been reported to decrease with increasing plant maturity (Perdomo et al., 1977; Powell et al., 1978; Rosero et al., 1980; Vona et al., 1984).

Phosphorus supplementation. Phosphorus is stored in the bone, and this can be utilized in periods of limited phosphorus intake. The utilization of stored phosphorus can result in variations in response to supplementation. Factors influencing both dietary and stored phosphorus utilization include the calcium to phosphorus ratio, age of animal, sex, fat and energy levels, environment, hormones, disease and parasites, protein and trace-element levels, chelating agents, and numerous others.

Range cows studied over a 5-year period in New Mexico did not respond to phosphorus supplementation except in a drought year (Judkins et al., 1985). During the drought, phosphorus supplemented cows had a shorter postpartum interval than did non-supplemented cows. Rib phosphorus levels declined during lactation, but these levels recovered during the dry period, even when no phosphorus was supplemented. Karn (1992) conducted a study in North Dakota in which cows were given free access to a phosphorus-containing salt mix. Cows consumed between 3 and 19 percent of their phosphorus requirement through this supplementation method, and there were no differences in performance between supplemented and nonsupplemented cows. The lack of response may have been related to the

low phosphorus intake levels of the supplemented cows. In a later study, Karn (1995) evaluated phosphorus supplementation for heifers. There was no response in live weight gain during the first year, when Hereford and Hereford x Angus cross heifers were used; but in the second year, weight gain was increased in Hereford x Simmental heifers fed phosphorus supplements compared to controls. Breed differences in mineral metabolism have been observed for both cattle and sheep and may have affected response to phosphorus supplementation. These heifers were used in subsequent studies, in which phosphorus supplementation improved calf weaning weight in 3 out of 5 years, giving an average improvement in calf gain of 7.9 kg with phosphorus supplementation (Karn, 1997).

Calcium

Calcium is the most abundant mineral in the body and is required by animals for bone formation, proper neuromuscular irritability, and milk production. The calcium requirement for maintenance of beef cattle is 15.4 mg/kg body weight (NRC, 1996). Additional calcium is required for growth, pregnancy, and milk production. Calcium requirements listed by NRC do account for efficiency of calcium absorption, which is considered to be 50 percent of dietary intake.

Calcium in forages. Calcium is found in both the vacuoles and cell walls of plants. In the vacuoles, it often precipitates as crystals of calcium oxalate. In the cell wall, calcium is found in the middle lamella, where it forms insoluble salts with pectic acids.

Reports on calcium levels in relation to plant maturity have been variable. In southern Wyoming, calcium declined with maturity in blue grama but not in western wheatgrass (Rauzi et al., 1969). Halvorson and White (1981) found calcium tended to increase slightly with age in vegetative and floral tillers of western wheatgrass and floral tillers of green needlegrass. Campbell (1973) reported that

calcium levels in plants grown on irrigated pastures in northeastern Colorado did not vary significantly from May to September. The calcium content of grass species grown in southern Idaho was very erratic throughout the year except for cheatgrass, which showed a steady decline (Murray et al., 1978). The calcium content of stems of timothy and brome grass was observed to decrease with maturity while the calcium levels in the leaves and heads of these species were observed to increase (Pritchard et al., 1964). Calcium absorption and retention has been reported to decrease with increasing plant maturity (Perdomo et al., 1977; Powell et al., 1978; Rosero et al., 1980; Vona et al., 1984). Neither Greene et al. (1987) nor Grings et al. (1996) found calcium to vary consistently with live:dead tissue class. Forbs were consistently higher in calcium than grasses in both Texas (Greene et al., 1987; Meyer and Brown, 1985) and Montana (Grings et al., 1996).

Calcium supplementation. Due to the variation of calcium in forages, levels of calcium in the diets of cattle grazing Western rangelands may vary in an inconsistent pattern, falling both above and below animal requirements (Grings, 1979). Cattle can compensate for short periods of low calcium intake through use of body stores. However, bone mobilization to obtain calcium for physiological functions can have detrimental effects on phosphorus status.

Calcium often is provided to grazing livestock as a by-product of meeting other nutrient needs. Legumes, fed as protein supplements, are high in calcium. Phosphorus supplements often use mono- (16.4 percent calcium) or di-calcium (22 percent calcium) phosphate. The concern in supplying calcium is often the maintenance of an appropriate ration of calcium to phosphorus to ensure adequate phosphorus absorption.

Calcium:Phosphorus Ratio. Literature concerning the importance of a calcium to phosphorus (Ca:P) ratio is varied with regard to ruminant nutrition. Simple-stomached animals have an optimal Ca:P ratio of between 1:1 and

2:1; but in ruminants, a ratio of 7:1 has been found to be satisfactory provided that the phosphorus in the diet is adequate and the imbalance is not long-term. Littlejohn and Lewis (1960) reported that a Ca:P ratio of 7.5:1 had no adverse effect on conception rate of dairy heifers, but growth rate was decreased by this high ratio. Ratios above 7:1 were reported by Wise et al. (1963) to result in decreased performance and efficiency of food conversion to body weight gains in Hereford calves. These authors also reported that a Ca:P ratio of 4.8:1 was most favorable in terms of efficiency of feed conversion. Feeding a low phosphorus forage can result in negative calcium balances, even in animals fed "adequate" calcium levels (Grings and Males, 1987).

Potassium

In animals, potassium plays an important role in the development of nerve impulses and in the contraction of muscle. Potassium requirements for cattle are between 0.6 and 0.7 percent of the diet.

Potassium in forages. Potassium does not form a stable structural part of any molecule within plant cells, but it does act as a cofactor to many enzymes. Grassland vegetation may be deficient in potassium in winter months (Karn and Clanton, 1977). Thomas and Hipp (1968) observed that on sandy soils, heavy rains or rapid plant growth could deplete the available potassium in the soil in a matter of days.

The potassium content of the stems, leaves, and heads of several grasses decreases with increasing maturity (Pritchard et al., 1964; Rauzi et al., 1969; Halvorson and White, 1981). Potassium concentrations of range grasses have been shown to be influenced greatly by live to dead tissue ratios (Greene et al., 1987; Grings et al., 1996). Potassium in dead tissue was always low, whereas live tissue potassium concentrations were very high at the beginning of the growing period and declined over time. Decreases in potassium absorption and retention were found with increasing plant

maturity in cool-season forages (Powell et al., 1978). Potassium absorption decreased or did not change, and potassium retention was not affected by stage of plant maturity in fresh tropical forages fed to sheep (Perdomo et al., 1977).

Potassium supplementation. Karn and Clanton (1977) reported that supplementation of potassium during the winter months prevented a depression in weight gains of weaned steer calves grazing sandhills range in Nebraska. Due to the high availability of potassium from feedstuffs, it can be supplemented easily when needed. Potassium concentrations in supplemental feeds such as hays and oilseed meals are high and can make a significant contribution to potassium intake if fed during periods when forage potassium is low.

Magnesium

Magnesium is necessary to activate many enzyme systems as well as being necessary for oxidative phosphorylation. The magnesium requirement for lactating beef cows has been determined to be approximately 0.20 percent of the diet dry matter (NRC, 1996). For growing animals, the requirement is 0.10 percent. A deficiency of magnesium can lead to grass tetany, a deficiency disease that results in considerable death losses of animals grazing in the world's temperate regions. Grass tetany is more likely to affect older animals, because the ability of the animal to mobilize bone magnesium decreases markedly with age. The availability of magnesium to the animal is very important to the incidence of tetany and may depend upon the levels of potassium, nitrogen, and higher fatty acids in the diet (Jung 1977; Fontenot et al., 1960).

Magnesium in forages. Magnesium is an essential part of the chlorophyll molecule of plants. It is also necessary to activate many enzyme systems and is necessary for oxidative phosphorylation. It is found in high concentrations in live tissue due to its association with chlorophyll. Magnesium

levels in the stems of several grasses were reported to decline with maturity, whereas levels in the leaves and heads of the grasses remained relatively constant (Pritchard et al., 1964). Blue grama showed a decrease in magnesium content with increasing maturity, but this did not occur in western wheatgrass (Rauzi et al., 1969). Halvorson and White (1981) found magnesium levels in the tillers of western wheatgrass and in the vegetative tillers of green needlegrass increased with maturity, while the magnesium content of green needlegrass floral tillers decreased.

Grasses grown on irrigated pastures in northeast Colorado showed an increase in magnesium content with advancing season, starting at a low of 0.21 percent in May and reaching a maximum of 0.30 percent in September (Campbell, 1973). Of seven grass species grown on cheatgrass range in southern Idaho, only cheatgrass showed a decline in magnesium levels with advancing season. The magnesium concentrations in other species were extremely erratic (Murray et al., 1978). Grings et al. (1996) found an effect of live to dead ratios on magnesium content of several range grasses growing in eastern Montana, with live tissue concentrations being greater than dead tissue in both warm- and cool-season grasses. This relationship did not hold true for sedges or forbs. A similar relationship for magnesium concentrations in live and dead tissue was observed by Greene et al. (1987) for forage species in the Rolling Plains of Texas.

Magnesium bioavailability from forages has been shown fairly consistently to increase with increasing plant maturity. This had been observed in a variety of forage types, including freshly chopped tropical grasses (Perdomo et al., 1977), warm-season grass hays (Vona et al., 1984), and cool-season forages (Powell et al., 1978; Rosero et al., 1980).

The K:(Ca+Mg) ratio of forage reportedly is correlated to the incidence of grass tetany (Kemp and t'Hart, 1957). When this ratio was greater than 2.2:1, the occurrence of grass tetany was increased. Butler (1963) also found

the K:(Ca+Mg) ratio to be positively correlated with the incidence of tetany, although he reported ratios as low as 1.25:1 to be associated with occurrence of the disorder. Stuart et al. (1973) reported that the K:(Ca+Mg) ratio was significantly increased after a temperature rise. This increase in the ratio was due to an increase in potassium levels, while calcium and magnesium levels decreased or remained constant. High dietary potassium depresses magnesium absorption from the rumen (Greene et al., 1983a).

Tetany-prone forages also are often high in crude protein, and it is thought that perhaps nitrogen interferes with magnesium metabolism. Several studies have reported increased urinary excretion and decreased plasma magnesium levels but no effect on absorption in ruminants fed high nitrogen diets (Head and Rook, 1955; Moore et al., 1972). The decreased magnesium bioavailability associated with grass tetany is a multi-faceted event.

Magnesium supplementation. Supplemental magnesium often is provided to lactating beef cows in temperate areas for the prevention of grass tetany. Availability of magnesium from inorganic sources does vary. Magnesium oxide is a common source of magnesium, but the bioavailability of the magnesium from this source can vary with particle size, source, and temperature of processing. Magnesium sulfate is a highly bioavailable source of magnesium, but it contains only about 20 percent magnesium, so that consumption of supplements containing this source must be relatively high to ensure adequate magnesium intakes. Reid et al. (1976) added magnesium sulfate to drinking water and obtained intakes of 14 g Mg/d for wintering beef cows. Reports of magnesium bioavailability in dolomitic limestone range from 28 to 71 percent of that of magnesium oxide for cattle (Gerken and Fontenot, 1967; Moore et al., 1971). Magnesite has been found to be poorly utilized by steers (Ammerman et al., 1972; van Ravenswaay et al., 1989). Other sources, such as acetate, citrate, basic carbonate, chloride, and

hydroxide forms have been found to be readily available to cattle (Henry and Benz, 1995).

Since supplementation of readily fermentable carbohydrates has been shown to improve magnesium absorption from forage sources, providing an energy source along with a magnesium supplement may aid in the prevention of grass tetany by improving magnesium utilization. Additions of starch and glucose to the diet have increased magnesium absorption (Madsen et al., 1976) or plasma magnesium levels (Wilson et al., 1969).

Magnesium fertilization has been successful at increasing forage magnesium concentrations. In areas where fertilization is feasible, this could be a useful method of increasing dietary magnesium, since several of the inorganic sources of supplementary magnesium may be somewhat unpalatable, making it difficult to maintain adequate intakes for prevention of grass tetany. Forage breeders have been successful at developing cultivars of cool-season grasses that have increased concentrations of magnesium. Mosely and Baker (1991) found a decreased incidence of grass tetany in lactating ewes grazing a cultivar of Italian ryegrass bred for high magnesium concentrations compared to a control cultivar. Utilization of cool-season forages bred for high magnesium content holds great potential as a means of magnesium "supplementation."

Sodium and Chlorine

Sodium and chlorine are both important to livestock for the maintenance of osmotic pressure within cells and for regulation of acid-base balance. Sodium also plays a role in maintenance of membrane potential and nerve impulse transmission. Beef cattle require 0.06 to 0.08 percent sodium in the diet. Lactation increases this need to 0.10 percent. There is no defined chlorine requirement for beef cattle, and deficiencies are not expected to occur.

Sodium and chloride levels in forages. Sodium is not known to be essential for plant growth,

but chlorine is involved in oxygen production in chloroplasts. Forage concentrations of sodium can vary greatly. Butler and Jones (1973) reported pasture sodium content to range from 0.002 to 2.12 percent, with a more typical range to be 0.05 to 1.0 percent. Minson (1990) surveyed the literature and, of 671 cited values for sodium in forages, found the means to be 0.22 percent with over 50 percent of the samples containing more than 0.15 percent sodium.

The effect of forage maturity on sodium concentrations has been variable. Morris (1980) reported variations in California annual grassland ranges depending upon season. Decreasing sodium concentrations with increasing plant maturity in some grasses have been observed by several researchers, whereas others have reported no effect (Minson, 1990). Murray et al. (1978) did not observe any effects of date of sampling on sodium concentrations in grasses from southern Idaho rangelands, and Grings et al. (1996) found no differences in sodium concentrations between live and dead tissues of several grasses in eastern Montana. Grings et al. (1996) found differences in sodium content of several grasses to vary due to the soil type on which plants were grown. Sodium content of annual bromes varied over time, but no predictable patterns were observed. All forage sodium concentrations were well below animal requirements.

Normal concentrations of chlorine in pasture have been reported to range from 0.1 to 2.0 percent of the diet dry matter. Chlorine deficiencies are not expected to be observed under practical conditions, and chlorine values of forages are reported very rarely.

Sodium and chloride supplementation. Sodium is supplemented easily and routinely to livestock to overcome deficiencies that may exist. Of significance to animal nutrition in the western U.S. may be the sodium content of water, as high-saline waters often are found in arid and semi-arid areas of the world. The average sodium concentration of surface waters in the U.S. is 55 mg/l, but values can range as

high as 7,500 mg/l (NAS, 1974). Based on the average surface water value, beef cattle may consume 30 percent of their sodium requirement from water, and this would be higher with more saline waters. Cattle can tolerate a total soluble salt content in water of up to 7,000 mg/liter and possibly higher, depending on the conditions.

Because livestock do exhibit a specific appetite for salt, it often is used as a means to encourage them to consume other supplementary nutrients, such as trace minerals. Variations in environmental supplies of sodium need to be considered in devising these strategies. If cattle are consuming high levels of saline waters, or if there is a prevalence of high sodium forages being consumed (i.e., *Atriplex* spp.), cattle may not consume supplemental salt in quantities that allow for desired consumption of other nutrients.

Sulfur

Sulfur is a component of several amino acids and B-vitamins. Sulfur is required by rumen microorganisms for growth, and deficiencies in sulfur often are reflected in decreased ruminal digestibility, which then affects the animal's ability to utilize its feed. Rumen microorganisms can synthesize necessary sulfur-containing amino acids, so that sulfur may be supplemented to ruminants in inorganic forms. Much of the sulfur added to ruminant diets undergoes conversion in the rumen. It may be converted to sulfide and then to amino acids by ruminal microorganisms. Some sulfide and sulfur amino acids may be absorbed across the rumen wall (Henry and Ammerman, 1995). Sulfate sulfur and sulfur amino acids are absorbed in the intestine. Regulation of sulfur levels in the body is intimately related to protein metabolism.

Sulfur levels in forages. Sulfur content of forages can be expected to vary with protein content, because it is a component of sulfur-containing amino acids. Murray et al. (1978) found sulfur levels to decrease rapidly over the

growing season for grasses growing on rangelands in southern Idaho, with all species being below levels suggested for beef cattle (0.15 percent) by June. Henry and Ammerman (1995) reported that values for apparent absorption of sulfur from plant materials have been in the 50 to 70 percent range.

Sulfur supplementation. Supplementation of sulfur can improve ruminal fermentation when animals are consuming low sulfur diets. This can be important when diets high in non-protein nitrogen are fed, and there is a need for sulfur for production of sulfur amino acids. Sulfur can be supplied in both inorganic and organic forms. Elemental sulfur may be less available than other forms (Fron et al., 1990). The ability of elemental sulfur to stimulate ruminal fermentation compared with other sulfur sources appears to depend upon the substrate being fermented and appears adequate to stimulate ruminal fermentation with natural feedstuffs (Spears et al., 1978).

Other nutrients in the diet need to be considered when evaluating appropriate supplementation levels. Boila and Golfman (1991) found increased methionine flows to the intestine in steers fed increased sulfur when dietary molybdenum was low, but when molybdenum was increased, supplemental sulfur had no influence on methionine flows. This may be related to formation of thiomolybdates in the rumen. These thiomolybdate compounds prevent utilization of sulfur by rumen microorganisms for methionine synthesis and also play a significant role in copper metabolism.

Sulfur fertilization of pastures is practiced in some areas. Fertilization may increase the sulfur content of the forage and improve digestibility, but at least a portion of this is related to increased yield and general forage quality. Greene et al. (1958) applied sulfur fertilizer to annual grasslands in the Sierra foothills of California and observed an increase in legumes in both the standing crop and diet of yearling steers as well as increases in the nutritive content of the species available.

Fertilizing oat-wheat pasture with ammonium sulfate in Texas did not improve weight gain of heifers over fertilization with urea (Hardt et al., 1991).

Toxicities of sulfur are of concern in Western rangeland due to associated impacts on copper metabolism. Waters containing high levels of sulfates exist in a number of areas, and this has an impact on metabolism of other nutrients. Surface water sulfur concentrations in the U.S. range from 0 to 3,383 mg/L (NAS, 1974).

Macronutrient Supplementation for Western Rangelands

Supplementary macrominerals do appear to be needed for cattle grazing Western rangelands. Sodium and phosphorus are the macrominerals most consistently deficient in Western rangeland forages. Due to lack of storage within the body, and limited levels of sodium in some supplementary feeds, sodium supplementation may be needed throughout the year. The need for magnesium is greatest in the early spring, when the potential for grass tetany exists. There is limited information on the economic value of potassium supplementation for mature grasses, but this nutrient often is provided in necessary levels through the process of providing other limiting nutrients such as protein. Sulfur supplementation should be considered when livestock are being provided a non-protein nitrogen source.

Before deciding on a mineral supplement of a specific concentration or a supplementation method, all environmental mineral sources should be evaluated. This may involve the analysis of water along with the analysis of all feedstuffs. Water may contain high concentrations of specific elements that may act as a mineral source, can interfere with absorption of other minerals, or can affect consumption of supplements.

In evaluating mineral supplementation needs, it is also critical to account for minerals provided

by supplementary feed sources. Many protein supplements, provided during periods of limited nutrient availability from range forages, may provide all of some minerals required during this period. For example, the feeding of 4 pounds of a good quality alfalfa hay to a gestating beef cow during winter months would also meet the requirements for all of the macrominerals with the exception of sodium and, perhaps, sulfur. Oilseed meals, used as protein supplements for grazing livestock, are also good sources of macrominerals.

Supplementation Methods

Mineral supplementation can be accomplished through a variety of methods, but consumption of minerals can vary from none to well above requirements, and this varies with the supplementation method used. Mineralized salt, either in loose form or in hard blocks, is a very common means of providing minerals on rangelands. However, consumption of minerals in this form can be erratic, and it is difficult to ensure adequate intakes. Minerals may be mixed with other feeds that improve palatability and consumption, such as liquid supplements or supplemental cakes, blocks, or pellets. This is most practical when nutrients such as protein or energy are limiting animal performance, and the major nutrients are being supplemented. Addition of soluble minerals to drinking water may assure a more consistent intake of supplementary nutrients; but, this is unfeasible in areas where surface water is the water source. Fertilization may alter the yield, digestibility, and mineral composition of forages and may be used as a means to supplement livestock. However, this may not be practical or economical on extensive rangelands, where water is limiting to plant growth or topography limits application.

Attempts have been made to provide limiting nutrients individually, with the assumption that animals will consume those nutrients that are lacking in the diet and will avoid those not needed. Although consumption of individual minerals does vary, animals do not consume

them at a level to meet nutrient demands (Burghardi et al., 1982; Muller et al., 1977; Pamp et al., 1977).

Decisions about timing of supplementation can be difficult due to variations in macromineral profiles in time and space. The economic cost of supplementation must be determined over a time scale of several years, due to variations in mineral profiles among years and the animal's ability to store some nutrients. Other factors to be considered in developing supplementation programs include caution in over-supplementing nutrients, due to excretion of excess nutrients into the environment, with the potential for subsequent movement of nutrients in the landscape to concentration points such as waterways. Improper balancing of minerals in a supplement can impact the supplementation program negatively by limiting effectiveness of minerals prevented from absorption or prevented from their physiological actions by other minerals.

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VITAMIN NUTRITION OF CATTLE CONSUMING FORAGES

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Introduction

Inadequate energy and (or) protein supply has been recognized as factors limiting beef cattle production when range forages undergo dormancy. However, some investigators have observed suboptimal animal performance with adequate supply of these macronutrients. Under these conditions, insufficient supply of the micronutrients may be involved because ruminants, like nonruminants, must receive all the essential nutrients in optimum quantities in order to maintain good health, to grow, and to reproduce at their maximum potential. For example, deficiencies in the fat-soluble vitamins, primarily A and E, are apt to be apparent when cattle have consumed dormant or low-quality stored forages for extended periods of time. A large body of research concerning vitamin nutrition of ruminants has been conducted over the last 60 years. The intent of this chapter is to focus on literature dealing with vitamins, which may impact production of ruminants consuming forages.

Vitamin A

California researchers (Guilbert and Hart, 1934; 1935) were among the first to investigate the vitamin A status of range cattle. They concluded that under normal conditions, range cattle could accumulate adequate reserves of vitamin A during the green season to meet their requirements during the dry season, when many forage plants are quiescent. However, they recommended supplementing cattle with good quality alfalfa hay during the dry season as a prophylactic measure against vitamin A deficiency and to prevent poor reproductive performance. This early research also demonstrated that 67 to 93 percent of the body vitamin A stores are found in the liver.

Guilbert and Hart sparked an epoch to be filled with many reports on forage vitamin composition, vitamin digestion and metabolism, and vitamin supplementation of ruminants consuming forages.

Vitamin A levels in plant material. The biologically active form of vitamin A (all-*trans*-retinol) is present in plants as precursors known as carotenoids. The most active of these carotenoid precursors is β -carotene, which, as early as the 1940s, was demonstrated to be the major carotenoid of plant origin. Kemmerer et al. (1942) showed that 61 to 94 percent of the carotene of dried forages and 94 to 98 percent of fresh grasses was β -carotene. This same laboratory (Kemmerer et al., 1944) found the β -carotene content of dried grasses to be 72.7 percent and the total β -carotene equivalent of 77.1 percent of the total carotene.

The amount of β -carotene in forages varies according to plant species, maturity, harvesting, processing, and storage conditions. Hamilton et al. (1956) collected samples of Indian ricegrass (*Oryzopsis hymenoides*), squirreltail grass (*Sitanion hystrix*), and several browse plants (*Artemisia* spp.; *Atriplex* spp.; *Chrysothamnus* spp.; *Eurotia lanata*; *Gutierrezia sarothrae*; *Leptodactylon pungens*; *Sarcobatus tridentata*; *Tetradymia inermis*) in November (beginning of dormancy) and April (before regrowth) at a site located on the Red Desert of Wyoming. Browse plants had relatively high levels of carotene, even in April (avg 45.5 ppm). The two samples of grasses were lowest in carotene content (avg 14.9 ppm) at both collection dates. The carotene content of the grasses and some plants having dry leaves or stems, such as broom snakeweed (*Gutierrezia sarothrae*) decreased markedly (30 to 50 percent) between November and

April. It was noted that the presence of a small number of green basal blades on the cured grasses presumably increased (approximately 45 percent) the carotene content of the samples collected in November. There was not an appreciable change in the carotene content of most of the other browse plants studied. Furthermore, the carotene content of the leaves and twigs differed for most browse plants. Sagebrush (*Artemisia* spp.), shadscale, and saltbush (*Atriplex* spp.), and winter fat (*Eurotia lanata*) had greater carotene content in the leaves, buds, and tips; whereas, big rabbitbrush (*Chrysothamnus pumilus*), broom snakeweed (*Gutierrezia sarothrae*), granite gila (*Leptodactylon pungens*), and greasewood (*Sarcobatus vermiculatus*) had higher carotene content in the stems. Therefore, consumption of plant species and (or) specific plant parts, as well as mature forage, could impact greatly vitamin A status of grazing livestock.

Seasonal and regional conditions can influence dietary β -carotene and subsequent vitamin A status of cattle. Forage samples taken from nine beef cattle ranches located in four soil order regions of Florida averaged 17.6 ppm carotene in the wet season (September to October) and 1.2 ppm carotene in the dry season (February to March) (Kiatoko et al., 1982). Liver vitamin A stores of the cattle doubled during the wet season, reflecting seasonal differences in forage carotene concentrations. Forage carotene content ranged from 6.0 to 16.3 ppm depending on the region. Likewise, liver vitamin A concentrations were lowest in cattle residing in the region with lowest forage carotene content. At a study site located in the foothills of the Sierras, near Marysville, California, Ighlesias and Morris (1982) found a positive correlation ($r = 0.70$) between cow plasma carotene and rainfall. These range cows had decreased liver vitamin A concentrations as the year progressed, which is an indication of vitamin A mobilization before the annual growing season.

Harvested forages are easily obtainable sources of feed that often are used to sustain livestock during periods of low standing crop

availability. Holding such hays in reserve for periods up to several years may deplete the carotene content. Schubert et al. (1956) analyzed 61 samples of stored native meadow hay harvested in the Northern Great Basin. The forage composition of the hay from native flood meadows was 50 percent sedges (*Carex* spp.), 40 percent rushes (*Juncus* spp.), and 10 percent grass and forb mixtures. Results from samples collected from the Squaw Butte Station indicated that the initial year's decline in carotene content of stacked hay is 60 percent. Of the remaining amounts, an average additional 75 percent deterioration was noted for the second year of storage. The carotene content for the newly cured hay ranged from 35 to 44 ppm, which is comparable to alfalfa hay (NRC, 1984). In another paper by the Oregon State researchers (Wheeler and Sawyer, 1956), carotene content of the same native hays ranged from 1.3 to 2.4 ppm at the time of harvest. The hay in the second study was bleached by leaving it in the swath for 3 to 6 weeks or until the green color had disappeared. Carotene content of dehydrated alfalfa dropped to 67, 50, 47, 43, and 37 percent of initial storage values at 3, 5, 7, 9, and 11 months, respectively (Blosser et al., 1950). In Blosser's study, wilted and sun-cured alfalfa had 75 and 36 percent, respectively, of the carotene content of the dehydrated material at the time these materials were stored. Carotene levels of dehydrated alfalfa were much lower after 5 months of storage during the warmer months of summer compared to the cooler months of autumn (Blosser et al., 1950). These studies collectively demonstrate the importance of proper harvesting, processing, and storing of forages in order to retain high levels of carotene.

Functions and utilization of vitamin A. Much of the interest in vitamin A's function in cattle has centered around its role in vision, reproduction, and immunity. Dietary β -carotene can elevate peripartal concentrations of blood β -carotene, enhance host defense mechanisms by potentiating lymphocyte and phagocyte function, and decrease the incidence

of certain reproduction disorders (Michal et al., 1994). β -carotene (Krinsky, 1989; Michal et al., 1994) and vitamin A (Miller et al., 1993) have been shown to be effective antioxidants and potent quenchers of free radical species. Additionally, vitamin A and (or) β -carotene also seem to be important factors in reducing the incidence of retained placentas (Chew et al., 1977) and metritis (Michal et al., 1994). Because of vitamin A's effectiveness in maintaining epithelial integrity in addition to its aforementioned functions, supplementation of range livestock may be advisable, particularly when range forage has gone dormant.

Deprivation of optimal carotene intake for extended periods of time may impair the animal's ability to utilize vitamin A. Inappreciable increases in liver vitamin A stores were noted when cattle were realimented to normal carotene intake or given repeated injections of vitamin A following suboptimal carotene intake (Byers et al., 1955). Erwin et al. (1957) noted a marked increase in liver vitamin A stores when 15 mg of carotene/45 kg of body weight (BW) was dosed intraruminally every other day for 10 days only if steers were not previously depleted of vitamin A. Grifo et al. (1960) corroborated earlier work and suggested that the duration of deficient carotene intake needs to be considered as a variable in evaluation of the vitamin A status of cattle subsequently fed carotene.

Diminished ability of cattle to utilize supplemental vitamin A often has been attributed to ruminal degradation. A number of papers reviewed by Ullrey (1972) indicated that appreciable amounts (40 to 70 percent) of carotene or vitamin A are degraded in the rumen. However, more recent evidence would indicate that ruminal degradation of vitamin A is not exceedingly high for cattle consuming diets high in forage. Disappearance of vitamin A during a 24-hour *in vitro* ruminal fermentation system was 16 and 19 percent when donor steers were fed hay and straw, respectively (Rode et al., 1990). Weiss et al. (1995) demonstrated that 80 percent of added retinol was recovered after a 24-hour

incubation period in fluid collected from ruminally cannulated cows consuming an 80 percent forage diet (20 percent corn silage and 60 percent grass hay). An alternative explanation for decreased storage of vitamin A in the liver following depletion of body stores could be related to reduced carrying capacity of the blood and (or) metabolism of vitamin A elsewhere in the body.

Wing (1969) reported that the apparent digestibility of carotene, in various forages fed to dairy cattle, averaged about 78 percent. Variables which influenced carotene digestibility included month of forage harvest, harvesting method, and plant species. Carotene digestibility was generally higher in forages of better quality. Therefore, the possibility of avitaminosis A in cattle grazing dormant range or lower quality forages is augmented by a reduction in digestibility of carotene.

Vitamin A supplementation. Erwin et al. (1955) demonstrated that steers consuming a diet of predominantly wheat straw had reduced liver stores of vitamin A compared to those consuming a diet consisting primarily of alfalfa meal. Feeding 16,000 IU additional vitamin A daily to cows before calving followed by 40,000 IU/day at the beginning of the calving season increased conception rates 11 percent and decreased calf morbidity approximately 50 percent (Meacham et al., 1970). Wheeler and Sawyer (1956) reported that night blindness developed in 28-day-old calves from cows not supplemented with vitamin A and fed native meadow hay low in carotene (< 5 ppm) for 1 year. Steers consuming supplemental vitamin A (5,000 IU/day) in a finely-ground salt mixture stored twice as much vitamin A in their livers over the winter months compared to non-supplemented steers (Page et al., 1958). Likewise, feeding 20,000 IU of vitamin A daily for 120 day to steer calves consuming native meadow hay increased plasma concentrations and liver stores of vitamin A (Wallace et al., 1964).

Baker et al. (1954) found that supplemental carotene during lactation was essential for

normal vitamin A nutrition of calves, regardless of liver vitamin A stores at parturition. Plasma vitamin A in calves is low at birth, increases during the first week, and stabilizes thereafter (Meacham et al., 1970). Furthermore, concentrations of β -carotene and vitamin A in the blood of cows decreased during the peripartal period (Johnston and Chew, 1984; Goff and Stabel, 1990). These collective findings are associated with vitamin A and carotene being components of colostrum and milk (Meacham et al., 1970; Johnston and Chew, 1984; Weiss et al., 1994).

Wheeler et al. (1957) reported that calves nursing cows on restricted carotene intakes (< 5 ppm) had plasma vitamin A levels of 2 to 14 $\mu\text{g/dL}$. In calves nursing cows grazing spring pasture, they found levels of 10 to 30 $\mu\text{g/dL}$. It is not known how much pasture intake contributed to vitamin A status of the calves in the study of Wheeler et al. (1957). Nonetheless, a single injection of vitamin A (6,000,000 IU) in peripartal cows has increased calf survival to weaning (Meacham et al., 1970).

Supplemental vitamin A may not always be needed when cattle are grazing rangelands during suspected dormancy. Plasma vitamin A levels of neonatal calves were not affected (29.1 vs. 29.9 $\mu\text{g/dL}$) by supplementing dams with vitamin A (Meacham et al., 1970). In another trial, Meacham et al. (1970) reported that calves injected with 300,000 IU of vitamin A at birth did not show increased plasma vitamin A concentrations nor increased growth performance compared to calves not receiving injectable vitamin A. Similarly, feeding vitamin A (16,000 IU/day during late gestation and 40,000 IU/day during early lactation) did not prove to be beneficial in a follow-up trial of Meacham et al. (1970).

After 5 years of data collection, Washburn et al. (1952) concluded that Eastern Colorado range maintained its carotene content for 8 months of the year. Cattle grazing sagebrush-bunchgrass range from May to September followed by meadow aftermath until

December, followed by hay low in carotene (< 2.5 ppm) from December to early May, did not show signs of vitamin A deficiency (Wheeler and Sawyer, 1956). Cows grazing southern New Mexico rangeland consumed plants adequate in carotene to maintain blood β -carotene and vitamin A levels above requirements (Watkins and Knox, 1953). The dominant grass species, black grama, along with browse plants were suspected to have provided a wintertime source of carotene. Despite the apparent mobilization of liver vitamin A in the study of Ighlesias and Morris (1982), liver biopsy data indicated that cows were not deficient in vitamin A at any point in time. On a practical basis, however, no more than 2 to 4 months of protection can be expected from stored vitamin A (NRC, 1996). Therefore, supplemental vitamin A, feed grade or ingestible, is recommended to prevent potential problems with productive efficiency of cattle when feed sources are most apt to be low in carotene.

Vitamin E

Vitamin E status likely will follow the same trend as that of vitamin A when cattle are consuming dormant rangeland or harvested forages. Kiatoko et al. (1982) showed that seasonal nutrient differences in forages were reflected in plasma levels of vitamin E. Plasma values were 42 percent higher in vitamin E concentration during Florida's wet season compared to the dry season. Furthermore, forage carotene content was positively correlated ($r = 0.56$) with plasma vitamin E concentration. This is not surprising, because both of these fat-soluble vitamins decrease in concentration as forages undergo dormancy and can function similarly in the animal's body.

Vitamin E levels in forages. Vitamin E is a generic term used for tocopherol compounds. The biological reference for vitamin E activity is α -tocopherol. In a review of 455 published articles, Dicks (1965) reported that the majority of tocopherol in forage matter is α -tocopherol. Therefore, vitamin E and α -tocopherol will be

used interchangeably throughout the remainder of this section.

The level of α -tocopherol in forage crops generally decreases as plants mature. In their review of the literature, Kivimae and Carpena (1973) found that concentrations of α -tocopherol in alfalfa and timothy (*Phleum* spp.) declined 20 to 65 percent depending on whether the crop was harvested in the late-vegetative or full-flowering stage of development. Brown (1953) reported extraordinarily large differences in α -tocopherol concentrations of vegetative versus fully mature grasses. Concentrations of vegetative grass samples ranged from 22.1 to 30.3 ppm, collectively. Upon maturity, α -tocopherol levels dropped 79, 89, 87, and 90 percent for meadow fescue (*Festuca pratensis*), orchardgrass (*Dactylis glomerata*), timothy (*Phleum pratense*), and perennial ryegrass (*Lolium perenne*), respectively. Leaves also were shown to contain three to four times more α -tocopherol than the stems (Brown, 1953; Dicks, 1965). As little as 33 to 37 percent loss in vitamin E can be expected from green-up to maturity for certain forages, e.g., sudangrass (*Sorghum bicolor*) and wheatgrass (*Agropyron* spp.) (Dicks, 1965). However, long term curing may decrease α -tocopherol levels even further.

The concentration of vitamin E is much higher in fresh grass than in harvested and processed forages. Canadian researchers (Hidioglou et al., 1994) noted that α -tocopherol concentrations of first-cutting alfalfa/timothy declined from 70 ppm to 35 and 15 ppm from the time of harvest for silage and hay, respectively. Average-quality [8.7 percent crude protein (CP); 54 percent total digestible nutrients (TDN)] grass hay had 12 ppm vitamin E in a study conducted at the University of Florida (Hidioglou et al., 1988). Alpha-tocopherol content averaged 9.1 IU/kg (as fed) in poor-quality (nutrient analyses not given), overly mature bermudagrass (*Cynodon dactylon*) hay (Njeru et al., 1995). The studies reviewed by Kivimae and Carpena (1973)

indicated that high moisture content and prolonged exposure to heat resulted in significant losses of α -tocopherol. Losses were heightened as storage duration increased. Researchers at Colorado State University (Nockels et al., 1996) reported that year-old brome and crested wheatgrass hay contained 8.1 IU of α -tocopherol/kg of DM. Supplementing vitamin E to cattle consuming low-quality range or harvested forages as a precautionary measure may be warranted due to the low levels of α -tocopherol in these forages.

Functions and utilization of vitamin E.

Vitamin E is known primarily for its action as an antioxidative component of cell membranes that prevents peroxidative damage to the cell membrane and membranes of subcellular organelles by free radicals (Burton and Ingold, 1989). The antioxidative role becomes very important during the immune response, when neutrophils produce large quantities of superoxide and hydrogen peroxide from molecular oxygen to destroy foreign organisms (Ross, 1977). Peroxidative inactivation of steroidogenic enzymes also can impair reproduction (Miller et al., 1993). Tissue content of α -tocopherol is important in protecting cattle from nutritional muscular dystrophy or white muscle disease (McDowell, 1989) and promoting increased productivity by enhancing immune (Reddy et al., 1986; Nockels, 1988) and reproductive (Shigemoto et al., 1980; Harrison et al., 1984) functions.

Vitamin E, like vitamin A, is not metabolized or oxidized extensively in the gastrointestinal tract of cattle consuming forages. Alderson et al. (1971) found that disappearance of vitamin E was only 8 percent in samples collected from abomasally cannulated steers fed an alfalfa hay:corn grain diet (80:20). Using radiolabeled α -tocopherol, Astrup et al. (1974) reported no significant degradation after a 24-hour *in vitro* incubation with ruminal contents from a fasted sheep fed an alfalfa chaff:oats (1:1) diet. Data from studies conducted in the 1990s suggest that ruminal metabolism of vitamin E is negligible for all forage (McDiarmid et al.,

1994), 50 percent forage (Weiss et al., 1995), and high concentrate (Leedle et al., 1993) diets.

Roquet et al. (1992) demonstrated that steers had much lower concentrations of vitamin E in the plasma when supplemental α -tocopherol was dosed directly into the duodenum compared to an intraruminal dose. They suggested that lower uptake of esterified vitamin E given directly in the duodenum was a result of insufficient time for emulsification preceding absorption. This seems to be a reasonable explanation, because cows fed supplemental fat, which would enhance emulsification capacity, have increased plasma concentrations of α -tocopherol (Weiss et al., 1994). Beef cattle would not be expected to consume quantities of fat sufficient to bolster levels of plasma α -tocopherol. However, the bioavailability of acetylated α -tocopherol can be increased when combined with D- α -tocopherol polyethylene glycol succinate (Hidioglou et al., 1992).

It has been suggested that < 1.0 to $1.5 \mu\text{g}$ of α -tocopherol/mL in serum can be considered deficient for ruminants (McMurray and Rice, 1982). Adams (1982) set the minimal plasma α -tocopherol level required for cattle at 3.0 to $4.0 \mu\text{g/mL}$, between 2.0 to $3.0 \mu\text{g/mL}$ as marginal, and $< 2.0 \mu\text{g/mL}$ as deficient. There is inconsistency, however, concerning the adequacy of relying solely on serum or plasma α -tocopherol concentrations as an index of vitamin E status. The liver is the major storage organ for α -tocopherol and helps maintain plasma α -tocopherol levels under short term inadequate intake of vitamin E (Hidioglou et al., 1988).

According to Charmley et al. (1992), circulating levels of vitamin E in different classes of cattle seem to be influenced by blood lipids, making serum α -tocopherol an unreliable index of vitamin E status. Weiss et al. (1994) concluded that when concentrations of plasma lipids are different because of diet, concentrations of α -tocopherol in the plasma should be expressed on a lipid basis. These

researchers suggested that elevation of the amount of α -tocopherol in plasma relative to blood lipid is necessary to increase concentrations of α -tocopherol in neutrophils. Others (Pudelkiewicz and Mary, 1969) suggested that when dietary vitamin E concentrations are kept constant long enough for stabilization of plasma and liver α -tocopherol, a blood sample might provide a satisfactory index of the vitamin E state of the animal. Recent data on yearling beef heifers indicated that both serum and liver α -tocopherol levels respond to incremental supplementation and withdrawal of vitamin E (Njeru et al., 1995). Therefore, it would appear as if serum α -tocopherol concentrations can be used to indicate vitamin E status of cattle fed forages as the primary dietary ingredient.

Vitamin E supplementation. Cattle consuming predominantly low-quality range or harvested forages are not likely to maintain blood α -tocopherol at the previously suggested levels. Mean plasma vitamin E concentration decreased from 3.3 to $2.3 \mu\text{g/mL}$ between the wet season to the dry season in the study of Kiatoko et al. (1982). Serum α -tocopherol values were $1.3 \mu\text{g/mL}$ for Holstein cows fed orchardgrass hay and 1.8 kg/day of grain during the last trimester of pregnancy (Lynch, 1983). Plasma concentration of α -tocopherol was $1.4 \mu\text{g/mL}$ for beef cows consuming 2 kg of average-quality grass hay (12 ppm vitamin E) and a barley-soybean meal mixture ad libitum (Hidioglou et al., 1988). Beef heifers fed bermudagrass hay (9.1 IU/kg of vitamin E) and 1.8 kg of a corn-based supplement for 28 days had plasma α -tocopherol levels of $1.8 \mu\text{g/mL}$ (Njeru et al., 1995). Beef cows fed alfalfa/timothy hay (15 ppm) at ad libitum intake beginning 5 months before calving through 30 days into lactation had plasma α -tocopherol levels of $2.6 \mu\text{g/mL}$; plasma α -tocopherol concentrations were $3.4 \mu\text{g/mL}$ for cattle fed silage (30 ppm) harvested at the same time and from the same field (Hidioglou et al., 1994). Results of these studies can be interpreted to suggest that cattle consuming forages with α -tocopherol concentrations

below 15 ppm are suspect for marginal vitamin E deficiency. To compound the marginal dietary deficiency many Western beef cattle may experience, vitamin E concentration in the blood decreases during the peripartal period (Goff and Stabel, 1990; Weiss et al., 1990b; Zobell et al., 1995). Thus, supplemental vitamin E may be required to maintain blood α -tocopherol at desirable levels.

A single injection of 3,000 IU of vitamin E i.m. 21 days before expected calving increased plasma α -tocopherol concentrations an average 5.6 percent through 30 days into lactation (Hidiroglou et al., 1994). Hidiroglou and Laflamme (1993) reported that maximum plasma vitamin E concentration occurs 24 hours after i.m. administration, dropping to near initial values within 10 days after the injection. This finding offers an explanation for the results of Hidiroglou et al. (1994), who observed no effect on plasma concentrations of α -tocopherol 10 days after administration. Moreover, biweekly injections would be necessary to sustain blood vitamin E at desirable levels.

Feeding supplemental vitamin E is an effective alternative to the more labor intensive injectable route. Cattle receiving 1,000 IU in 25 g of molasses showed a progressive increase (1.4 to 6.7 $\mu\text{g/mL}$) over a 28 day supplementation period (Hidiroglou et al., 1988). Vitamin E reached the minimal level required (Adams, 1982) between day 1 and 7. Njeru et al. (1995) noted a rapid increase in serum α -tocopherol during the first 3 days of daily supplementation (500, 1,500, and 3,000 IU of vitamin E/animal). Serum α -tocopherol reached the minimal desirable levels by day 14 for all supplemental treatments and continued to increase at diminishing rates to 28 days of supplementation. Upon withdrawal of the supplement, serum α -tocopherol levels declined rapidly, reaching initial levels (1.8 $\mu\text{g/mL}$) within 28 days, suggesting continuous supplementation is required to maintain serum vitamin E at the minimal concentrations outlined by Adams (1982).

Dietary supplementation with vitamin E at levels above those recommended as nutritional requirements may allow for optimal immune response (Tengerdy, 1990) and promote calf health (Zobell et al., 1995). When vitamin E was injected (6,000 IU) into peripartum dairy cows, killing ability of neutrophils was correlated to concentrations of α -tocopherol in neutrophils (Hogan et al., 1992). Percentage of neutrophils phagocytizing also has been enhanced in response to 1,000 IU of supplemental vitamin E in the diet (Weiss et al., 1994). Reddy et al. (1986) observed higher bovine herpes virus antibody titers in calves supplemented with 125 IU of vitamin E/day than in control calves. Feeding vitamin E (1,400 IU/day) in conjunction with *Brucella abortus* strain 19 vaccine may have enhanced the levels of total and IgM natural antibody to *Salmonella typhimurium* of beef heifers fed direct-cut orchardgrass silage (Nemec et al., 1990). Alpha-tocopherol has been shown to enhance IgM production significantly when added to cells isolated from Jersey cows and cultured in pokeweed mitogen (Stabel et al., 1992). In another study, Reddy et al. (1987) observed that 1-day-old calves receiving 2,800 mg of vitamin E as dl- α -tocopherol/week for 12 weeks had significantly higher serum IgM concentrations. However, supplying supplemental vitamin E to the calf directly may not be necessary.

The incidence or severity of vitamin E-responsive disease in calves seems to be influenced by placental and mammary gland transfer of α -tocopherol (Hidiroglou et al., 1972). Calves must receive dietary vitamin E, because placental transfer of α -tocopherol is very limited (Hidiroglou, 1989; Van Saun et al., 1989); consequently, levels of vitamin E in neonatal blood are 1.0 $\mu\text{g/mL}$ or less (Reddy et al., 1985; Hidiroglou et al., 1994). Maternal supplementation with vitamin E can provide partial protection for the offspring from nutritional muscular dystrophy (white muscle disease). Supplementing approximately 1,000 IU/day of vitamin E during the peripartal period significantly increased concentrations of α -tocopherol in the colostrum (Weiss et al.,

1994) and colostrum fat (Weiss et al., 1990a; 1992) compared to that of dairy cows not fed supplemental vitamin E. Feeding an additional 1,000 IU of α -tocopherol to beef cattle between 60 to 100 days prepartum increased vitamin E in the colostrum from 8.8 to 12.2 $\mu\text{g/mL}$ (Zobell et al., 1995). Calf plasma vitamin E concentrations postpartum (48 hours) were 37.5 percent greater when dams consumed an additional 1,000 IU of α -tocopherol. Others (Parrish et al., 1950; Hidirolou, 1989) have shown that pre- and postpartum maternal vitamin E supplementation results in a rapid increase in serum α -tocopherol concentration of neonates following consumption of colostrum. Furthermore, plasma concentrations of vitamin E in the neonate can be maintained above Adams' (1982) minimal level if maternal supplementation continues into the early stages of lactation (Njeru et al., 1994). Therefore, vitamin E supplementation is recommended for brood cows consuming poor-quality forage late in gestation through early lactation.

Vitamin D

Vitamin D is a pro-hormone formed by ultraviolet irradiation of skin (D_3) or plant material (D_2). A general scheme of vitamin D metabolism and the factors that influence vitamin D activity were presented by Littledike and Goff (1987). Vitamin D enters the blood from the gut or the skin and rapidly accumulates in the liver and adipose tissue. In the liver, vitamin D is converted to 25-hydroxyvitamin D [25-(OH)D]. This metabolite is the major circulating form of vitamin D in animals under normal conditions and serves as the precursor of the other vitamin D metabolites (Horst and Littledike, 1982). Once 25-(OH)D reaches the kidney, it is converted to the most biologically active form, $1,25\text{-(OH)}_2\text{D}$. The role of $1,25\text{-(OH)}_2\text{D}$ is to maintain normal blood Ca and P concentrations by facilitating Ca and P transport across the intestinal brush border (Wasserman and Taylor, 1976) and enhancing bone resorption (DeLuca, 1984).

Vitamin D levels in forages. According to Horst et al. (1981), vitamin D_2 in natural feedstuffs supplies the majority of vitamin D in ruminant animals. In 1949, Wallis et al. reported on the vitamin D_2 content of 66 forages from different parts of the country. In this report, vitamin D_2 values of sun-cured roughages ranged from 26.7 to 638 IU/kg. Dehydrated forages had vitamin D_2 levels roughly 19 percent that of sun-cured forages. Blosser et al. (1950) noted that the vitamin D_2 value for dehydrated alfalfa was 62 percent of sun-cured hay harvested at the same time. Despite lower concentrations of vitamin D_2 in certain forages, cattle housed outside are not suspected to be deficient in vitamin D.

Vitamin D supplementation. In all but the extreme Northern latitudes, sunlight stimulates sufficient endogenous production of vitamin D_3 (Littledike and Goff, 1987). Smith and Wright (1984) concluded that the synthesis of the vitamin D_3 in the skin plays a dominant role in vitamin D status of grazing animals. Others (Hidirolou et al., 1985; Hidirolou, 1987) demonstrated a significant increase in plasma D_3 and 25-OHD_3 concentrations following exposure to UV irradiation. Indeed, vitamin D status is improved more effectively by increasing exposure to the natural sunlight spectrum than by supplementing with high dietary levels of D_3 (Hidirolou and Karpinski, 1989). Hidirolou and Karpinski (1989) noted that plasma 25-OHD_3 concentrations increased continuously and plateaued between day 65 to 75 at about 21 ng/mL when vitamin D_3 was supplied in the diet. Exposure to UV irradiation for 10 hours/day increased 25-OHD_3 concentrations from 7.5 to 29.6 ng/mL, which plateaued about 3 weeks sooner than dietary vitamin D_3 treatment. Holick (1987) surmised that prolonged exposure to UV does not significantly increase the previtamin D_3 concentration above about 15 percent of the initial provitamin concentration. Therefore, cattle under normal range conditions would not be expected to exhibit vitamin D intoxication unless overzealous use of injectable preparations is common practice. Parenteral administration of 15 million IU of vitamin D_3

in a single dose caused toxicity and death in many pregnant dairy cows (Littledike and Horst, 1982).

Injectable preparations given at moderate levels should not cause ill effects. Nevada researchers (Bradfield and Behrens, 1968) showed an increase in fall pregnancy of 11.0 and 12.9 percent for beef cattle injected with vitamin A, D, and E and bred under range and pasture conditions, respectively. Vitamin D concentration in the preparation ranged from 2,500 to 100,000 IU/mL. It is difficult to attribute these effects to vitamin D, because vitamin A (100,000 to 250,000 IU/mL) and vitamin E (30 to 50 mg/mL) also were included in the injectable preparations. In light of the previous discussion, vitamins A and E presumably would have a greater impact on reproductive performance. Nonetheless, Miller et al. (1993) hypothesized that nutrients required for antioxidant defense may be essential for production of 1,25-(OH)₂D. Hence, a deficiency in vitamin A or E or both could potentiate a vitamin D deficiency. Additional research is needed to substantiate this possibility, but supplementing all three of these fat-soluble vitamins may be warranted for high producing beef cattle.

Vitamin K

The ruminal microorganisms generally synthesize and supply vitamin K in amounts sufficient to meet the ruminant animal's requirements. Supplemental vitamin K usually is justified only when cattle are suspected to have consumed sufficient quantities of vitamin K antagonists. Consumption of natural vitamin K antagonists can be a problem in certain regions in the U.S.

Sweetclover [*Melilotus officinalis* (yellow-flowered) and *Melilotus alba* (white-flowered)] is a biennial legume commonly grown in the Northern Plains (Hoveland and Townsend, 1985). Sweetclover produces a distinct, vanilla-like odor due to the presence of coumarin in the plant. Metabolism of coumarin

by fungi during the molding process produces the vitamin K inhibitor, dicumarol. Because dicumarol antagonizes vitamin K, an essential component of the blood clotting process, feeding moldy sweetclover hay to cattle may cause hemorrhage and uncontrollable bleeding. Typical early signs of sweetclover poisoning include hematomas in subcutaneous tissues of the ventral cervical area, ventral abdominal wall, and muscles of the hind limb, and hemorrhage in carpal and (or) tarsal joints (Alstad et al., 1985).

Successful treatment of dicumarol intoxication has been demonstrated with injectable vitamin K₁ (Alstad et al., 1985) and vitamin K₃ (Radostits et al., 1980). However, responses to vitamin K therapy have been somewhat dependent on differences in dicumarol source and dosages. Therefore, prevention (avoiding moldy sweetclover hay) is perhaps a better alternative than treatment.

B vitamins

Microbial synthesis of the B vitamins in the rumen is thought to satisfy the ruminant's requirements. Wegner et al. (1940; 1941) reported that thiamin, niacin, riboflavin, biotin, pantothenic acid, and pyridoxine were synthesized in heifers fed natural and semi-purified diets. Agrawala et al. (1953) were the first to establish that the B vitamin self-sufficiency exhibited by ruminants was due to the synthesis of the vitamins by ruminal microorganisms. Despite early indications of B vitamin self-sufficiency, many subsequent inquiries have been made regarding the adequacy of B vitamin production by the ruminal microbes.

Increasing organic matter (OM) digestion in the rumen via dietary manipulations has increased B vitamin production in the rumen (Hollis et al., 1954; Kon and Porter, 1954; Sutton and Elliot, 1972). As early as 1944, Lardinois et al. recognized that production of B vitamins was not maximized in the absence of readily fermentable carbohydrate. Conrad and Hibbs

(1954) found that grain additions to mature grass hay diets increased ruminal quantities of B vitamins. Likewise, addition of starch to inoculum collected from ruminally cannulated steers fed alfalfa and timothy hay increased B-vitamin production in an artificial rumen (Hunt et al., 1952; 1954). Work of Miller et al. (1986) corroborated the conclusions of Conrad and Hibbs (1954), who stated that ruminal synthesis of B vitamins was not affected by feeding different ratios of grain to hay when high-quality legume was fed. Thus, supplementation with B vitamins does not appear to be necessary if cattle are consuming high-quality forage or supplements that improve ruminal digestibility.

B vitamin supplementation. Cattle experiencing stressful production situations may require supplemental B vitamins. Byers (1981) summarized 14 studies that indicated niacin supplementation helped cattle adjust to the first 21 to 38 days in the feedlot. With 50 to 250 ppm niacin supplementation, growth rate and feed efficiency were improved in most trials, averaging 9.7 and 10.9 percent, respectively. Riddell et al. (1981) found a greater response to supplemental niacin in cows stressed by parturition than for those in mid-lactation. It has been suggested that the improvement in performance resulting from supplemental niacin is related to factors occurring in the rumen (Brent and Bartley, 1984).

Feeding niacin to ruminally cannulated cattle has increased bacterial protein production and increased the molar proportion of propionate (Riddell et al., 1980). Using an *in vitro* system, Riddell et al. (1980) found a substantial improvement in microbial protein synthesis with niacin supplementation (0 to 400 ppm) of brome hay and brome:corn (1:1) substrates; however, IVDMD was not increased significantly (57 to 58.6 percent for brome hay; 71.9 to 72.5 percent for the mixture). Ruminal responses to supplemental niacin have been equivocal. Many laboratories (Schussler et al., 1978; Bartely et al., 1979; Riddell et al., 1980; 1981; Shields et al., 1983) have reported

improved microbial protein synthesis, while others (Schaetzel and Johnson, 1981; Abdouli and Schaefer, 1986a,b) showed that supplemental niacin did not increase production of microbial protein. These discrepancies support the hypothesis of Byers (1981) who suggested that there is an optimum ruminal niacin concentration, below which microbial protein synthesis will occur, and above which there is no net microbial protein synthesis.

In contrast to the studies reviewed by Byers (1981), supplemental thiamine (Edwin et al., 1976) and the B vitamin complex has not improved growth performance of weaned calves (Cole et al., 1979; 1982) or of calves adjusting to the feedlot (Zinn et al., 1987). Zinn et al. (1987) demonstrated that ruminal synthesis of most B vitamins is correlated closely with feed or energy intake. They further suggested that responses to supplemental B-vitamins would be expected for animals at low intakes, which may offer a partial explanation for the slight reduction in morbidity in their trial and trials of Cole et al. (1982).

Recent results of Dubeski et al. (1996a) indicated that B vitamin status may be compromised because of decreased synthesis and (or) increased demand. Injecting a vitamin B complex plus vitamin C into calves recuperating from 3 days of feed deprivation enhanced the humoral immune response (measured by IgG antibody titers) on day 14 and day 28 after infection with bovine herpes virus-1. Injections were administered every 2 day at twice the daily estimated amount (thiamin = 13.5 mg; riboflavin = 33.8 mg; niacin = 135.0 mg; folic acid = 60.0 mg; pantothenic acid = 216.0 mg; vitamin B₆ = 108 mg; vitamin B₁₂ = 270.0 mg; sodium ascorbate = 1,000.0 mg). In a companion paper, Dubeski et al. (1996b) demonstrated that plasma concentrations of certain vitamins critical to the immune response in cattle (vitamin B₆; vitamin B₁₂; pantothenic acid; ascorbate) were decreased by the immune challenge. However, ascorbate was the only vitamin of the water-soluble vitamins measured in the calves'

plasma that tended to decrease in concentration following consumption of prairie grass hay (4 percent CP; 1 percent of BW) 20 days after weaning. The B vitamins measured increased slightly over the 20-day weaning period. This particular aspect of the results could have several meanings: (1) mobilization of the vitamins from limited body reserves (i.e. vitamin B₁₂ from the liver); (2) the post-weaning feeding regimen was not a sufficient stressor; (3) 20 days after weaning provided ample time for the ruminal microorganisms to produce the B vitamins; or (4) synthesis by the ruminal microbes supplied adequate quantities of the B vitamins during the 20-day period, even at restricted intake.

Supplementation of the B vitamins appears to be beneficial only to counteract overt stress and disease. There is no evidence to indicate that beef cattle require vitamin B supplementation under normal production situations.

Conclusions

As a result of the availability of low cost sources of vitamins A and E, regular supplementation of cattle fed low-quality forage should be considered. Supplementing other vitamins would not be recommended, except under special circumstances. These conditions include supplemental vitamin D for cattle raised in confinement, supplemental vitamin K for cattle consuming forages containing dicumarol, and perhaps supplemental B vitamins in overly stressed cattle exposed to disease. The benefit of advocating such programs is increased production efficiency. Aside from direct effects on reproduction in the case of vitamins A and E, producers will benefit from cattle in better health.

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TRACE MINERAL SUPPLEMENTATION OF THE BEEF COW AND REPRODUCTIVE PERFORMANCE

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Introduction

Providing nutrients in adequate amounts is important for maintaining beef cow fertility. A nutrient is considered essential, if upon removal from the diet, there is an interference with an animal's ability to grow and (or) reproduce. Adequate mineral intake is required for proper functioning of many metabolic processes including reproduction. In general, deficiencies of copper, cobalt, iodine, selenium, zinc, manganese, and phosphorus may occur in cattle maintained on forage-based diets. The effects of copper, zinc, manganese, and phosphorus on beef cattle reproduction are the focus of this paper.

Trace Minerals

A mineral becomes limiting or deficient when the amounts consumed are not adequate to meet desired performance requirements. In addition, stage of production (pregnancy or lactation) dictates the dietary mineral requirements. Table 1 indicates how copper and zinc requirements vary for growth, pregnancy, and lactation for beef cattle.

Mineral deficiencies may be classified either as primary or secondary (Graham, 1991) with a primary mineral deficiency caused by inadequate dietary intake of one or more essential minerals. A secondary deficiency (also referred to as a conditional deficiency) is due to impaired absorption, distribution, or retention of minerals. A secondary deficiency can be caused by a preexisting disease condition or interaction between minerals, which negatively affects metabolism. Both primary and secondary deficiencies can occur at the same time, and evaluating the mineral status of cattle can become complex.

Table 1. Copper and zinc requirements for cattle at different stages of production^a.

Performance Level	Copper --mg/kg DM intake--	Zinc
Growth	8-15	26-35
Pregnancy	13-20	13-21
Lactation	8-14	8-31

^aAdapted from Graham (1991).

Supplementing trace minerals has been shown to have an impact on reproduction. When zinc, copper, and manganese were added to a supplemental grain mix containing phosphorus and compared to either no supplement, a grain-urea mix, or a grain mix with phosphorus, the

average length of time from the beginning of breeding season to conception was 22 days for the trace mineral supplement, 29 days for the grain mix with phosphorus, 35 days for the grain-urea mix, and 42 days for nonsupplemented cows (Doyle et al., 1988). Another study evaluated the effects of an organic-inorganic trace mineral combination versus inorganic trace minerals only on reproduction. Conception rates were not influenced statistically by type of trace mineral supplement, but cows which received the trace mineral supplements tended to have higher conception rates, compared to a control with no added trace elements.

The reasons that intake of bioavailable minerals is crucial in postpartum animals include proper involution of the uterus, display of estrus, ovulation, conception, and maintenance of a new fetus. Immediately following parturition, the blood supply is shunted from the reproductive organs to mammary glands to enhance milk production. Repair of the endometrium competes with milk production for minerals needed for enzyme systems. The nutritional and mineral status at the cellular level is vital to endometrial pathology, embryonic viability, and fertility. In a study conducted by Manspeaker et al. (1987), copper, zinc, manganese, iron, and magnesium chelates were added to the basal diet fed to dairy heifers. Following parturition, endometrial tissue involution and regeneration was more effective, fewer infections were observed, and increased ovarian activity and decreased embryonic mortality were measured in supplemented heifers compared to heifers receiving no supplemental minerals.

Iodine is also essential for reproductive performance. Silent heat, early embryonic death, weak calves, retained placenta, and decreased conception rates have been observed in iodine deficient cows (Corah and Ives, 1991). Bull fertility (decreased libido and sperm quality) also can be reduced with inadequate iodine levels. Iodine is provided easily in salt mixtures, and a deficiency is rare because of the common use of iodized salt.

Copper. Copper is stored in the liver and is necessary for a variety of enzyme systems. When a copper deficiency occurs, productivity may be reduced due to metabolic alterations of enzyme systems. Delayed or suppressed estrus and embryo death (between 30 to 50 days of gestation) have been identified as common symptoms of copper deficiency in beef cattle (Herd, 1994). Copper deficiency in cows can result in decreased conception, infertility, anestrus, and fetal reabsorption. Dairy cows with higher serum copper levels had significantly less days to first service, fewer services per conception, and fewer days from calving to conception than cows with lower copper serum levels. In another study, dairy cows with low copper serum levels responded to supplemental copper and magnesium with increased percentage of cows that conceived at 75, 100, 125, and 150 days after calving compared to control, copper supplemented, or magnesium supplemented only (Ingraham et al., 1987).

Infertility associated with copper deficiency also may be caused by an excess of molybdenum in the diet. In a study by Phillippo et al. (1987), heifers were fed experimental diets containing marginal copper levels and excess molybdenum or excess iron. Heifers receiving the diet with marginal copper levels and excess molybdenum exhibited delayed puberty, lower ovulation rates, and lower conception rates compared to heifers consuming the diet containing excessive iron. Depressed libido and reduced spermatogenesis, which caused impaired fertility in bulls, has been attributed to excess dietary molybdenum (Thomas and Moss, 1951).

Zinc. Zinc is involved in virtually every phase of cell growth, and a zinc deficiency can have a negative impact on productivity. Zinc appears to have more of an impact on male rather than female fertility. Zinc serves as an activator of enzymes necessary in steroidogenesis, which regulates secretion of testosterone and related hormones. Inadequate zinc levels can cause impaired spermatozoon maturation and a decrease in circulating testosterone (Apgar,

1985; Puls, 1990). The importance of zinc in growing bull calves was demonstrated when animals were fed a zinc deficient diet from 8 to 21 weeks of age. Reduced testicular size for unsupplemented calves was measured compared to calves receiving zinc (Pitts et al., 1966). When zinc then was added to the diet of the deficient calves, testicular size equaled that of the controls by 64 weeks of age. These results suggest that effects of a deficiency can be overcome by supplementing the deficient mineral. Similarly, Maas (1987) reported impaired growth, delayed puberty, and decreased appetite in zinc deficient bull calves. A loss of appetite results in lowered mineral ingestion, which further can decrease feed utilization through hindered nutrient metabolism.

Zinc deficiency in gestating cows may result in abortion, fetal mummification, lower birth weight, or altered myometrial contractility with prolonged labor. When cows with low zinc serum levels were supplemented with zinc prior to calving, there was a lower incidence of dystocia (Duffy et al., 1977). Inadequate zinc levels also have been associated with decreased fertility and abnormal estrus.

Manganese. Manganese is stored in the liver, kidneys, and bones. Manganese is among the least toxic of all minerals for ruminants because mature beef animals only absorb 10 to 18 percent of dietary inorganic manganese. Manganese absorption drops rapidly with high levels of dietary calcium, phosphorus, or iron in the diet, which can influence the dietary requirement greatly. Fertility was high in cattle fed low levels of dietary manganese and a good balance between calcium and phosphorus. However, fertility was depressed if either calcium or phosphorus levels became too high and no longer balanced in relation to each other (King, 1971).

Manganese deficiency in cows results in silent estrus, anestrus, infertility, abortion, immature ovaries, and dystocia (Pugh et al., 1985). Corah and Ives (1991) suggested that typical responses of females supplemented with

manganese include increased ovarian activity and conception rate. The primary mechanism by which manganese has a role in reproduction is through cholesterol synthesis. Manganese is necessary for synthesis of cholesterol, which in turn is required for ruminant steroidogenesis. Inadequate levels of manganese disrupt steroidogenesis, resulting in decreased levels of circulating hormones, abnormal sperm in males, and irregular estrous cycles in females (Brown and Casillas, 1986).

In addition to signs of reduced reproduction in mature cattle, calves born to deficient dams have general weakness, poor growth, and "knuckle over" at the fetlocks (Dyer and Rojas, 1965; Wilson, 1966). Manganese supplementation is effective in reversing reproductive problems and calf skeletal changes that are due to a deficiency.

Phosphorus. Of the macro-minerals, phosphorus often has been considered one of the most important needed to maintain normal reproductive performance. Forage (the major nutrient source for producing beef cows) has a high level of calcium and a low level of phosphorus, which might lead to the assumption that supplemental phosphorus is necessary, especially when cattle are grazing mature forage during late fall and through the winter months. Numerous studies that have shown a positive impact on reproduction with phosphorus supplementation (Underwood, 1966; McDowell, 1985) have been conducted in areas of the world with extreme phosphorus deficiencies and low fertility in cattle. Results may not be as applicable to the production settings in the United States.

Call et al. (1977) conducted a study for 2 years using Hereford heifers fed diets containing either 66 percent or 172 percent of the NRC requirement for phosphorus. Reproduction parameters (age at puberty, pregnancy rate, and percent live calves) were similar between treatment groups. In addition, bone sections and tissue phosphorus levels were not different. As might be expected, fecal and urine excretion were much higher for the heifers receiving the

high level of phosphorus. A second study reported by Butcher et al. (1979) utilized Hereford heifers fed basal diets containing 0.14 percent or 0.36 percent phosphorus (66 percent or 174 percent NRC requirement) for 4 years. During late gestation of the fourth year, half of the cows in each treatment group were reassigned to a very low level of phosphorus, 0.09 percent, while the other half of each group remained on their original diets. Supplemental phosphorus levels had no negative effects on the remaining gestation period, calving, or lactation. A decrease in appetite and subsequent weight loss were observed in the low level phosphorus group, however. There were no differences in the percentage of cows bred by natural service during the breeding season. These data suggested that phosphorus levels below 50 percent of NRC recommendations were still adequate for maintaining fertility.

Forage Mineral Content

Beef producers are faced with the challenge of balancing mineral requirements according to the animal's level of production and mineral content available in feed sources. Forages may provide all the essential minerals required by cattle, but if the forage is deficient in one or more minerals, then a mineral supplement would be necessary to maintain normal metabolic functions. Severe mineral deficiencies are uncommon, while marginal deficiencies are difficult to identify and are more likely to occur.

Bioavailability of minerals is defined as the proportion of ingested element that is absorbed, transported to the action site, and converted to an active form (O'Dell, 1984).

Distribution of the mineral in the plant, chemical form, and mineral interaction can influence bioavailability. Forage mineral content and bioavailability varies (Spears, 1994). Factors such as soil mineral level, soil pH, climatic conditions, plant species, and stage of plant maturity influence forage mineral

content. When comparing legumes and grasses grown in the same location, legumes have been shown to be higher in calcium, copper, zinc, and cobalt than grasses. Grasses do, however, contain higher levels of manganese. Concentrations of minerals in forages often decrease as plants mature, and dry matter content increases more rapidly than mineral uptake.

Mineral analysis of native range grass collected from the same pasture three different years during winter grazing period was similar between years for zinc, copper, manganese, iron, potassium, calcium, and phosphorus (Clark et al., 1994). These results suggest that forage mineral content does not vary tremendously from year to year; however, the method of mineral analysis does not indicate bioavailability of the minerals which may be affected by year-to-year variation in growing conditions.

Deciphering the Feed Tag

Finding mineral requirements for a particular group of animals is the easy task. Knowing if you have a deficiency and then properly supplying adequate amounts becomes more difficult. Diagnosing mineral status of the herd requires additional information such as animal symptoms, performance, liver, blood and (or) hair analysis, and feed (possibly water) analysis. Once you have a number of values gathered, the bioavailability and interactions of minerals can be considered in formulating a desired mineral supplement.

However, after you have defined your deficiency, is it as simple as formulating a supplement available to your cows? No? Why not? The first problem is that all minerals are not created equal in regard to utilization. Secondly, feed tags do not always tell you everything you need to know and often may be confusing. Many times, the levels added to trace mineral supplements are given only in order of incorporation and not in the exact quantities added to the mix. For example, you

may find a trace mineralized salt containing copper, but the amount of copper is not stated, only that copper oxide is the fourth most used compound in a supplement containing 98 percent salt. In reality, this supplement contains very little if any available supplemental copper because of the form in which the copper occurs.

Even when all the minerals are listed individually on a feed tag, determining if mineral requirements are met can be difficult and confusing. It would not be uncommon for you or have your forage tested at a lab and your mineral analysis reported back to you as a percent of the forage. When you looked up the animal requirements, you would find it listed as parts per million (ppm) in the diet, and, upon

reading the feed tag, you find the amount of mineral given as milligrams per pound (mg/lb). You are now comparing apples, oranges, and grapes. Although the conversions to a common denominator are relatively simple, care must be taken, because being off by one decimal point may be the difference between a deficient and toxic mineral supplement. Table 2 provides an example of a "miscalculation."

The calculations in Table 2 are correct if the supplement contained 0.02 percent copper. In practice, you should never find a mineral supplement containing 2 percent copper. To help simplify conversions between units commonly used in reference to nutrients, the following table (Table 3) has been provided.

Table 2. Example of a common error in calculating daily intake of copper for cows.

Item	Grass Hay	Mineral Supplement	Total Intake
Amount fed / day	22 lb	2 ounces	
Conversion to kg	22 lb x 0.454 = 10 kg	2 ounces x 0.02835 = 0.0567 kg	10.0567 kg
Copper analysis	5 ppm	2%	--
Conversion to mg/kg	5 x 1.0 = 5 mg/kg	0.02 / 0.0001 = 200 mg/kg^a	--
Daily intake of copper	10 kg x 5 mg/kg = 50 mg	0.0567 kg x 200 mg/kg = 11.34 mg	61.34 mg ^b

^aA common error occurs at this point; when converting from percent to ppm, use the whole number, not the decimal equivalent (2% = 2 / 0.0001 not 0.02 / 0.0001).

^b61.34 mg copper / 10.0567 kg feed = 6.1 mg/kg (ppm) copper. This example shows the copper requirement not being met when actually it would be toxic at 1,134 ppm copper.

Table 3. Conversion factors for commonly used units in reference nutrients.

Unit	Conversion Factor Multiply going right→ ← Divide going left	Unit
lb	0.454	kg
lb	454.0	g
oz	0.02835	kg
oz	28.35	g
g	0.001	kg
g	1000.0	mg
mg / kg	0.454	mg / lb
g / kg	0.454	g / lb
ppm	1.0	mg / kg
ppm	0.0001	%
ppm	0.454	mg / lb
ppm	0.91	g / ton
g/ton	0.00011	%

Summary

Maintaining fertility in beef cattle requires adequate dietary intake and absorption of essential minerals. The minerals are necessary for normal function of various enzyme systems. Feeding a diet deficient in a single mineral can affect reproduction negatively in beef cows and bulls. The influence of an iodine, copper, zinc, or manganese deficiency on fertility is summarized in Table 4. When evaluating cattle diets for the different stages of production, levels and interactions of minerals should be considered. If a deficiency is evident, then supplementing to meet the animal's requirement could have a positive impact on reproduction and profitability for the beef cattle producer.

Table 4. Summarized influence of iodine, copper, zinc, and manganese deficiency on fertility of beef cattle.

Deficiency	Female Fertility	Reference	Male Fertility	Reference
Iodine	↑↑ Silent heat ↑↑ Embryonic death ↑↑ Weak calves ↑↑ Retained placentas ↓↓ Conception rates	6	↓↓ Libido ↓↓ Sperm quality	6
Copper	↑↑ Delayed or suppressed estrus ↑↑ Embryo death ↓↓ Conception rates	11, 12, 13		
Copper^a	Delayed puberty ↓↓ Ovulation rates	19	↓↓ Libido ↓↓ Spermatogenesis	24
Zinc	↑↑ Dystocia ↑↑ Abnormal estrus	8, 15	Impaired growth Delayed puberty ↓↓ Testosterone ↓↓ Testicular size ↓↓ Libido	1, 15, 20 22
Manganese	↑↑ Anestrus ↑↑ Abortion ↑↑ Dystocia ↓↓ Ovarian activity ↓↓ Conception rates	2, 6, 21	↑↑ Abnormal sperm	2

^aCopper with excess molybdenum in the diet.

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TRACE MINERAL SUPPLEMENTATION OF THE BEEF COW TO IMPACT IMMUNOLOGIC RESPONSE

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Introduction

The role of minerals in beef cattle diets continues to be a strong area of interest for producers, veterinarians, and scientists. Minerals are required for a variety of metabolic functions, including the immune system's response to pathogenic challenges. Maintaining the immune response through proper mineral supplementation may have a positive impact on herd health and, ultimately, profitability of cow-calf operations. However, mineral supplementation strategies quickly become complex because of differences in forage mineral bioavailability, interactions among minerals which can inhibit mineral absorption, and difficulty in easily assessing cow mineral status. The effects of copper, zinc, cobalt, and chromium on the immune system are the primary focus of this paper.

Immune System Background

When an animal is exposed to a foreign substance (antigen), the defense mechanism of the immune system has three ways to respond: (1) cell-mediated immunity, (2) humoral immunity, and (3) the phagocytic system. Resistance to a disease challenge is dependent upon the speed and effectiveness of each

response mechanism. The immune system is comprised primarily of lymphocytes and phagocytes which are produced from cells in the bone marrow. Lymphocyte production and differentiation is regulated by lymphoid organs, such as the spleen and lymph nodes. Vitamins A and D are important for differentiation of lymphocyte cells into T-lymphocytes and B-cells. Cell-mediated immunity requires T-lymphocytes, and these cells mature in the thymus and then accumulate in the lymph nodes from where they respond to antigens. The functions of the T-cells include killing virus-infected cells, helping B-cells build antibodies, regulating the level of immune response, and stimulating activity of other immune cells, such as macrophages. One routine method for evaluating a cell-mediated response is intradermal injection of a foreign substance such as phytohemagglutinin (PHA-P, a bean protein) and then measuring the swelling of the skin at specific hours post-injection.

The second type of response is referred to as humoral immunity. B-cells are processed in intestinal lymphoid tissue and differentiate into antibody-producing cells. The B-cells migrate to areas other than the thymus, produce antibodies in the presence of an antigen, and help form antigen-specific T-cells. Some antigens are T-independent and can stimulate

B-cells directly. The humoral immune response is measured as an antibody titer in blood serum.

In the process of vaccinating animals against diseases, an antigen is introduced as either a modified live or killed organism. The B-cells respond to the vaccine and build antibodies. The level of antibodies produced is at a maximum level approximately 10 days after injection and is referred to as the "primary response." When the vaccine is injected a second time, there is a much more rapid response by B-cells, and higher levels of antibodies are produced which persist for months. The response to a booster vaccination is called the "secondary response."

The maximum response by T-cells and B-cells may require days, while the phagocytic system responds immediately and utilizes both neutrophils and macrophages. Neutrophils are responsible for ingesting pathogens and degrading them (phagocytosis). Neutrophils produce free radicals and oxidants to destroy the membrane of the engulfed pathogen. In the absence of adequate antioxidants, the membrane of neutrophils may also be destroyed and reduce the function of the neutrophil. Actions of the macrophage include phagocytosis, processing and presenting antigens to lymphocytes, and releasing substances which promote responses of the immune system.

Nutritional status influences an animal's immune system and its ability to respond to pathogenic challenge. In order for the immune system to function properly, energy, protein, vitamins, and minerals must be provided to the animal in adequate amounts. Nutrient deficiencies have resulted in depressed immunocompetence and increased susceptibility to infectious disease (Beisel, 1982). Energy is required for protein synthesis

and cell replication. Protein provides amino acids, which are needed for acute phase proteins, antibodies, and cytokines. Vitamins A and D are necessary for lymphocyte differentiation into T-cells and B-cells. Vitamin E serves as an antioxidant to protect cellular membrane polyunsaturated fatty acids in the process of phagocytosis by neutrophils. Minerals also contribute to the antioxidant enzyme system.

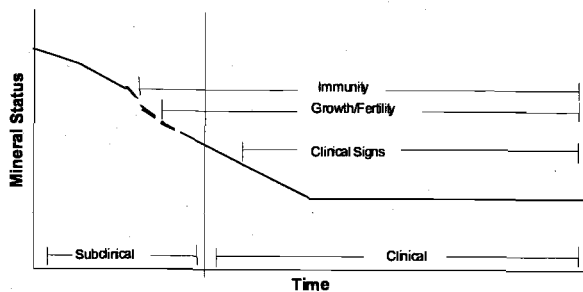
Trace Elements, Role in Immunity

Trace elements that are thought to have an impact on productivity of grazing cattle include copper, zinc, cobalt, manganese, selenium, and iodine. Deficiencies of these minerals have been shown to alter various components of the immune system (Suttle and Jones, 1989). Specific trace mineral deficiencies which have been shown to decrease neutrophil function in ruminants include copper, cobalt, selenium, and molybdenum (Jones and Suttle, 1981; Aziz and Klesius, 1986; MacPherson et al., 1987). Decreased cellular immunity, lowered antibody response, and disrupted growth of T-dependent tissue have resulted from inadequate intake of zinc (Fletcher et al., 1988). Trace mineral requirements for beef cattle are given in Table 1.

Subclinical mineral deficiencies in cattle may be a larger problem than acute mineral deficiency, because specific clinical symptoms are not evident so as to allow the producer to recognize the deficiency (Figure 1). Animals with a subclinical status can continue to reproduce or grow but at a reduced rate, they have decreased feed efficiency, and the immune system may be depressed.

Table 1. Trace mineral requirements of beef cattle given as dietary concentration (ppm).

Reference	Cu	Zn	Mn	Co	I	Fe	Se	Cr
NRC ^a 1984	8	30	40	0.1	0.5	50	0.2	--
ARC ^b 1980	12	30	25	0.1	0.5	30	0.1	--
Puls ^c 1990	10 ^d	45 ^e	40	0.1	0.5	100	0.3	--

^aNational Research Council Beef Cattle Requirements^bAgricultural Research Council^cPuls, 1990, Mineral Levels in Animal Health^dCopper:Molybdenum ratio; minimum 3.0, adequate 4.3, ideal 6.0-10.0^eRequirement is considered adequate with 0.3 percent calcium also in the diet, however; for each additional 0.1 percent increase in calcium, add 16 ppm zinc.**Figure 1.** Effects of Trace Mineral Deficiencies on Immune Function in Cows and Calves

Source: Wikse, 1992, TAMV Beef Cattle Short Course

Copper. Copper deficiency has been identified as the most common trace mineral deficiency of cattle in the world (McDowell, 1985). Copper is an essential trace element required for numerous enzyme systems: iron metabolism, mobilization, and connective tissue metabolism; integrity of the central nervous system, and the immune system. Copper functions in the immune system through the following: energy production, neutrophil production and activity, antioxidant enzyme production, development of antibodies, and lymphocyte replication (Nockels, 1994). The importance of copper for maintaining the functions of the immune system has been demonstrated in several studies. Copper deficiency in cattle can alter the immune system and increase an animal's susceptibility to disease. Viral and bacterial challenges have been shown to increase serum ceruloplasmin and plasma copper in copper-repleted cattle, indicating a major protective role for copper in

infectious diseases (Stable et al., 1993). Low copper status has resulted in decreased humoral and cell-mediated immunity, as well as decreased neutrophil bactericidal capability in steers (Jones and Suttle, 1981; Xin et al., 1991).

During gestation, the developing calf is dependent on its dam for supplying copper, manganese, zinc, and selenium. The fetus accumulates copper in the liver at the expense of the dam with most of the accumulation occurring after 180 days of gestation. Lower than normal tissue reserves in the fetal calf as a result of deficiency in the dam can impair development and growth (Abdebrahman and Kincaid, 1993). Deficient copper levels in cows have resulted in increased incidence of scours in their calves (Smart et al., 1986). Occurrence of abomasal ulcers shortly after birth and respiratory problems both have been attributed to inadequate copper levels in calves (Naylor et al., 1989).

Copper deficiency in cattle may be caused by low levels of copper in forage. Absorption of copper is higher for dried forage compared to fresh grasses due to a slower passage rate through the gut, allowing for more absorption. Interactions with other dietary mineral sources must be given consideration; particularly, high levels of molybdenum or sulfur. Molybdenum ties up copper, making it unavailable to the animal, and creates problems when dietary molybdenum levels are in excess of 1 to 3 ppm or the copper to molybdenum ratio falls below 3:1. The interaction of molybdenum and copper can be intensified with sulfur. Sulfur

forms thiomolybdates which bind to copper in the rumen to form insoluble complexes that are poorly absorbed (Gooneratne et al., 1989; Spears, 1991). In general, 10 ppm copper (dry matter basis) in the diet is considered adequate. Providing 0.2 to 0.5 percent copper in a mineral mix can correct a copper deficiency caused by low forage copper. However, an excess of 0.5 percent may be required if interactions with other minerals decrease copper absorption. It is important to assess the copper status of cattle before routinely adding excess copper to diets, because ruminants are more sensitive to copper toxicity than are nonruminants. Copper levels in the diet exceeding 200 to 800 ppm for cattle and 115 ppm for calves are potentially toxic (Corah, 1993).

Liver biopsy provides the best indication of copper status in live cattle. Puls (1990) suggests liver copper levels of 25 to 100 ppm (wet weight basis) are adequate, with 0.5 to 10 ppm being deficient and 250 to 800 ppm being toxic. Serum copper levels are not a good indication of copper status. All copper circulating in the blood is not available to the animal, and serum copper values can be affected by a number of factors, including dietary molybdenum and sulfate, infection, trauma, and stage of gestation (Puls, 1990). In addition, serum copper levels do not correspond to liver copper, and are not considered a reliable indicator of copper status in cattle (Clark et al., 1993). Cattle with low plasma copper levels have been found to have adequate liver copper levels (Mulryan and Mason, 1992). If serum copper values are used, a value below 0.6 ppm would indicate a potential deficiency.

Given the complexity of determining copper status in cattle because of interactions with other minerals, variability of available copper in forage and bioavailability of copper in the animal, dependence on a single variable of copper status can result in an erroneous diagnosis. For a more accurate understanding of copper status, correlations must be made between copper tissue levels, forage analysis, water analysis, and possibly plasma

ceruloplasmin activity (Wikse et al., 1992). The most obvious clinical symptom is a change in the appearance of the hair coat. The color may look faded, and overall hair condition is rough. Other symptoms include general anemia, abnormal bone and ligament development, and a reduction in growth rate.

Zinc. Zinc is involved actively in enzyme systems through metabolism of feed constituents such as protein and carbohydrate as components of insulin. As in the case of copper, zinc is required for maintaining responsiveness of the immune system. Zinc functions in the immune system through energy production, protein synthesis, stabilization of membranes against bacterial endotoxins, antioxidant enzyme production, and maintenance of lymphocyte replication and antibody production (Nockels, 1994). Zinc deficiency has been shown to have an important impact on immunity. Calves with a genetic disorder which interferes with zinc metabolism resulting in zinc deficiency exhibit thymus atrophy and impaired lymphocyte response to mitogen stimulation (Perryman et al., 1989). A lower percentage of lymphocytes and higher percentage of neutrophils in the blood has been observed in animals consuming a diet deficient in zinc (Droke and Spears, 1993).

Zinc has been shown to have a positive impact on immunity in stocker and feedlot cattle with limited research in beef cows. Weaned calves normally experience stress due to transportation, changes in feed, and handling, which increases susceptibility to infectious diseases. During this period of stress, providing adequate dietary zinc may be critical, because stress has been shown to have a negative impact on zinc retention (Nockels et al., 1993). Infection also can have a detrimental effect on zinc status in cattle. Infecting cattle with a bovine rhinotracheitis challenge increased urinary zinc excretion, which caused a negative balance (Orr et al., 1990). Feed intake often is depressed when feeder cattle are stressed, and the reduction in intake results in a decrease of trace minerals

ingested. Supplying zinc to steer calves which had undergone stress (weaning, transportation, exposure to new cattle, and vaccination) was shown to increase feed intake (Spears et al., 1991). Serum zinc levels were lowest during the peak morbidity in a natural outbreak of bovine respiratory disease, and steer calves challenged with infectious bovine rhinotracheitis virus had a decline in serum zinc (Hutcheson, 1989). It has been suggested that immune capacity can be lowered substantially due to inadequate dietary levels of zinc before any clinical symptoms appear (Fraker, 1983). Zinc supplementation for stressed cattle enhanced recovery rate in infectious bovine rhinotracheitis virus-stressed cattle (Chirase et al., 1991). Zinc methionine also has been shown to increase antibody titer against bovine herpesvirus-1 (Spears et al., 1991).

Limited research has been done to determine the effects of zinc supplementation on beef cows. The dietary zinc requirement for gestating beef cows may increase during the last trimester of pregnancy. Liver and plasma zinc levels have been shown to decrease prior to parturition due to demands for deposition in fetal tissue (Xin et al., 1993). Supplementing zinc to dairy cows during lactation resulted in fewer infections of mammary glands (Spain et al., 1993). In grazing cows with suckling calves, zinc supplementation resulted in a 6 percent improvement in weight gain for calves with no change in cow weight gain (Mayland et al., 1980).

Zinc status of cattle is not easily assessed. Currently, there is not a good indicator for determining marginal deficiencies. Levels of 25 to 100 ppm (wet basis) in liver and 0.8 to 1.4 ppm in serum have been suggested to be adequate (Puls, 1990). Collecting blood for zinc analysis requires a specialized blood tube for mineral analysis. Analyzing hair for zinc also may be useful for long term monitoring. Clinical signs of zinc deficiency included parakeratosis, rough hair coat, joint stiffness, and reduced immune response. Feedlot cattle can have reduced gain but minimal clinical signs.

The recommended dietary level is 30 to 40 ppm (NRC, 1984), and zinc movement in the body is regulated precisely within this requirement range. A level of 80 ppm zinc has been suggested for stressed and sick feedlot cattle due to decreased feed intake and increased excretion (Hutcheson, 1989). Usually available stores are not available and zinc plasma levels can decrease rapidly if animals are fed a deficient diet (NRC, 1980). High dietary calcium decreases the absorption of zinc; therefore, the zinc requirement in the diet increases. Other minerals (copper, phosphorus, and iron) also can interact and reduce bioavailability of zinc. Excess zinc inhibits copper and iron absorption and utilization. Zinc toxicity is fairly rare in ruminants with the maximum tolerable level reported to be 500 ppm (NRC, 1984).

Cobalt. Cobalt functions primarily as a component of vitamin B₁₂, which is synthesized by rumen microorganisms. Cobalt also appears to have a role in the immune system of cattle. Neutrophils isolated from cobalt deficient calves had reduced ability to kill a pathogen (MacPherson et al., 1989). Weight gain of cattle consuming a low cobalt diet was unaffected until 40 to 60 weeks, but the immune status (measured as neutrophil function) was reduced after 10 weeks (Paterson and MacPherson, 1990).

Cobalt serum levels are not considered to be a good indicator to cobalt status; however, liver levels reflect status better than serum values. Vitamin B₁₂ concentrations in serum and liver are more reliable indicators of cobalt status. Puls (1990) reports vitamin B₁₂ values which indicate adequate cobalt levels are between 0.25 to 2.50 ppm (wet basis) in liver and 0.40 to 0.90 mg/L in serum. If hair samples are analyzed, a normal value for Co is 0.03 ppm (dry weight). Forage cobalt concentrations provide a reliable indicator of cobalt availability (Spears, 1994), but levels in forage can be influenced by cobalt level in soil and soil pH.

Clinical symptoms of cobalt deficiency include loss of appetite (an early symptom), anemia, loss of condition, weakness, rough hair coat, and reduced conception rates. Animals in a deficient state respond rapidly to dietary cobalt supplementation. Appetite increases in a week, weight gain follows quickly, but remission from anemia occurs more slowly. Toxicity symptoms are similar to those for deficiency. Cobalt levels are considered toxic if above 10 ppm in the diet.

Chromium. Chromium has been shown to play a role in the immune system. Chromium aids insulin function, increases serum immunoglobulins and retention of other trace minerals, and reduces serum cortisol. Cortisol has been found to inhibit production and actions of antibodies, lymphocyte function, and leucocyte population (Munck et al., 1984). Chromium supplementation in calves reduced serum cortisol and increased serum immunoglobulins (Chang and Mowat, 1992). Effectiveness of vaccines may be improved with adequate levels of chromium by reducing cortisol levels and their inhibitory effects on the immune system.

Stressed feeder calves receiving supplemental chromium had improved weight gain and reduced morbidity the first 28 days while on a corn silage diet (Moonsie-Shageer and Mowat, 1993) suggesting that chromium may be limiting in corn silage diets. Chromium supplementation reduced rectal temperature and increased blood antibody titers. Implications from this study suggested inclusion of chromium in preconditioning diets, during marketing and shipping, or in receiving rations may improve performance and immunocompetence.

Dairy cows fed diets based on grass hay, haylage, and corn silage were supplemented with chelated chromium (0.5 ppm) 6 weeks prior to parturition and until 16 weeks of lactation or received no supplement. A humoral response was measured, and supplemented cows had an increase in antibody titer. It appeared that the chromium had a

significant immunomodulatory effect in cows (Burton et al., 1993).

Investigating the use of chromium supplementation is fairly new, and little is known about the dietary requirement of ruminants. Puls (1990) does not indicate a required dietary level, but does suggest that a chronic dose would be 30 to 40 mg/kg zinc chromate for 1 month. Normal serum chromium is given as 0.25 to 0.30 ug/L and liver chromium as 0.04 to 3.8 ppm on a wet basis. Chromium interactions with other minerals appears to be positive. It has been suggested that supplemental chromium prevents stress-induced losses of copper, zinc, manganese and iron (Schrauzer et al., 1986).

Trace Mineral Sources

Trace minerals for supplements are available in different forms: inorganic, chelates, proteinates, and complexes. Chelates, proteinates, and complexes often are grouped together and are referred to as protected minerals. However, there are differences among them. Chelated minerals are associated with 1 to 3 moles of amino acids and form a closed ring structure. Proteinated minerals are associated with either amino acids or small peptides, which result in an open ring structure. Complexes are minerals bonded to an organic compound. All forms of protected minerals have a neutral electrical charge, while inorganic minerals possess either positive or negative charges.

The process of chelating minerals to organic compounds occurs naturally through digestive metabolic pathways. Positive or negative charges common to inorganic sources enhance the possibility of ionic binding to transport or enzymatic proteins. The problem with minerals chelated in this manner is that minerals may be bound to compounds with increased molecular size and decreased absorption. Protected minerals have a neutral charge; therefore, the minerals are not bound to large molecules, and bioavailability of the minerals is increased.

The availability of copper oxide, copper sulfate, and organic copper has been compared in several studies. The source of copper (copper sulfate and copper lysine) did not affect soluble copper concentrations when using an *in vitro* system to estimate availability. Copper lysine appeared to be equal to copper sulfate when growth rate, feed intake, feed efficiency, plasma copper, ceruloplasmin activity, and immune response of growing steers were used as indicators of utilization (Ward et al., 1993). Lactating beef cows at a commercial cow-calf operation deficient in copper had increased liver copper from either copper proteinate or copper sulfate supplements when compared to a copper oxide supplement (Clark et al., 1993). These results suggested copper availability from proteinate or sulfate forms was higher than the oxide form. Contrary to these findings, calves fed copper lysine had 53 percent greater apparent copper absorption and increased retention than calves fed copper sulfate during a repletion period (Nockels et al., 1993). The zinc source also was evaluated in this study, and no differences between zinc methionine and zinc sulfate were found.

Zinc methionine supplementation enhanced recovery rate of IBR stressed cattle compared to supplementing zinc oxide (Chirase et al., 1991). When cattle were challenged with bovine herpes virus, antibody titer formation following vaccination was enhanced with zinc methionine compared to the basal diet without additional zinc or zinc oxide additions.

Montana State University Research

A study was completed recently at the Montana State University to determine if the form of supplemental trace minerals (complexed versus inorganic) fed during the last trimester of gestation influenced cellular immunity, blood cell counts, and serum copper and zinc concentrations of heifers and their calves. Pregnant cross-bred beef heifers were allotted to pasture according to expected calving date and weight. Treatments compared were control, complexed mineral, and inorganic mineral fed ad libitum in mineral feeders. The

control heifers received trace mineralized salt only, while the inorganic treatment heifers received a supplement which contained 8,818 ppm zinc, 2,472 ppm copper, 4,987 ppm manganese, and 704 ppm cobalt in the inorganic sulfate form. The complex-treatment heifers received a supplement with zinc methionine, copper lysine, manganese methionine, and cobalt glucoheptonate providing the same level of each mineral described for inorganic supplement. Blood samples were collected 30 days following the start of supplementation to measure serum copper, zinc, and complete blood cell counts in heifers, and in calves within 24 hours of birth. A skin fold test was conducted to measure a cell-mediated immune response on the same day blood samples were collected.

Phytohemagglutinin (PHA-P) was injected intradermally at two locations on the neck, and the swelling response was measured at 0, 6, 12, and 24 hours after injection for cows and 0, 4, 8, 12, and 24 h after injection for calves. As heifers calved, they were removed from supplemental mineral-treatment groups and placed in a common pasture. The heifers were bled a second time 1 week after the last calf was born to determine blood cell counts. The time interval from when heifers were removed from mineral treatments until this blood collection ranged from 7 to 42 days.

Heifers consuming either complex or inorganic mineral supplements had a greater swelling response than did the control-supplement heifers at 6 hours post-injection. Maximum swelling appeared sooner in heifers fed the complex mineral supplement (at 6 hours) with the inorganic-mineral supplement groups reaching the maximum response at 12 hours (Figure 2).

Swelling response in the calves was not affected by mineral treatments. These data suggest that a chemical form of mineral supplement may influence the initiation of cell mediated response to pathogens.

White blood cell counts (Figures 3 and 4) were highest for complex-supplemented heifers and their calves compared to those supplemented with inorganic minerals or control. Both complex and inorganic supplemented heifers had higher segmented neutrophils than controls (Figure 5). Other studies have reported an influence on blood cells from mineral supplementation. Blood samples collected after removal from the supplement were similar for all cell counts. Results indicate that mineral supplementation influenced cell counts; however, changes in cell types were dependent on continued supplementation and not on body mineral storage. Movement of minerals within the body may be regulated within the requirement range. Readily available stores of zinc are quite small, as indicated by drops in plasma zinc values to the deficiency range within 24 hours after switching animals to diets very low in zinc (NRC, 1980).

Serum copper and zinc levels for both heifers and calves are given in Table 2. Serum copper concentrations for the calves were increased by providing cows added mineral supplementation; however, the levels measured are below those considered adequate (0.6 mg/L). Previous studies have shown that fetal calves accumulate copper in the liver and are born with lower serum copper than adults (Puls, 1990; Abdebrahman and Kincaid, 1993). During the first 3 days postpartum, liver copper decreases and serum copper levels increase as liver copper is converted to the copper dependent enzymes. Serum zinc was similar among supplement treatments, and levels of zinc were in the normal range of 0.80 to 1.00 mg/L (Puls, 1990).

Serum copper and zinc values in the heifers were not influenced by supplementation. The validity of utilizing blood serum as an indication of mineral status in the heifers may be questionable. Supplemented heifers were consuming levels of copper (24 ppm) and zinc (88 ppm) which were twice NRC (1984) requirements; however, heifer serum mineral levels indicate marginal copper deficiency and adequate zinc according to values reported by

Puls (1990). Liver samples may have been a more accurate indicator of mineral status in the heifers.

Supplementing 2-year-old heifers in late gestation with zinc, copper, manganese, and cobalt influenced cell-mediated immunity in heifers and blood cell counts in heifers and their calves. Heifers receiving complexed minerals had the highest response to cell-mediated immunity and number of white blood cell and neutrophils, while heifers receiving inorganic minerals had intermediate responses. Future research will continue to investigate the influence of trace mineral supplementation on beef production with emphasis on cow-calf operations.

Summary

Minerals can have a substantial influence on herd health, production, and profits for the producer. The importance of minerals dictates the need for continued research in several different areas, such as evaluating the mineral source to determine levels required in order to maintain immunity responses, methods to assess animal mineral status more easily, and determining optimum levels of specific minerals according to animal performance goals. The following question needs to be addressed: Is it possible to develop optimum mineral feeding strategies which maximize production and minimize financial cost to the producer?

Figure 2 Effects of Mineral Supplementation on Heifer Skinfold Thickness 6, 12, and 24 hours Post Injection with PHA-P

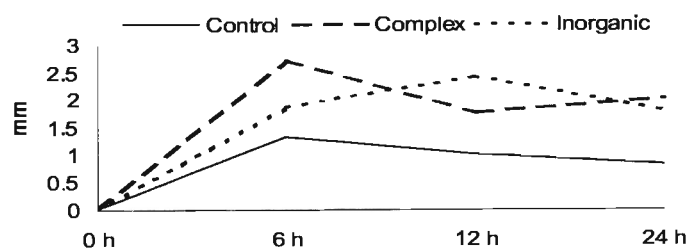


Figure 3. Influence of Cow Mineral Supplementation on Calf White Blood Cell Counts

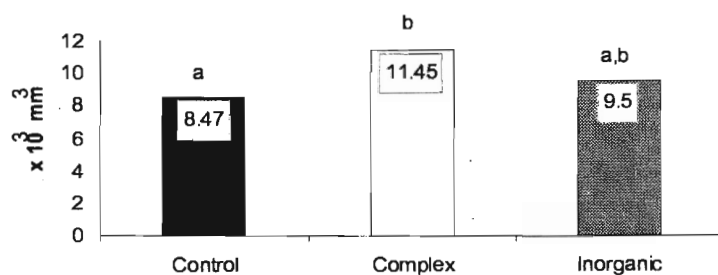


Figure 4. Influence of Mineral Supplementation on Heifer White Blood Cell Counts

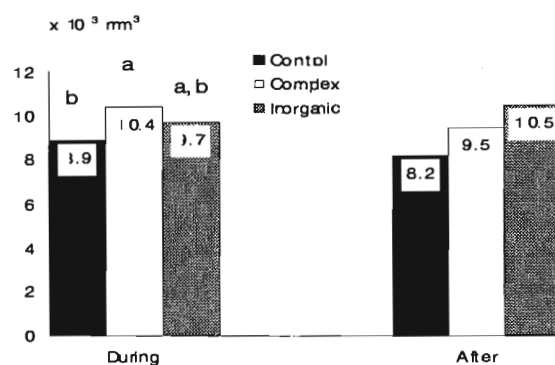


Figure 5. Influence of Mineral Supplementation on Heifer Neutrophil Counts

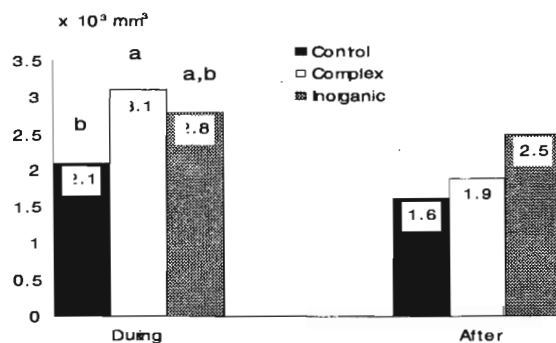


Table 2. Influence of mineral supplementation on copper and zinc serum levels in heifers and their calves.

<u>Item</u>	<u>Complex^a</u>	<u>Inorganic^b</u>	<u>Control</u>
Serum copper levels, mg/L			
Heifers	0.60	0.61	0.63
Calves	0.34 ^c	0.33 ^c	0.31 ^d
Serum zinc levels, mg/L			
Heifers	0.73	0.70	0.68
Calves	1.23	0.88	1.00

^aComplex supplement contained the following organic mineral complexes: zinc methionine (8,818 ppm zn), copper lysine (2,472 ppm cu), cobalt glucoheptonate (704 ppm co) and manganese methionine (4,987 ppm mn).

^bInorganic supplement contained zinc, copper, cobalt, and manganese in the sulfate forms and provided minerals at the same level as the complex supplement.

^{c,d}Means in the same row with different superscripts are different ($P < 0.07$).

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Chapter 4. Supplementation Strategies

SUPPLEMENTATION STRATEGIES

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Introduction

Livestock production systems are dynamic but must reach a long-term equilibrium in order to be biologically and economically sustainable. The system is biologically sustainable if the number of grazing animals is in a long-term balance with the amount of forage produced. The balanced system may be highly productive if the grazing animals have high genetic potential and if their requirements are met to a high degree. Alternatively, the system may be balanced yet much less productive if the requirements (and potential) of the animals are lower and (or) nutrients are available from the vegetation at a lower level or in a less favorable pattern. In the latter case, the production system may be biologically but not economically sustainable.

Grazing animals develop a behavioral pattern in seeking and consuming forages that satisfy some proportion of their physiological needs for nutrients (Stuth, 1991). Some of these activities are instinctive and some may be learned, but a settled-on pattern of behavior becomes characteristic of the animals within the bounds set by the local circumstances. Depending on the size and topography of the area, grazing animals may graze the entire area if small, may graze a small portion (e.g., valley site) of a large but totally accessible area, or may travel the entire area with intermittent stops to graze small preferred patches. Supplementation can be an enhancement to behavioral strategies by increasing the efficiency with which the grazing animals harvest forage and extract nutrients from it. Conversely, supplementation can be intrusive if a sustainable strategy is disrupted by a negatively impacting behavioral change.

The productivity of the unsupplemented grazing animal is determined, therefore, by its potential to produce and how well its nutrient requirements are satisfied by quantity, quality, and consistency of the grazed forage. Supplementing nutrients to grazing cattle is an adjustment for increasing the efficiency of transfer of forage nutrients to consumable products (meat, milk, and fiber). Once the proper species, classes, and numbers of animals are selected, practical questions of methods and timing are appropriate. Adopting supplementation does not diminish the need to maintain balance between the supply of and demand for forage; but, supplementing can increase harvest efficiency (i.e., forage intake; Huston et al., 1993) and the nutritional value of the forage (i.e., digestibility; DelCurto et al., 1990a,b), and release the production system to capitalize from more efficient animals having higher requirements (Holloway et al., 1975). Often, the final answers to a supplementation strategy may be weighted more by economic than by biological constraints, and it is common that the optimal management practice supports less than maximal productivity. The most frequently asked questions regarding supplemental feeding are what and how much should be fed. Also important is what method should be used in feeding. In this discussion on supplementation strategies, feeding frequency and hand- vs. self-feeding are considered. Both have biological and economic impact on the success of the practice.

Frequency of feeding

Physiological activities of the ruminant, including those within its gastrointestinal system, do not proceed at a constant rate (Swain et al., 1996). Rather, almost all processes are cyclical and vary in activity

within the 24-hour day (Beever and Siddons, 1984). For example, cattle generally graze until the reticulorumen is full of freshly grazed, poorly chewed forage, then lie down and ruminate. A mouthful of forage and liquid are regurgitated, chewed, and then swallowed. This process reoccurs many times until most of the material that was originally swallowed, but not chewed, has been further processed and made more accessible for attack by rumen microorganisms and their digestive enzymes. Fermentation rises along with the release of ammonia and the production of end products of fermentation (short-chain fatty acids), thereby increasing the absorption of these metabolites through the rumen wall and into the bloodstream. The ruminal contents decrease in mass as fermentation occurs. Undigested particles are carried along with the liquid phase that contains ruminally synthesized products as both exit the rumen to the lower tract where they are further processed. At some point, the animal rises to defecate, drink water, and (or) resume grazing to begin the cycle again.

The number of times that these activities occur within the day depends on many factors that include forage availability (that influences harvest rate), forage quality (that influences total intake, ruminating duration, and passage rate), and environmental factors (such as day length, temperature, wind speed, precipitation, etc.). Some cycles occur many times within a 24-hour period (eating cycles with rises and falls in rumen ammonia and blood urea levels), some approximately at 24-hour intervals (common watering interval), and some less frequently (hormonal cycles, including those associated with the estrus cycle).

Supplemental feeding affects the normal cycles, and, depending on the composition of the supplemental feed, different changes occur (Doyle, 1987). High grain (starchy) feeds contain a relatively small amount of protein (less than 15 percent) but are highly and rapidly fermented by the rumen microorganisms. Rumen microorganisms in grazing animals, especially when forage quality is low, are adapted to fermentation of fiber (cellulose), a

rather slow process. If grain is introduced into the rumen, fermentation increases and short-chained fatty acids are produced at an accelerated rate, thereby increasing the acidity of the rumen environment (drop in pH level). If this dietary change is abrupt and a substantial amount of grain is fed, the animal is in danger of acute lactic acidosis, which puts the animal in physiological crisis and may cause death. If the grain is introduced gradually and fed frequently, the rumen microbial population will adapt and capitalize on the more accessible nutrients (high energy and adequate protein). Although the fiber may be less well digested (Russell and Wilson, 1996), the increased value of the grain can more than offset a small decrease in fiber digestion and possibly in forage consumption. In some instances, low-level grain feeding stimulates fiber digestion by creating more microbial activity and either does not affect or slightly increases forage consumption (Doyle, 1987; Obara et al., 1991). This usually occurs when the rumen environment is maintained at a somewhat steady state (daily dietary ingredients are proportionally similar).

Feeding of a high protein supplement does not result in an abrupt increase in volatile fatty acid production but increases ruminal ammonia and stimulates the microbial population to ferment fiber. If the forage in the diet is low quality (low in digestibility and protein), then the animal will benefit from protein feeding in four important ways. The protein in the supplement is broken down partially in the rumen. The products that include peptides, amino acids, ammonia, and various carbon fragments become part of the ruminal metabolic pool, yield some energy, and stimulate fermentation of dietary fiber. Benefits include: (1) a contribution to the digestible energy (fermented fragments), (2) increased fiber digestion and energy yield from fiber, (3) increased flow of protein (from diet and from rumen synthesis) to the lower tract for digestion, and (4) increased forage consumption because of decreased ruminal fill. Intermittent feeding of starch (high grain supplements) results in constant adjustments in the rumen population.

Intermittent feeding of a protein concentrate, which is usually lower in starch and higher in fiber, is relatively non-intrusive to the dynamic equilibrium of the rumen population.

The dynamics of the relationship between the ruminal microbial population and the host animal suggest that steady state nutrition is not essential for normal metabolic processes to continue. Hunt et al. (1989) showed that feeding of cottonseed meal at 12-, 24-, and 48-hour intervals to steers equally increased the particulate passage rate and intake of low-quality grass hay. An earlier study by McIlvain and Shoop (1962) showed that weaner steers grew approximately as well grazing on rangeland during a winter feeding period and subsequent summer period whether they were fed daily equivalents of 1 to 1.5 lb of cottonseed cake daily, every third day, or weekly. Similar results have been reported at other locations with other classes of cattle either grazed or fed low-quality forages (Collins and Pritchard, 1992; Huston et al., 1986, 1996, 1997; Melton and Riggs, 1964; Wettemann and Lusby, 1994).

However, conflicting results have occurred when high-grain supplements were fed at different intervals. Chase and Hibberd (1985a) found that alternate-day feeding of high-grain supplements reduced intake of native grass hay (crude protein (CP) = 5 percent) compared to daily feeding of the same supplements. Moreover, a separate study by these same researchers (Chase and Hibberd, 1985b) showed that feeding corn at levels above 2 lb/day to adult cows decreased both intake and digestibility of native grass hay (CP = 4.2 percent). Similar results were reported by Adams (1986). Presumably, these reductions were the result of lowered pH in the rumen, thereby decreasing the activity of fiber-digesting microorganisms. On the other hand, Beaty et al. (1994) fed cows supplements of increasing protein (decreasing grain) content and found daily feeding only slightly more effective than less frequent feeding (three times per week) with no interaction for frequency X composition. Huston et al. (1996) found that

feeding a cottonseed meal:sorghum grain mixture (30:70) was of no value for cows grazing dormant Texas rangeland when fed at a low level either three times per week or weekly. However, when the mixture was fed at a high level (to provide equal protein with 2.1 lb/head/day cottonseed meal alone), it was as effective as the cottonseed meal even when fed in a once/week feeding of up to 30 lb/cow. This was a surprising result and requires additional study. Perhaps at the low feeding level, the expected decline in forage intake and fiber digestion occurred, thereby negating any benefit. At the higher feeding level (approximately 4.25 lb/day), the amount of energy and protein supplied may have offset any disadvantage due to substitution. The question of why those cattle fed a very high level of grain once per week were not adversely affected with grain overload (lactic acidosis) is open to question.

It is likely that the effectiveness of infrequent feeding of protein supplements is dependent on the demonstrated capacity of the ruminant for nitrogen recycling (Houpt and Houpt, 1968; Hume et al., 1970). A high protein supplement fed every 3 to 7 days results in a large increase in rumen ammonia within a few hours after feeding (Beaty et al., 1994) followed by a rise in blood urea concentrations. In cows fed supplements once per week, at least one subsequent peak in blood urea occurs on about day 4 (Huston, unpublished data). This presumably is associated with recycling of absorbed nitrogen back to the rumen, where it again stimulates fiber digestion, protein synthesis, and forage intake before being reabsorbed in various forms and converted partially to urea once again. It seems clear that infrequent feeding, although not always biologically optimal, is an acceptable and safe practice; but, at the present, it should not extend to high-grain supplements or those containing readily hydrolyzable nonprotein nitrogen.

Timing of supplementation

Supplemental feeding should be planned to maximize the value of the nutrients supplied and minimize the negative effects on animal behavior. Robinson (1996) suggested that feeding cows a protein supplement 1 hour before feeding a mixed ration provided rumen-soluble nitrogen at a low point of rumen ammonia and stimulated microbial growth prior to the ingestion of the mixed ration. The result was a rise in milk production. Night feeding of dairy cows increased fermentation rate without changing animal performance (Nia et al., 1995) and increased digestibility of the rest of the diet while concurrently decreasing the ruminal escape of dietary protein (Robinson, 1997). Clearly, these findings are interesting but not applicable to most range livestock settings.

Adams (1986) showed that steers fed a corn supplement in the early afternoon (during resting time) gained more weight than those fed during the morning grazing period. Additional work is needed in this area to clarify the interrelationships between time of supplementation, ingestion of forage, and grazing behavior.

Hand-feeding vs. self-feeding

Critical to the success of supplemental feeding is selecting a method that will deliver the desired amount of feed to the herd with minimal variability among the individual cows. Bowman and Sowell (1997) examined available information and concluded that optimal trough space and supplement allowances were important for hand-feeding. Inadequate space excluded some individuals from consuming supplement, and excess space increased the impact of dominant cows. Approximately 1 m per cow is adequate trough space for hand-feeding. Better distribution among the individuals in the herd accompanied higher feed allocations. Although self-feeding tended to reduce the percentage of cows that did not consume supplement, the disparity (coefficient of variation) in amount consumed

among individuals could be just as large or larger as when cows were hand-fed. Other factors that affected average consumption and within herd variability included supplement form (liquid, block, tub, etc.), formulation (block hardness, urea vs. preformed protein content, nutrient levels, etc.), and animal factors (e.g., social interactions).

In studies with ewes (Weir and Torell, 1953) and cows (Riggs et al., 1953), self-feeding of a cottonseed meal and salt mixture was shown to have similar effects on animal performance with hand-feeding cottonseed meal at the recommended level. Salt levels of 25 to 35 percent of the mixture were considered necessary to limit intake to desired levels. In a study in Venezuela with crossbred steers grazing Pangola pastures, Chicco et al. (1971) found a mixed ingredient supplement (57 percent polished rice, 40 percent sesame meal, and 2.8 percent bone meal; CP = about 23 percent) increased gains similarly whether self-limited by an addition of 30 percent salt or hand-fed without salt (46 percent and 57 percent, respectively). Brandyberry et al. (1991) found that approximately 20 and 30 percent salt in mixtures would limit intake of a supplement by steers to 1 kg per head per day during summer and winter, respectively. They found very similar grazing behavior in steers that were either self-fed or hand-fed daily in very small (4 ha) pastures. Whether these similar behavior patterns would be displayed in extensive pastures was not tested.

Clearly, the question of feeding method (hand-feeding vs. self-feeding) involves both feeding frequency and timing and their effects on grazing behavior. In small pastures or paddocks, feeding method would not be as important as in extensive situations. In small enclosures, time and distance do not restrict animal grazing opportunity. Whether cows visit a feeding location once a day, several times per day, or once every few days will not have a major influence on their opportunity to graze the entire area. On the other hand, cows on an extensive area may shorten their grazing time if they visit a feeding location frequently.

In a study with sheep (Hatfield et al., 1990), supplemented ewes fed daily loafed more than those that were unsupplemented, and as a result, grazed less and tended to weigh less after the winter feeding period. This illustrates the possibility that feeding a small amount to animals that are marginally undernourished because of extensive, low availability of forage may be detrimental rather than beneficial if grazing behavior is disrupted. Self-feeding would reduce the "anticipation factor" and encourage the animal to continue grazing longer. Self-fed animals have continuous access to the supplement (less "bully" effect), except occasionally when the dominant individual "stands guard" at the trough. Hand-feeding daily allows aggressive individuals to consume disproportionately greater amounts compared with those that are more submissive. The alternative of hand-feeding greater amounts at less frequent intervals is less disruptive and reduces the variation in consumption, presumably because dominant cows are less aggressive during the feeding event (Huston et al., 1997).

Conclusion

It is suggested that the most appropriate feeding method may be different for various production systems. If practical, frequent feeding to attain steady state conditions is most desirable (Beaty et al., 1994). If all else is equal, hand-feeding and self-feeding in small pastures give similar results. Therefore, the method of choice should be determined by economics and value of convenience. In extensive pastures, the additional considerations of animal behavior and grazing distribution are important. It is suggested that daily hand-feeding is the least desirable method for extensive systems. Some feed types (e.g., liquid feeds containing NPN as a major crude protein source) that should be continuously accessible must be self-fed. Other feeds, such as high-protein meals and cubes, can be fed infrequently for immediate consumption by the herd. Some feeds, such as self-limiting meals, blocks, and tubs, can be self-fed or fed infrequently for consumption

during a portion of the feeding interval. Major consideration should be given to the effects of the supplement on the animals, grazing behavior and on the value of the consumable forage. The most palatable supplement may be the least valuable choice.

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***Chapter 5. Dynamics of Supplementing Grazing
Animals***

SUPPLEMENTATION IN AN UNCERTAIN ENVIRONMENT: DYNAMICS OF THE GRAZING RESOURCE

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Introduction

This paper intends to discuss sources of uncertainty in the grazing animal's nutritional environment. In like manner, the intent is to discuss sources of uncertainty in animal response to that environment during components of the annual cycle. Managerial response to uncertainty is a matter of ecological health of the resource, animal well-being, and economics. A strategic method the manager can use to respond to such a complex environment is suggested.

The period of time when rangeland forage meets or exceeds the requirements of producing animals can be very short to year long. All rangeland vegetation exhibits periods of non-growth, because of low temperatures or no water. Three arenas of uncertainty characterize variation in the animal's grazing environment.

Plant

The nutritional content of plants varies in time and space. Nutrient content varies among plant kinds and parts and among plants of the same species. Nutrient content varies because of differences in phylogeny, phenology, the microsite, and associated plants.

Animal

On the same forage resource, animals may select very different diets with very different nitrogen and dry matter digestion (DMD) content. Variation in total ingestion and utilization of nutrients by individuals is large, including response to under- and over-nutrition. Variation in requirements of individuals is large, because

of differences in demographics related to age, sex, and physiological state.

Management

Values and economics dictate animal well being. Available information and experience dictate when and how often management intervenes to supply deficient nutrients. Managers evaluate alternative strategies to meet animal requirements. Managers experience a continual tradeoff between meeting the needs of the individual and the herd.

Characterization of Uncertainty

Plant. Availability of nutrients above animal requirements in different plant tissues drives the system. Obviously, the greater the portion of nutrients in the environment above requirements, the lower the risk animals will not find nutrients to meet requirements. If all nutrients are below requirements, management must assess the impact of under-nutrition or provide a supplement.

Animals prefer a variety of plants and plant parts to ensure optimal ingestion rates and avoid non-nutrient toxins or nutrients that act as toxins. The range of nutrient content of individual plant or plant parts can vary easily by 100 percent at any time of the year (Figure 1). The extreme range of nutrient content of the diet also can vary widely at any time of the year. Note that early in the season, actual diets are often lower in nutrient concentration than the average available; late in the season nutrients are only slightly better than average.

The point of this discussion is that what happens to the nutrient content of individual plants with the advance in season is really irrelevant if the animal has diet choices. What is important is how long animals can find enough high quality nutrients to meet requirements.

Processes that generate patches across a landscape have the potential to create different distributions of plant nutrients. As spatial scale increases from a small, single patch to landscapes and regions, more vegetation patch generating processes are included. At the same time, the diversity of the total nutrient bank available to free-grazing herbivores increases. Not only is there an opportunity for greater temporal variation in tissue-nutrient content, but there is greater opportunity for nutrient renewal from recently bitten plants when the size of a pasture or home range increases. That is, there is greater opportunity for the patterns of defoliation and renewal to be asynchronous. One might expect that when conditions are dry or very wet the impact on phenology and nutrient uptake would be minimal among microsites compared to intermediate conditions or sequences of wetting and drying. We all have observed the impact of year-to-year sequences, i.e., a wet year following dry years or dry years following wet years.

The range of available nutrient content among plants, sites, and years is huge at all times of the year, especially in the early growing season. In regions with non-growing season precipitation, the range of available nutrient content among plants decreases dramatically. The range is a result of differences in different life forms vs. variation within life forms. In regions with growing season precipitation, the range of available nutrient content can be large, because some tillers are long shoots and senescing, some are short shoots and senescing, some are growing, vegetative short shoots (Figure 1).

Therefore, it is the frequency distribution or amount of nutrients at any point in relation to animal requirements that's important (Figure 1). Any lack of high quality components in the forage mix constrains the ability of the animal to

ingest nutrients to complete components of the life cycle or perform at economical rates. The amount of high quality forage consumed usually is constrained by availability, distribution, and the physical limitations of prehension and accessibility (Bailey, 1995). Unlike low quality forages, intake of high quality forage usually is not limited by fill or digestibility. However, immature tissue might act as a nutrient toxin early in the season. Rittenhouse and Rounds (unpublished) found that diet N content was less than the average available early in the growing season, but, later in the growing season, diet N was greater than the average available.

We assume herbivores, especially ruminants, can substitute among plant-nutrient storage units (plants and plant parts) to obtain a high-quality diet. The challenge of the free-grazing animal is to meet the nutritional requirements necessary to complete life processes by finding and ingesting scarce forage with nutrient concentrations higher than its requirement and mixing it with more abundant forages with lower nutrient concentrations. Past explanations of diet content vs. requirements are irrelevant, because of the animal's ability to adapt to a variable environment. What is important is the point at which the animal can no longer find enough plant tissue greater than requirement to maintain a diet equal to requirement. The implication is that diet quality is impacted by herbage allowance and the variety of nutrient-storage units with quality above requirements. As grazing management intensifies, animals have an increased risk of being unable to find high quality nutrients. If animals are not able to find enough high quality nutrients in the occupied pasture, rate of ingestion decreases, and they must graze longer to compensate (Demment et al., 1987). The key to maintaining a quality environment for the free-grazing herbivore is to maintain choices. Choices should include a variety of patches on the landscape and choices of plants and plant parts within patches.

Animal. Variation in requirements of individuals is large. Variation in ingestion and utilization of nutrients by individuals is large, including response to under- and over-nutrition. Variation

in requirements of individuals in a herd at any point in time is large because of differences in physiological state(s).

The animal component of the system poses two important sources of uncertainty, i.e., those associated with the individual animal and those associated with variation in herd composition.

The range in nutritive value of individual diets is represented by a wide statistical distribution, and the position of any individual in that distribution changes with time and conditions. Variation in total ingestion among animals often is represented by coefficient of variation (CVs) of 30 to 50 percent. The combined effect of differences in DMD ingestion and diet utilization can vary by 30 to 50 percent. Digestibilities of the same diet by different animals can vary 20 to 30 percent. Differences in lignified diet fiber can be large; however, differences in diet N among animals is usually small. Likewise, consider the standard deviation (SD) of the maintenance requirements, including variation in basal metabolic rate (BMR), activity, clinical and sub-clinical disease, upper and lower critical temperatures, body condition score (BCS), days to calving, potential milk production, and biological type (size, breed, etc.).

Animals exhibit moderate differences in rumen response to different mixes of food in the diet (i.e., associative effects.) The amount of dietary digestible energy obtained from a high fiber diet mixed with a starch-based energy supplement varies significantly among individual animals.

Herd composition varies widely during the annual cycle. Herd composition is most critical during the last third of gestation and the first 60 days following parturition. The distribution of requirements in the herd is caused by factors like the percent conception on first estrus and length of the breeding season.

Breed-back within a herd in relation to BCS varies widely (Figure 2). Some cows consistently breed back with BCS of 3 or even less; others require BCS of 5 or more to ensure breed-back.

Management. Perhaps the greatest source of uncertainty in forage-based systems is management. Management controls the biological type of producing animals, biological type of the sire, the breeding season, disease prevention and control, replacement forages/feeds, and supplemental feeds. Managerial decisions are made in a climate of economic and financial uncertainty, governmental uncertainty, regulatory uncertainty, and market uncertainty. The financial and managerial skills of the owner/operator are uncertain.

Management determines how many, when, where, and how long animals might occupy an area. Management restricts choices. Management controls herbage allowance and grazing pressure.

The question is, "How much is the operator willing to pay to gain the last unit of economic margin from the production system?" Of course, if the system were perfectly deterministic, the answer is fairly straight-forward. Unfortunately, the system is suffused with uncertainty.

Discussion

Two strategies could be used to address the issue of deficient nutrients. First, treat the issue as a nutrient-balance problem, i.e., ingestion vs. requirements. Second, treat the issue as a risk-management problem. These two approaches result in very different strategies to deal with uncertainty.

In order to deal with uncertainty, the operator needs a valiative tool to project system response into the future (in this case, the animal system) and a way to determine how far into the future to let the system run before measuring an indicator of integrated response. Integrated response to environment and managerial decisions might be measured as conception rate or time from parturition to first estrus. An integrated indicator of response might be body condition score.

Until recently, we lacked a valiative tool that would facilitate predictions about the length of time it would take for an animal to gain or lose a body condition score, given initial conditions, the physiological state of the animal, the environment, and some estimate of diet quality. Production occurs in an environment of uncertainty. The best possible decisions in regard to dealing with under-nutrition will come from the combined use of a valiative tool (model), like NRC 1996, and periodic indicators (measurement) of animal status, like BCS. Obviously, the greater the uncertainty in the system, the more difficult it is to represent the state of the animal adequately, and the more difficult it is to know when to adjust inputs such as kind and level of supplement or management. Neither the prediction nor the measurement are without error.

How important is it to be correct? What is the cost of taking a measurement (e.g., BCS)? What is the cost or benefit of making a timely adjustment? The greater the days to calving the greater the flexibility. The closer to calving, the more critical decisions become, especially in regard to supplemental nutrients. Yet, one can never know. Statistically, the Kalman filter, used in either the uni-variate or multi-variate case, is a very powerful tool to help determine the actual status of the system (Jazwinski, 1970).

Supplementation of grazing animals traditionally has been approached as a nutrient balance issue. The goal is to feed sufficient nutrients to replace deficient nutrients, where deficiency is defined in relation to some response goal. However, which animal does the manager feed for? the average animal? the one that always seems to breed back at BCS 3.0? or, the one that needs BCS 5.0? The nutrient balance approach is most appropriate when animals are wintered on harvested forage, because diet choice is limited and nutrient content of food is more or less uniform (Rittenhouse and Bailey, 1996).

For each grazing environment, the manager must ask additional, fundamental questions. What percentage of the herd should be reproduction vs. disposable animals; for example, yearlings in a

cow-calf/yearling operation? How much variation in the herd is essential to respond to extremes in environmental conditions? Most managers strive for as much genetic uniformity in the herd as possible and then manage to maintain the maximum uniformity in offspring for marketing purposes. Is that the best strategy in uncertain environments, or is some optimal variation in traits desired? Therefore, the tradeoff becomes genetic uniformity vs. the cost of feeding to bring all carcasses to uniformity standard.

Managers treat the supplementation issue from both the perspective of the individual animal and the herd. In reality, we manage the herd to ensure a percentage of the animals produce a calf every year. That means some animals are underfed and some are overfed. A legitimate question is whether the manager would do a better job of attaining the desired response within the herd if she/he knew the stochasticity that characterizes the uncertainty [note the subtle change in emphasis from meeting requirements to obtaining the desired response]. For example, would a rancher make better decisions if she/he knew the protein or total digestible nutrients (TDN) content of the average animal's diet throughout the year vs. making decisions based on the previous year's herd response to some level of feeding? So, the basic question is whether one is better off to track the diet of the animal (presumably to know if nutrients ingested balance with nutrient demand), or simply to provide some level of nutrients based on previous experience, monitor some indicator of response (like BCS), and adjust periodically?

How much of the uncertainty in the system can be ignored without consequence? If the system is linear, the cost function is quadratic and all variables are Gaussian, uncertainty can be ignored, and decisions based on averages are just as good as those that include conditional probabilities (Jameson, 1985). Is the relationship between level of supplement and BCS mathematically linear (not necessarily a straight line)? Is the economic consequence of underfeeding the same as the economic benefit of overfeeding? In this case, the cost function

probably is not quadratic; it probably is skewed to the right. In other words, the cost of a female not producing offspring every year is more important than some added increment of cost to ensure another calf. At what point are those costs equal? Are the variables Gaussian? Most analyses show that distributions can be skewed to some extent without materially affecting the decision.

There seems to be ample evidence that uncertainty in the environment can be ignored. Decisions based on averages are just as good as decisions based on the stochasticity of the system. The best decisions would be based on a simple prediction of response, based on current system status. Then, the question becomes how long to let the system run before taking another measurement and adjusting inputs.

I am not aware of a specific analysis to test the above assumptions/hypotheses. It makes sense to me that one would make better decisions using a combination of predicted response and actual measurement of the status of the system (BCS) than tracking inputs, like nutrient composition of diets at a point in time based on fecal analysis. Methods like fecal analysis at best estimate the nutrient composition of the diet of an average herd animal. How does knowing the nutrient composition of an animal's diet at a point in time help the manager make better decisions over the next time-step? If it helps explain animal response to an incremental adjustment in level of supplement, maybe yes.

Managers use a combination of science and biology to make production decisions. They surround themselves with information, tested ideas, and competent advisors. Decisions are couched in economical and environmental contexts. The operator calls on observation and past experience to modify inputs and project outcome/benefit. Each manager is different and develops very different strategies to deal with uncertainty. All can be successful to

varying degrees. Success is measured in many ways. However, there is no strategy that guarantees against failure. At some point, asynchronous, negative events may all come together at the same time and overwhelm the system.

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Post Script. *"In the grand scheme of things, managers who are adaptive survive longer than those who are predictive."*

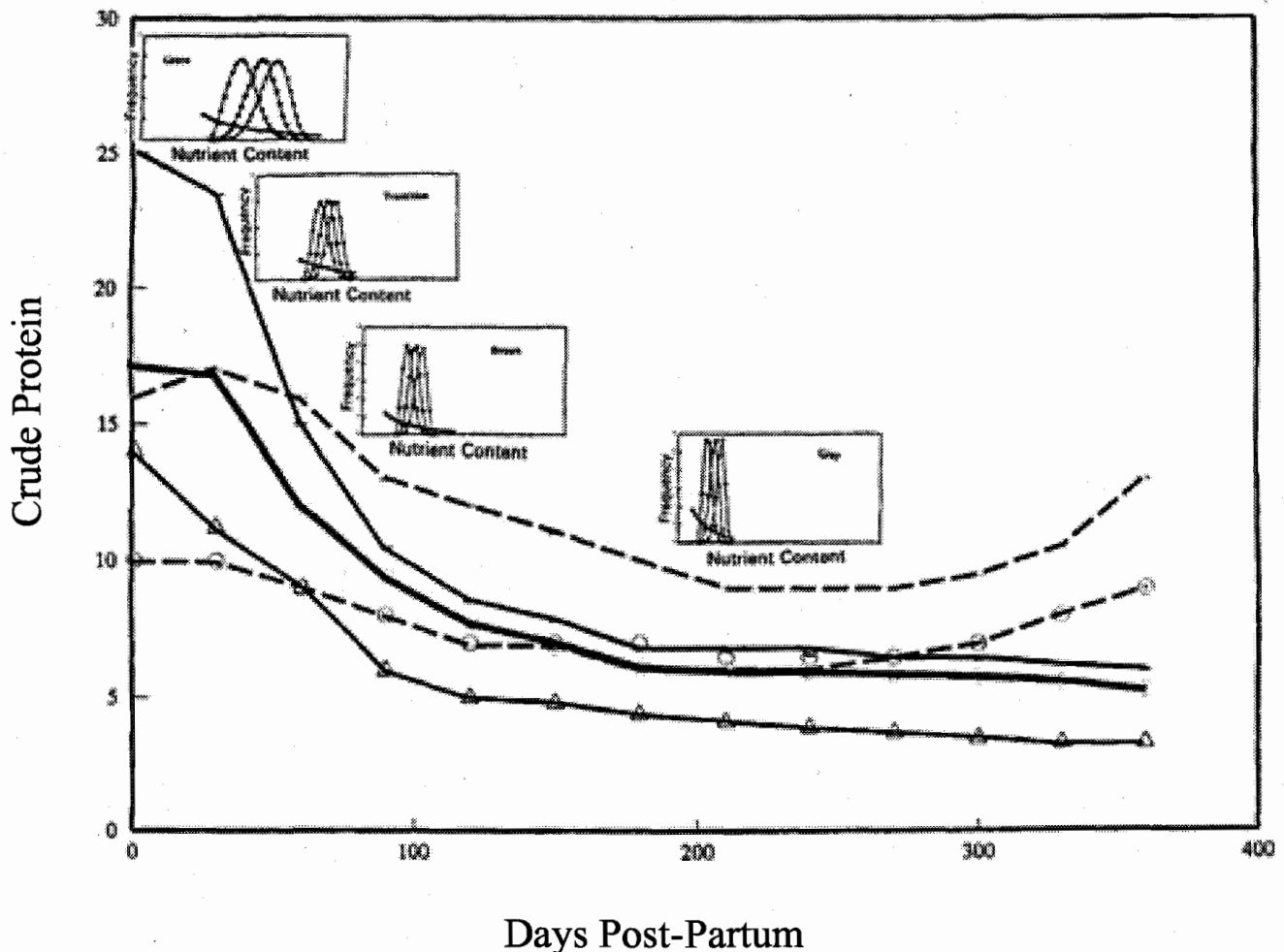


Figure 1. Plant and animal uncertainty in the system. Crude protein is an example of limiting nutrient. The solid, narrow lines represent the range of nutrient concentrations found in different plant storage organs and kinds of plants. The dashed line represents the range of requirements of individuals in the herd for this nutrient. The solid, wide line represents what is normally depicted as the potential diet composition of animals under free-grazing conditions. This line is idealized, because animals seldom graze under conditions of unlimited resource or without competition from cohorts. The inserts represent the potential distribution of nutrients within the range of nutrient concentrations (green to gray) and show how those distributions might change with depletion. The challenge of the animal is to find enough food with nutrient concentration greater than requirements to mix with food with nutrient concentration lower than requirements so the weighted average equals requirements.

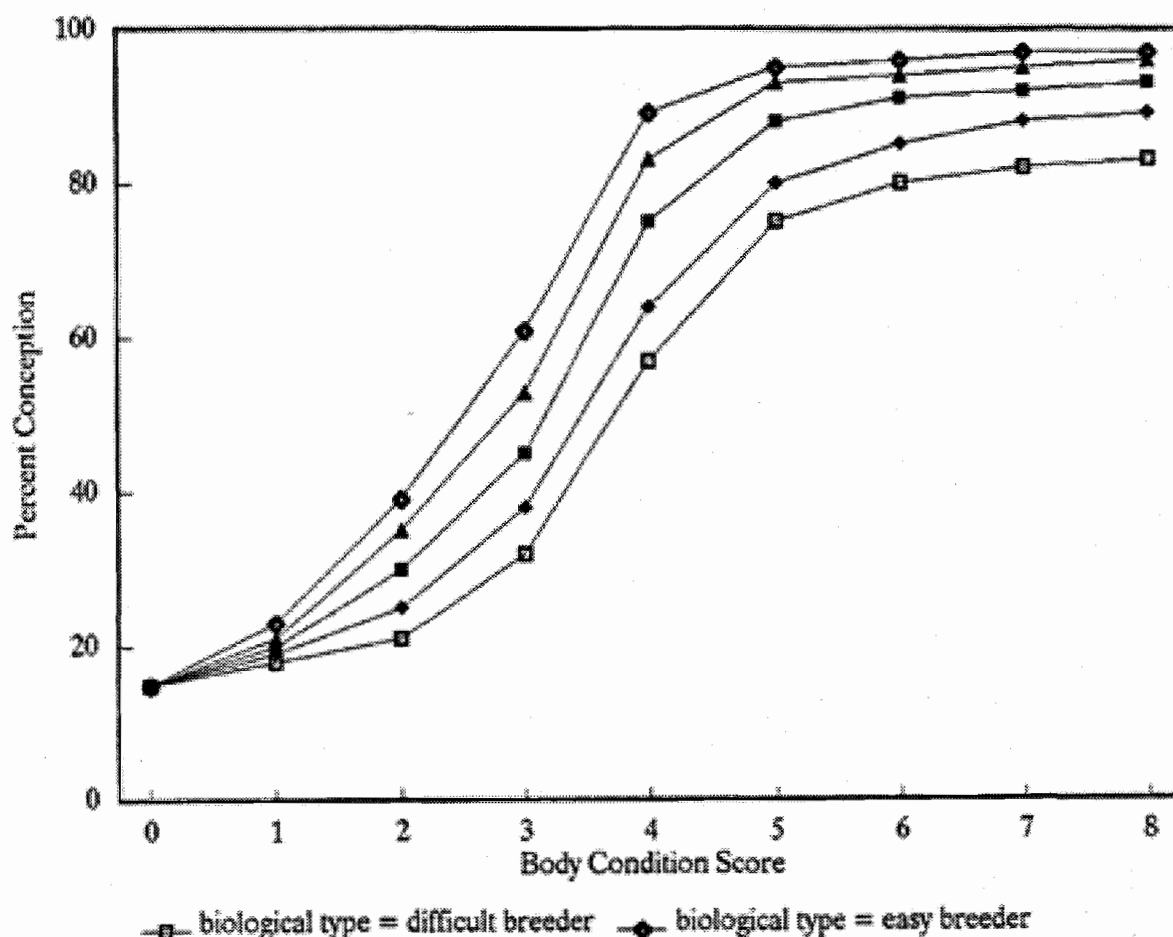


Figure 2. The range of breed-back response of individuals in a herd with different BCS at parturition. Some individuals maintain a 365-day production cycle with minimal BCS, while others require high BCS to ensure breed-back. Granted the end product (the carcass) must fall within the range of industry standards, but animals should be suited to the available forage resource to maintain good economic margins and manage economic risk effectively. The huge difference in the level of inputs (cost) required to bring animals to different BCS at parturition depends on initial conditions. Animals with high requirements absolutely must begin the period of under-nutrition in high BCS, and that must be maintained up to parturition. The cost will be high. The cost of underestimating feed required to meet the goal escalates as animals approach parturition. Animals with low requirements that begin the period of under-nutrition with good BCS require fewer inputs to maintain enough BCS to breed back. The cost of underestimating feed requirements as animals approach parturition is less, because increments of feed are used more efficiently.