MINERAL NUTRITION AND ITS IMPACT ON REPRODUCTION

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Introduction

Requirements have been published for 13 different minerals in beef cattle diets. Other minerals such as chlorine, chromium, molybdenum, and nickel are known to be essential for beef cattle; however, there is currently not enough data available to accurately determine requirements. For some of the required minerals, requirements vary depending on cow size and stage of production. This variability results from increased mineral demand for the products of conception and for milk production. For these minerals, requirements are always greatest during peak lactation and lowest for non-lactating cows in mid-gestation.

Minerals are essential for the proper function of numerous physiological processes. From a production perspective, proper mineral nutrition is critical for metabolic function, health, and reproduction. Unfortunately, mineral nutrition is one of the most complicated and least understood components of nutrition. This review will focus on the macro and trace minerals that have been shown to impact reproduction in males, females, or both.

Minerals and Reproduction

Calcium. Calcium (Ca) is the most abundant mineral in the body and 99% is found in the skeleton; however, small proportion of body calcium that lies outside the skeleton is important to survival (Suttle, 2010). As it relates to reproduction, Ca has a well-documented role in sperm capacitation. The capacitation process results in increased membrane permeability to Ca. This influx of Ca is necessary for the fusion of the plasma membrane and the outer acrosomal membrane and the subsequent initiation of the acrosome reaction (Singh et al., 1978; Triana et al., 1980). In addition to its role in capacitation and acrosome reactions, calcium is also a common cellular signaling mechanism that can impact reproduction in a number of ways. Not only is calcium intricately involved in muscle contraction, but it is also important for sperm motility. Sperm motility is correlated with cyclic AMP concentration. Calcium, along with magnesium and manganese, is a potent stimulator of adenylate cyclase, an enzyme that converts adenosine triphosphate (ATP) to cAMP (Rojas et al., 1992; Tash et al., 1983). In most circumstances, very little if any supplemental Ca is necessary for cattle grazing early in the growing season. However, as the season progresses and the forages begin to mature, there may be need for supplemental Ca. Furthermore, the ratio of Ca to phosphorus should be maintained between 1.5:1 and 7:1 to avoid an imbalance.

Phosphorus. Phosphorus (P) is the second most abundant mineral in the body and approximately 80% is found in the bones and teeth (Suttle, 2010). However, P is also an essential component of DNA and RNA, phospholipids, and has a key role in a host of metabolic processes. Given the importance of P to so many physiological processes, it is not surprising that it can impact reproduction. Early experiments documented tremendous responses to P supplementation in the form of meat and bone meal; however, subsequently, it was determined that these responses were more likely due to the protein content of the feed rather that the P (Suttle, 2010). Read and coworkers conducted experiments in 2 areas in South Africa (Read et al., 1986a). In one location, supplemental P had little to no effect on reproduction. However, in the other, unsupplemented cows experienced severe reductions in pregnancy rates. The unsupplemented cows at the second location had lower bone P concentrations than the supplemented cows (Read et al., 1986b). In other research, range beef cows in North Dakota that were supplemented with P had slightly greater conception rates than control cows in 1 year, but not in a second (Karn, 1997). While supplemental P did not have a profound impact on reproduction, it did consistently increase calf weaning weights (Karn, 1997). In contrast to these findings, some researchers have observed no response (Call et al., 1978) to supplemental P or responses only in drought years (Judkins et al., 1985). More research on the effect of dietary P concentrations on reproduction is certainly warranted. However, for beef producers, it appears that supplementing to meet, but not exceed, the NRC (1996) requirements (Tables 1-3) is the most effective and economical management practice.

Copper (Sulfur and Molybdenum). Copper (Cu) is present in and essential for the activity of numerous enzymes, cofactors, and reactive proteins (Suttle, 2010). Copper deficiency has been associated with delayed or depressed estrus (Phillippo et al., 1982); however, results have been inconsistent. An exact mechanism whereby Cu might affect reproduction has not been identified, but it is likely due to any combination of enzymes. Sulfur and molybdenum were intentionally mentioned in the title of this section because of the challenges they present to Cu metabolism. The combination of S and Mo in the rumen results in the formation of thiomolybdates which form insoluble complexes with Cu and reduce its absorption. A percentage of the thiomolybdates are absorbed by the animal and can reduce the existing stores of Cu in the system. Given the relatively high concentrations of Mo in feeds and forages and the amount of high-sulfate water and feeds (e.g. distillers co-products), Cu deficiency is arguably one of the most common mineral concerns in the Upper Great Plains. Supplementation to overcome these antagonisms requires formulation of supplements with increased levels of Cu or utilization of organic Cu sources.

Impaired reproductive function under these conditions may not be due exclusively to a Cu deficiency. Research suggests that Mo alone or in the form of thiomolybdate may have a negative impact on reproduction (Humphries et al., 1983; Phillippo et al., 1987; Kendall et al., 2006). More research needs to be conducted to further describe this relationship.

Iodine. Iodine (I) has only one known, but vital function as a constituent of thyroid hormones (Suttle, 2010). Very little research has been conducted on the effect of iodine nutrition on reproduction. However, Hemken (1960) attributed infertility, sterility, and poor conception rates due to delayed or depressed estrus to thyroid dysfunction that occurred in response to increased I losses during peak lactation. In iodine-deprivation in male goats has resulted in decreased libido and a deterioration in semen quality (Pataniak et al., 2001). Forages and feeds grown in many areas of the Upper Great Plains are deficient in I and livestock need to be supplemented. This is generally accomplished with the use of iodized salt. Under certain circumstances, supplementation above the NRC (1996) requirement (Table 4) may be necessary. Use of brassicas as cover crops for fall grazing has become increasingly popular. These crops can provide excellent quality feed for ruminants; however, many of them contain compounds called goitrogens that can interfere with thyroid hormone production. Generally, these goitrogens are largely destroyed by ruminal microorganisms, but if consuming large amounts, the microorganisms may not be able to detoxify them adequately.

Manganese. Manganese (Mn) is among the least well researched trace minerals. It is an integral component of many enzyme systems and has a significant role in reproduction. Manganese has been linked to the function of the corpus luteum and, because of its role as an enzyme cofactor, the synthesis of cholesterol and sex hormones (Suttle, 2010). However, recent research suggests that the effect of Mn on cholesterol and steroid hormones may not be as significant as once thought. Hansen et al. (2006a,b) fed pregnant heifers diets deficient enough in Mn to result in deformed calves, but did not observe any effect on plasma cholesterol concentrations or conception rates. Manganese deprivation has also been shown to restrict testicular growth in rams (Masters et al., 1988). For most beef producers, supplementing Mn to meet the nutrient requirements (Table 4) of their cattle is the best management practice.

Selenium. Selenium (Se) can be a challenging mineral to deal with on many beef cattle operations. In certain locations across the Midwest and Upper Great Plains, Se is deficient in the soil and hence the feeds and forages grown there. Yet in other locations, the Se concentrations found in feeds may exceed levels considered to be toxic. As with many other trace minerals, Se is a component of several enzyme systems. Many of these systems function as antioxidants, but there are numerous biologically active selenoenzymes. Production responses to Se supplementation of deficient animals has improved fertility in heifers (MacPherson et al., 1987) and reduced the incidence of endometritis and cystic ovaries (Harrison et al., 1984). Both of these later responses may have beneficial effects of female fertility. In males, Se deficiency has resulted in reduced semen viability (Slaweta et al., 1988). Among the selenoenzymes is phospholipid hydroperoxide glutathione peroxidase (PHGPx/GPX4). Most of the selenium found in the testes is associated with PHGPx/GPX4, which is an antioxidant that protects the cells from oxidative stress (Boitani and Puglisi, 2008). Selenium supplementation should be based on the amount of Se in the basal dietary ingredients. In some areas, supplementation will result in beneficial responses, in others, it may be the straw that breaks the camel’s back relative to toxicity. Given the narrow window between the requirement and toxicity, feed analysis and careful formulation is as essential for Se nutrition as for any other mineral.

Zinc. Zinc (Zn) is among the most ubiquitous of the trace minerals. It is an integral component of over 300 enzymes and is associated with numerous biological processes. Among the biological processes dependent upon Zn is gene expression. As such, although not been well researched, the importance of Zn to reproductive function should not be underestimated. The vast majority of the research that has been conducted to date has looked at the effect of Zn on male fertility. Early research observed hypogonadism in Zn-deprived bull calves (Pitts et al., 1966) and in ram lambs fed a severely Zn-deficient diet, spermatogensis was nearly completely halted (Martin and White, 1992). Supplementation of Zn to the rams resulted in complete recovery. Zinc supplementation has also increased ejaculate volume, sperm concentration, percent live, and percent motility in bulls (Arthington et al., 2002; Kumar et al., 2009). Furthermore, utilization of a combination of organic and inorganic Zn sources supplemented at the NRC (1996) requirement resulted in improved fertility than Zn supplemented from inorganic sources alone. A large percentage of the genetic improvement on an cow-calf operation stems from the bull battery. As such, proper Zn nutrition becomes an incredibly important economic decision for beef producers. However, while meeting the animals' requirement should be the objective, supplementing beyond the requirement is likely to be fruitless and economically wasteful.

Mineral Supplementation

For most producers, the place to begin development of a mineral program is simply identifying the animals' requirements. It is important to recognize that, while published requirements are based on years of published research, our understanding of mineral nutrition in beef cattle is cursory at best. A growing body of research suggests that mineral requirements can vary significantly by breed, production, and the presence of antagonists. Producers should work with their nutritionist or Extension personnel to adjust their mineral program accordingly to account for these factors.

Mineral status can have a tremendous impact on the response to supplementation. If an animal's mineral stores are adequate, it is unlikely that supplementation will result in a biologically or economically significant response. However, if an animal is in a deficient state, and production has been compromised, the response to supplementation can be dramatic.

The first step in determining mineral status of the cowherd is to objectively analyze various performance and production measures. If there appears to be a reduction in a particular measure, be sure to rule out other potential causative factors. It is also essential to evaluate the current mineral program. Is it well balanced? What percentage of the cow's requirements does it meet? And, perhaps most importantly, are the cows consuming enough? The solution to the problem may be as simple as including a small amount of molasses to the mineral supplement to increase consumption.

The second step in determining mineral status is to determine how much of each mineral is supplied by the diet. Because of the inherent variability in the mineral content of the feeds and the potential error associated in predicting feed intake, this estimation can be challenging. Water also contributes a significant amount to the mineral nutrition of a beef cow. However, because of the extreme variability in mineral content and intake, most producers should only consider water as a source of potentially detrimental minerals (i.e. sulfur and iron).

The third and final means of assessing mineral status is to directly sample the animal. Mineral status can be evaluated by sampling and analyzing blood and/or tissue. For most minerals, a liver sample is the most reliable means of determining mineral status, especially for trace minerals. Mineral concentrations in blood are generally not good indicators of mineral status unless an animal is severely deficient. Liver samples can be obtained either post-mortem or from a live animal via liver biopsy. The liver biopsy procedure is simple and inflicts very little stress upon the animal. Consult your veterinarian or Extension personnel to find out more information on collecting liver biopsies.

When formulating mineral supplements, the source of each mineral can have a dramatic impact on the effectiveness of the supplementation program. In general, inorganic sources are the most cost-effective means of supplying minerals to a beef cow. However, all inorganic mineral sources are not created equal. Research suggests that sulfate and chloride forms of various minerals are the most bioavailable, followed by carbonates, with oxides being the least bioavailable. One exception to this rule of thumb is copper oxide. When the powdered or granular form of copper oxide is included in a mineral supplement, it is a very poor copper source. However, research indicates that copper oxide needles, administered as a bolus, can be an extremely effective means of delivering copper to cattle on forage-based diets.

Organic mineral sources represent another option for producers to supply minerals to their cowherds. Research suggests that some organic mineral sources are indeed more bioavailable; however, production responses to supplementation have been variable. Positive responses to organic mineral supplementation are most likely during stressful periods in the production cycle (i.e. calving and weaning), or when mineral antagonists (i.e. sulfur, molybdenum, iron, or aluminum), are present in large amounts. In these situations, producers should objectively weigh any expected benefit to animal performance against the added cost of including organic minerals in their supplementation program.

When evaluating a mineral supplement, it is extremely important to read the feed tag carefully to determine the guaranteed amount and source of each mineral. In some cases, a mineral source may be listed as an ingredient on the tag without a guaranteed analysis. In this situation, producers should err on the side of caution and assume that there is essentially no manganese in the mineral supplement.

Developing the most cost effective mineral program is certainly not a formula that can be applied to every farm and ranch around the country. Producers should carefully evaluate their production system, its resources, level of production, and production constraints, to develop the most cost-effective program for their operation. Keep in mind that more expensive mineral supplements do not always correlate with increased production or performance. Any cost associated with change in a mineral program must be accompanied by a corresponding increase in production or performance (i.e. weaning rate, weaning weight, etc.) to offset the added expense.

Conclusion

Mineral nutrition can have a profound impact on the fertility of both males and females. However, to optimize reproductive efficiency, beef producers should strive to provide their cattle with the energy, protein, vitamins, and minerals necessary to meet the needs of the animal. Supplementation of minerals should be based upon the supply of minerals in the basal feed ingredients and the needs of the animal. Rarely is oversupplementation of any benefit to the animal and it ultimately results in added expense for the operation. Strategic use of organic mineral sources may be beneficial to reproductive efficiency.

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Table 1. Nutrient requirements of beef cows (1000 lb mature weight).[a]

	Months since calving											
	1	2	3	4	5	6	7	8	9	10	11	12
10 lb peak milk production												
Ca, %	0.24	0.24	0.23	0.22	0.20	0.19	0.15	0.15	0.15	0.24	0.24	0.24
P, %	0.17	0.17	0.16	0.15	0.14	0.14	0.11	0.11	0.11	0.15	0.15	0.15
20 lb peak milk production												
Ca, %	0.30	0.32	0.30	0.27	0.24	0.22	0.15	0.15	0.15	0.24	0.24	0.24
P, %	0.20	0.21	0.19	0.18	0.17	0.15	0.11	0.11	0.11	0.15	0.15	0.15
30 lb peak milk production												
Ca, %	0.35	0.38	0.35	0.32	0.28	0.25	0.15	0.15	0.15	0.24	0.24	0.24
P, %	0.22	0.24	0.22	0.21	0.19	0.17	0.11	0.11	0.11	0.15	0.15	0.15

[a]Adapted from Nutrient Requirements of Beef Cattle (National Research Council, 2000).

Table 2. Nutrient requirements of beef cows (1200 lb mature weight).[a]

	Months since calving											
	1	2	3	4	5	6	7	8	9	10	11	12
10 lb peak milk production												
Ca, %	0.24	0.25	0.23	0.21	0.20	0.19	0.15	0.15	0.15	0.26	0.25	0.25
P, %	0.17	0.17	0.16	0.15	0.14	0.14	0.12	0.12	0.12	0.16	0.16	0.16
20 lb peak milk production												
Ca, %	0.29	0.31	0.29	0.26	0.24	0.22	0.15	0.15	0.15	0.26	0.25	0.25
P, %	0.19	0.21	0.19	0.18	0.17	0.15	0.12	0.12	0.12	0.16	0.16	0.16
30 lb peak milk production												
Ca, %	0.34	0.36	0.34	0.31	0.27	0.25	0.15	0.15	0.15	0.26	0.25	0.25
P, %	0.22	0.23	0.22	0.20	0.18	0.17	0.12	0.12	0.12	0.16	0.16	0.16

[a]Adapted from Nutrient Requirements of Beef Cattle (National Research Council, 2000).

Table 3. Nutrient requirements of beef cows (1400 lb mature weight).[a]

	Months since calving											
	1	2	3	4	5	6	7	8	9	10	11	12
10 lb peak milk production												
Ca, %	0.23	0.25	0.23	0.21	0.20	0.19	0.16	0.16	0.16	0.27	0.26	0.26
P, %	0.17	0.17	0.16	0.15	0.15	0.14	0.12	0.12	0.12	0.17	0.17	0.17
20 lb peak milk production												
Ca, %	0.28	0.30	0.28	0.26	0.24	0.22	0.16	0.16	0.16	0.27	0.26	0.26
P, %	0.19	0.20	0.19	0.18	0.17	0.16	0.12	0.12	0.12	0.17	0.17	0.17
30 lb peak milk production												
Ca, %	0.33	0.35	0.32	0.30	0.27	0.24	0.16	0.16	0.16	0.27	0.26	0.26
P, %	0.22	0.23	0.21	0.20	0.18	0.17	0.12	0.12	0.12	0.17	0.17	0.17

[a]Adapted from Nutrient Requirements of Beef Cattle (National Research Council, 2000).

Table 4. requirements and maximum tolerable concentrations of minerals

Mineral	Unit	Gestation[a]	Early lactation[a]	Maximum tolerable concentration[b]
Calcium	%	Refer to Tables 1 through 3		1.5
Chromium	ppm (mg/kg)	---	---	100[c]
Cobalt	ppm (mg/kg)	0.10	0.10	25
Copper	ppm (mg/kg)	10	10	40
Iodine	ppm (mg/kg)	0.50	0.50	50
Iron	ppm (mg/kg)	50	50	500
Magnesium	%	0.12	0.20	0.6
Manganese	ppm (mg/kg)	40	40	2000[d]
Molybdenum	ppm (mg/kg)	---	---	5-10[e]
Phosphorus	%	Refer to Tables 1 through 3		0.7
Potassium	%	0.60	0.70	2
Selenium	ppm (mg/kg)	0.10	0.10	5
Sodium	%	0.06-0.08	0.10	---[f]
Sulfur	%	0.15	0.15	0.3 or 0.5[g]
Zinc	ppm (mg/kg)	30	30	500

[a]Adapted from Nutrient Requirements of Beef Cattle (National Research Council, 2000).
[b]Adapted from Mineral Tolerance of Animals (National Research Council, 2005).
[c]When chromic oxide (Cr_2O_3) is fed, the maximum tolerable concentration is 3000 ppm.
[d]If fed adequate concentrations of dietary iron.
[e]For copper-adequate cattle.
[f]Ruminants can consume 0.016 oz salt (NaCl) per lb body weight.
[g]To prevent polioencephalomalacia (PEM), the maximum tolerable sulfur concentration is 0.3% for cattle consuming at 85% or more of their diet as concentrate and 0.5% for cattle consuming at least 40% forage in their diet. Dietary sulfur concentrations below the maximum tolerable concentrations may have adverse effects on copper absorption.

Notes