EFFECTS OF INCREASING TETANY RISK RATIO AND MAGNESIUM SUPPLEMENTATION ON MINERAL BALANCE AND FEEDING BEHAVIOR BY RUMINANTS

by

Tess Marie Norvell

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APPROVAL

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Tess Marie Norvell

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency and is ready for submission to The Graduate School.

Dr. John A. Paterson

Approved for the Department of Animal and Range Sciences

Dr. Glen Duff

Approved for The Graduate School

Dr. Carl A. Fox

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ABSTRACT

Three experiments were conducted to evaluate the effects of increasing the tetany risk ratio on blood serum Mg levels, nutrient digestion, mineral balance, and Mg supplementation source and feeding behavior. Experiments 1 and 2 were randomized complete block designs, with 24 wethers were maintained in individual metabolism crates and assigned to four treatments (6 wethers/treatment). Experiment 1 compared tetany risk ratios (TRR) of 1.6, 2.3, 2.9, or 3.5. Dry matter, NDF, and N digestibilities were not different between treatments. Nitrogen retention decreased ($P < 0.05$) as the tetany risk ratio increased. No treatment differences were recorded in Mg, Ca, K, or P balance. The TRR 2.3 treatment had the greatest decrease ($P < 0.05$) in serum Mg after 15d. Experiment 2 compared tetany risk ratios of 1.5, 2.6, 1.5 plus MgO, or 1.5 plus MgCl. The TRR 2.6 treatment showed increased ($P < 0.05$) DM, NDF, and N digestibilities when compared to all other treatments. Nitrogen digestibility decreased ($P < 0.05$) with the addition of supplemental Mg. No treatment differences in Mg, Ca, K, or P balance were recorded. The TRR 2.6 treatment had the greatest decrease ($P < 0.05$) in serum Mg after 5 d. Experiment 3 was a cafeteria study using a switchback design, 23 Angus heifers were weighed and randomly assigned to one of two locations (11 heifers in drylot, and 12 heifers on pasture) containing two mineral supplements (0.0% Mg and 10.0% Mg). The groups were rotated between locations after 15 d for 30 d of measurements. Individual mineral consumption (grams/d), feeder attendance (trips/d), and feeding duration (seconds/d) were measured using a GrowSafe® individual feeding system. Heifers consumed 119% more ($P < 0.01$) 0.0% Mg supplement each day than the 10.0% Mg. Heifers made almost twice as many ($P < 0.01$) trips to the feeder, and spent an additional 91.3 s consuming the 0.0% Mg than the 10.0% Mg. Total mineral intakes were 87.3 % greater ($P < 0.01$) when supplemented on pasture compared to drylot. During the first 15 d, total mineral intakes were higher ($P < 0.01$) than for the second 15 d.

CHAPTER 1

INTRODUCTION

Hypomagnesemic tetany is a metabolic disease that kills or affects approximately 350,000 beef cows in the United States annually (Fontenot, 1979), with related death losses predicted at $50-150 million (Mayland and Sleper, 1993). The two most common forms of hypomagnesia are grass and winter tetany. Grass tetany occurs in ruminants grazing early spring grasses, while winter tetany occurs in ruminants consuming cereal forages such as wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), and rye (*Secale cereale* L.). Tetany can be the result of multiple factors, including low dietary Mg and Ca levels and high dietary K and N levels in forages (Robinson et al., 1989). The degree of risk for tetany prone forages is calculated using the tetany risk ratio [(%K * 255.74) ÷ ((%Ca * 499) + (%Mg * 822.64))], with 2.3 and greater indicating risk. Tetany is most prevalent in mature lactating cows, due to Mg and Ca losses in the milk and the cow's inability to mobilize adequate amounts of bone Mg (Storry and Rook, 1962).

The onset of tetany usually occurs 5 to 7 d after consumption of toxic forages, and death then follows within 2 to 24 h (Harris et al., 1985). Symptoms of tetany include a brownish discoloration of the light pigmented areas of the skin, staggering, increased pulse, strenuous breathing, diarrhea, frequent urination, and overall in-coordination (Harris et al., 1985). However, due to the limited amount of time from poisoning to death, the first sign of a tetany outbreak is typically an expired animal. Consequently, the majority of tetany research has concentrated on prevention of the disease, through Mg

supplementation. Although, other preventative methods include delaying turnout on tetany-prone pastures (pastures containing stressed immature plants), grazing less susceptible animals (steers, heifers, and dry cows) on tetany-prone pastures, and culling animals with previous instances of tetany (Kvasnicka and Krysl, 1992).

Ruminant animals do not have readily available Mg stores and rely on daily intakes of Mg to meet metabolic requirements, and prevent tetany (Ritter et al., 1984). The most common source of supplemental Mg is MgO. Magnesium oxide contains 56-60% Mg, and is the lowest priced form of supplemental Mg sold by the feed industry (Ammerman et al., 1972). Ammerman et al. (1972) examined the effects of feeding Mg deficient diets with different sources of supplemental Mg (MgO, $MgCO_3$, and $MgSO_4$) on feed intake by lambs. Both MgO and $MgCO_3$ were determined to be a good sources of Mg when feed intake response and balance were compared to the Mg deficient diet and to the $MgSO_4$ supplemented diet (Ammerman et al., 1972). Magnesium supplementation had an immediate and marked improvement in feed intake between the Mg deficient group and all supplemental Mg groups (Ammerman et al., 1972).

Free-choice mineral supplementation is the most widely used method of providing Mg and other minerals to grazing cattle, but this approach also allows for more individual mineral consumption variation when compared to other supplementation methods (Greene, 2000). Supplements should be formulated to supply minerals in adequate amounts and be provided in a palatable form to allow for adequate intakes (Greene, 2000). Additionally, little evidence has been presented to show that cattle will eat mineral supplements based on metabolic requirements (Coppock et al., 1972).

The objectives of this research were to determine how increasing the tetany risk ratio might influence: 1) DM and fiber digestion, 2) N, Mg, Ca, K and P balance and changes in blood serum Mg levels, and 3) to determine ruminant preference and feeding behavior for mineral supplements with or without added amounts of Mg when fed in a drylot or on pasture.

CHAPTER 2

LITERATURE REVIEW

The Role of Magnesium in Ruminant Physiology

Magnesium is an essential nutrient for ruminant animals. Magnesium is primarily found in the intracellular fluid after consumption. The majority of stored Mg is located in the bone (65-70%), soft tissues (15%), and muscle (15%), with only about 1% in the extracellular fluid (NRC, 1996). Mature lactating cows do not have the ability to mobilize large amounts of bone Mg reserves and suffer Mg and Ca losses in the milk, making them the more susceptible to tetany compared to younger animals (Storry and Rook, 1962). Ritter et al. (1984) examined the labile Mg reserves in cows supplemented with Mg prior to being turned out on tetany-prone pastures. Supplementing Mg prior to early spring turn out provided no long-term protection against tetany after cows were no longer offered supplemental Mg while being turned out on tetany-prone pastures (Ritter et al., 1984). Consequently, ruminants depend on daily intakes of Mg to meet metabolic requirements (Ritter et al., 1984).

Magnesium is a required component in every major metabolic pathway, where it primarily functions as a cofactor for enzymatic reactions. Magnesium is a relatively small divalent cation with a large charge, making it the metal ion least likely to be polarized but allowing Mg to be the best polarizer of other molecules (Fontenot et al., 1989). As a result, Mg mainly operates in the form ATP-Mg, but also functions in glycolysis, energy-dependent membrane transport, formation of cyclic-AMP,

transmission of genetic code, maintenance of electrical potentials across nerve and muscle membranes, and nerve impulse transmissions (NRC, 1996). Extracellular Mg is essential for normal nerve conduction, bone and mineral formation, and muscle contraction (NRC, 2005). Consequently, another indication of Mg deficiency is hyperexcitability caused by a reduction in nerve resting membrane potential (NRC, 2005).

Magnesium is primarily absorbed through active transport in the rumen (Tomas and Potter, 1976). Secretion of Mg into the small intestine surpasses Mg absorption, causing the animal to rely on the rumen as a primary site of Mg absorption (Cragle, 1973). Previous research has shown that high levels of K in the diet reduce Mg absorption through the rumen and increase fecal Mg excretions (Greene et al., 1983; Kunkel et al., 1953; Newton et al., 1972; Wylie et al., 1985). Magnesium does not have a specific set of regulating hormones, thus Ca homeostasis is strongly correlated with Mg metabolism and the prevalence of tetany.

The Role of Calcium on Magnesium Homeostasis and Tetany

Calcium is the most abundant mineral in the body. Calcium is a divalent cation that primarily functions as a structural element of bones and teeth, and as a result is the most copious mineral in the ruminant body (NRC, 1996). Calcium also plays a role in blood clotting, membrane permeability, muscle contraction, nerve impulse transmission, cardiac regulation, hormone secretion, and activation and stabilization of enzymes (NRC, 1996).

Calcium is primarily absorbed through both active transport and passive diffusion in the duodenum and jejunum (McDowell, 1992). Calcium homeostasis is strongly correlated to Mg metabolism. Calcium regulating hormones, such as parathyroid hormone (PTH), 1,25-dihydroxyvitamin D_3, and calcitonin (CT) also affect the renal threshold for Mg and control Mg bone resorption and release (Fontenot et al., 1989). Parathyroid hormone inhibits urinary Mg losses resulting in increased plasma Mg concentrations. Increases in PTH within the animal promotes bone mineral resorption and the release of bone Ca and Mg ions into the extracellular fluid (Fontenot et al., 1989). However, for every 1 Mg ion that is released 43 Ca ions are released. Thus trying to prevent tetany by increasing Mg concentrations through PTH stimulation will upset Ca homeostasis. Increasing concentrations of both 1,25-dihydroxyvitamin D_3 and calcitonin will cause a decrease in plasma Mg concentrations by promoting Mg excretion through urinary losses (Fontenot et al., 1989). Hypomagnesia effects the Ca regulating system by reducing the production of PTH and 1,25-dihydroxyvitamin D_3 receptors that require Mg as a coenzyme (Fontenot et al., 1989). This pathway is demonstrated in Figure 2.1.

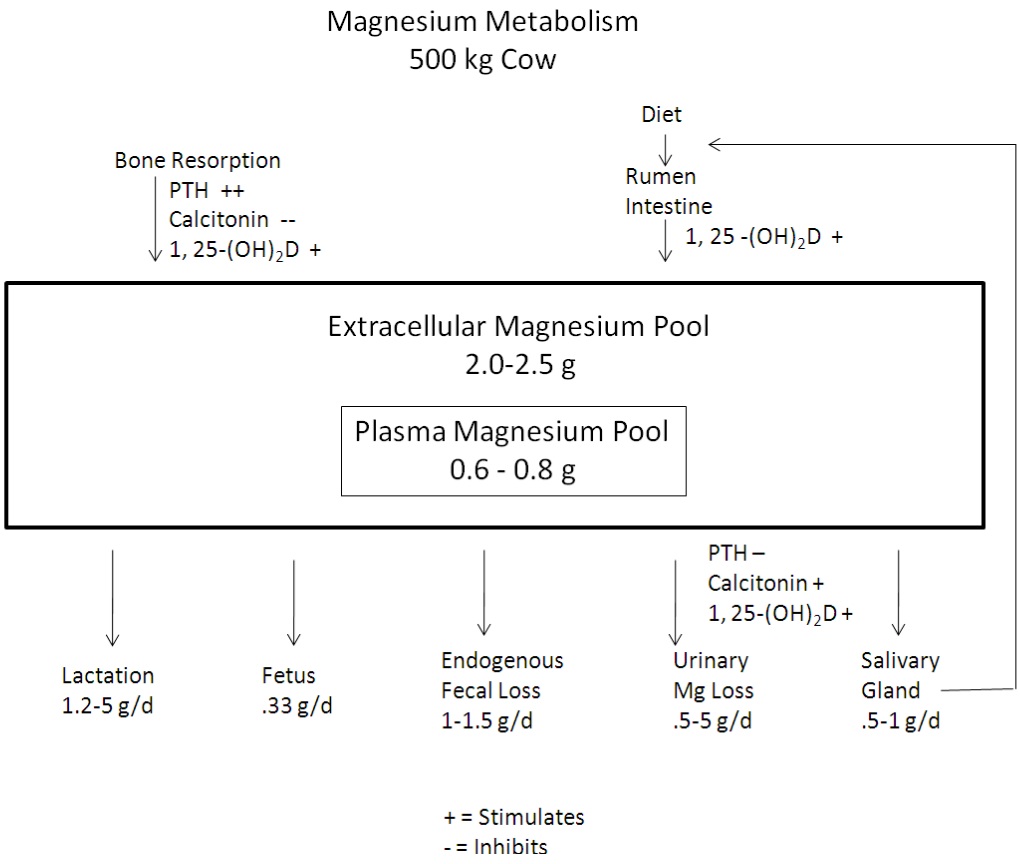

Figure 2.1. Factors influencing magnesium absorption and metabolism in ruminants (Fontenot et al.,1989).

Magnesium and Ca are the two most prevalent divalent cations in the intracellular fluid, and act as stabilizers of biological membranes (Fontenot et al., 1989). Balance of Mg and Ca in the cell is crucial in maintaining the control of membrane-associated metabolic and physiologic phenomena (Fontenot et al., 1989). Additionally, both Mg and Ca deficiency can result in tetany by ruminants. Calcium and Ca-regulating hormones play key roles in Mg metabolism, and are a necessary component in understanding the tetany risk ratio and the dietary cation anion balance (DCAB) ratio.

The Effect of Potassium on Magnesium Absorption and Tetany

Potassium is a major cation in intracellular fluid and the third most abundant mineral in the body (NRC, 1996). Potassium is predominately located in the intracellular fluid, with 98% of K found within the cells of the body (McDowell, 1992). Potassium is crucial in acid-base regulation, maintaining osmotic pressure, nerve impulse transmission, muscle contraction, and water balance (NRC, 1996).

Potassium is primarily absorbed in the rumen and omasum, with additional absorption occurring in the upper portion of the small intestine (McDowell, 2003). The majority of K absorption is a result of salivary excretions (McDowell, 1992). Potassium has been shown to have inhibitory effects on Mg absorption and metabolism (Kunkel et al., 1953; Newton et al., 1972; Greene et al., 1983; Wylie et al., 1985).

Understanding Tetany and Mg, Ca, and K Interactions

Hypomagnesia can be the result of reduced Mg intake, reduced Mg availability, reduced labile skeletal Mg, and (or) increased urinary Mg excretions (Ritter et al., 1984). However, Mg homeostasis is dependent on Ca regulating hormones, and Mg absorption can be altered by increased levels of K.

Ritter et al. (1984) examined the labile Mg reserves in 30 pregnant beef cows supplemented with Mg prior to being placed on tetany-prone pastures. Treatments included a tall fescue hay with free choice Mg-deficient salt mineral supplement, 6.4 kg of corn silage supplemented with 114g MgO/d, and tall fescue hay with free choice salt mineral mix containing 40% MgO. Cows were fed the treatment diets for 45 d prior to

being placed on tetany-prone pastures where no additional Mg supplements were provided. Serum Mg levels in all three treatment groups decreased below normal levels (2.0 mg/dL) after 15 d on the pasture, and continued to decrease over the final 30 d on the pasture. A total of 8 of the 30 cows were treated for tetany related symptoms over the progression of the experiment. It was concluded that supplementing Mg prior to early spring turn out provided little long-term protection against tetany in cows grazing spring, tetany-prone pastures with no additional Mg supplementation. Consequently, ruminants depend on daily intakes of Mg to meet metabolic requirements and aide in prevention of tetany (Ritter et al., 1984).

Ammerman et al. (1972) examined the effects of feeding Mg deficient diets with different sources of supplemental Mg (MgO, $MgCO_3$, and $MgSO_4$) on feed intake by lambs. Both MgO and $MgCO_3$ were determined to be good sources of Mg when feed intake response and balance were compared to the Mg deficient diet and to the $MgSO_4$ supplement diet. Magnesium supplementation had an immediate and marked improvement in feed intake between the Mg deficient group and all supplemental Mg groups. Lambs fed the Mg deficient diet averaged 300 g of DM intake/d over 6 d, while the supplemented MgO group had an average intake of 600 g of DM intake/d and the $MgCO_3$ averaged intakes of 700 g of DM intake/d (Ammerman et al., 1972).

Chester-Jones et al., (1989) compared the effects of feeding increasing levels of MgO (0.2, 0.6, 1.2, and 2.4%) to sheep on nutrient digestion, metabolism of Mg, Ca, P, Na, and K, blood and tissue mineral concentrations, and hematological and histological tissue changes. Results showed that increasing levels of MgO caused a linear decrease in

apparent DM, CP, and ADF digestibilities. Increasing levels of MgO decreased P absorption and retention linearly and fecal P excretion increased linearly. Serum Ca concentrations were also decreased linearly with the addition of increased Mg to the diet for the first 30 d, but Ca concentrations remained in the normal range for the 0.2, 0.6, and 1.2% MgO treatments throughout the experiment. Serum Ca levels fell below the normal levels with the 2.4% MgO treatment after d-10 and remained lower the following 40 d of the experiment. Consequently, supplementing ruminants with excess Mg in the diet will resulted in depressed nutrient utilization and macro-mineral absorption and retention. This experiment agrees with the NRC (1996) recommendation that feeding Mg at a concentration of 0.5% of the daily intake or below will have no adverse affects on nutrient utilization or macro-mineral absorption and retention.

Potassium has been shown to have inhibitory effects on Mg absorption and metabolism (Kunkel et al., 1953; Newton et al., 1972; Greene et al., 1983; Wylie et al., 1985). Kunkel et al. (1953) examined the effects of feeding two dietary levels of potassium bicarbonate (0.0, and 5.0%) and the relationship of low water and salt (NaCl) supply with high K intakes in producing tetany. The addition of K bicarbonate to the diet decreased DM intake and serum Mg levels across all potassium treatments (low water, low salt). However, no clinical signs of tetany were observed with any dietary treatment.

Other investigators reported similar results when comparing two dietary K levels (0.6 and 4.9 %) on Mg metabolism in wethers dosed with two levels of intravenous Mg (0.0, and 0.2 mg Newton et al., 1972). Apparent Mg absorption was depressed in wethers fed the high K diet, receiving no Mg dose when compared to the low K diet and the high

Mg dose. The high K and Mg dosed wethers had lower Mg turnover rates indicating that high K levels interfered with Mg absorption in ruminants (Newton et al., 1972). Similarly, Greene et al. (1983) examined the effects of three dietary K levels (0.6, 2.4, and 4.8%) fed to steers with abomasal and ileal cannulaes on Mg absorption. Magnesium absorption decreased linearly with increasing levels of dietary K. Additionally, the primary site of Mg absorption occurred in the rumen. The high K diet (4.8%) caused a 39% decrease in ruminal Mg absorption, and decreased total serum Mg levels. Potassium was primarily absorbed in the small intestine at low levels of K intake, but absorption occurred in the rumen when high levels of K were fed. Results indicated that increasing levels of dietary K decreased apparent Mg absorption and retention in steers.

Wylie et al. (1985) conducted two metabolism trials with sheep equipped with ruminal catheters, and abomasal and ileal cannulaes to measure the effects of K infusion into the digestion tract on absorption and flow of minerals. Potassium bicarbonate treatments were infused into the abomasum or illeal cannulaes at a rate of 12.0 and 33.6 g/d. Results showed that ruminal infusion of K depressed ruminal Mg absorption and total tract Mg absorption by 43% (Wylie et al., 1985). Potassium infusion into the rumen also decreased Ca flow from the preintestinal region, suggesting that the role K plays in grass tetany is through the depression of both Mg and Ca absorption. Therefore, K plays a role in grass tetany by reducing Mg absorption through the rumen wall.

Interactions between the DCAB ratio and Tetany

The dietary cation-anion balance (DCAB) calculates the balance of the number of negatively charged and positively charged ions in the diet (Tucker et al., 1988), and indicates the acid :base status of the animal. A negative DCAB ratio for prepartum dairy cows has been shown to prevent milk fever through reducing the decline in blood serum Ca levels before the initiation of lactation (Block, 1994). Several mechanisms have been accredited for increasing blood Ca levels, including increasing Ca bone mobilization both directly and indirectly. Indirect methods would be for reduced Ca retention through urinary excretion which will indirectly increase intestinal absorption of Ca (Block, 1994). The DCAB ratio has not been well studied in beef cattle, but the literature suggests keeping the ratio below 150 meq/kg may prevent milk fever in beef cattle (Agriculture, 1999).

Takagi and Block, (1991) studied the effects of feeding two levels of Ca (0.48% and 0.82%) with three different DCAB ratios (-27, 61, 284 meq/kg) on Ca, P, and Mg metabolism by wethers. Phosphorus absorption was greater in all of the high Ca diets when compared to the low Ca diets, but no differences in P absorption were recognized across DCAB ratio treatments. There were no differences in Ca absorption between the three DCAB ratio treatments. Feeding normal to high levels of Ca increased Ca excretions in the urine in the low DCAB ratio groups which decreased Ca retention. There were no differences in Mg apparent digestibility, absorption, or retention across all treatments. Results suggest that feeding wethers NRC acceptable levels of Ca in the diet will have no effect on Ca, P, or Mg digestibility in wethers at any DCAB ratio level in the

diet. Additionally, without the added stress of lactation there was no need for excess Ca in the diet and therefore no need for the animal to increase resorption.

Goff et al. (1991) researched the effects of feeding low and high DCAB ratio diets (-228 meq/kg or 978 meq/kg) on the incidence and prevention of milk fever. Forty-seven Jersey cows in their third trimester of gestation were fed either a high or low DCAB ratio diet for six wks prior to parturition. Five more cows developed milk fever in the high DCAB ratio group than the low DCAB ratio group. Plasma Ca concentrations were significantly higher in the low DCAB ratio group at parturition compared to the high DCAB ratio group, but there were no differences in plasma PTH or 1,25-dihydroxyvitamin D_3 between both groups at parturition. Plasma Mg concentrations increased in both groups two d after calving, suggesting that lowering the DCAB ratio allowed the animal to increase production of 1,25-dihydroxyvitamin D_3 and increase bone Ca resorption. Additionally, Fontenot et al. (1989) described the relationship between Ca regulating hormones and subsequent interactions with Mg. Increases in PTH and 1,25-dihydroxyvitamin D_3 within the animal promotes bone mineral resorption and the release of bone Ca and Mg ions into the extracellular fluid (Fontenot et al., 1989). This explains the increase in plasma Mg concentrations in the previous study. For every one Mg ion that is released, forty three Ca ions are released. Trying to prevent tetany by increasing Mg concentrations through PTH stimulation will potentially upset Ca homeostasis.

Magnesium Supplementation and Behavior for Grazing Ruminants

Ruminants rely on daily intakes of Mg to meet metabolic requirements and aide in the prevention of tetany (Ritter et al., 1984). Free-choice mineral supplementation is the most widely used method of providing Mg and other minerals to grazing cattle, but this approach also allows for more individual mineral consumption variation when compared to other supplementation methods (Greene, 2000). Forms of free choice mineral supplementation methods include liquid supplements, mineral blocks, and loose minerals. However, block supplementation has been shown to decrease mineral consumption by as much as 10% when compared to loose mineral supplementation (McDowell, 1996). Other mineral supplementation strategies include direct and indirect methods of providing mineral. Direct mineral supplementation methods include the addition of minerals to water, mineral licks, mixtures, drenches, rumen preperations and injections. Indirect methods include the use of fertilizers containing minerals, altering soil pH, and altering the plant species in the pasture.

Supplements must be formulated to supply minerals in adequate amounts and be provided in a palatable form to allow for adequate intakes (Greene, 2000). The most common source of Mg in mineral supplements is MgO. Magnesium oxide contains 56-60% Mg, and is the cheapest source of supplemental Mg sold by the feed industry (Ammerman et al., 1972). Magnesium, P, and other inorganic mineral salts tend to reduce free-choice mineral consumption due to decreased palatability (Greene, 2000). As a result, commercially available mineral supplements containing Mg often have

inadequate amounts of Mg to protect against tetany due to decreased palatability (McDowell, 1996).

Frye et al. (1977) researched the effects of MgO combined with different mineral carriers (1:1 ratio of MgO and trace mineralized salt, 1:1:1 ratio of MgO, trace mineralized salt, and cotton seed meal, 1:1:1 ratio of MgO, trace mineralized salt, and dry sugarcane molasses, and 1:1:1 ratio of MgO, trace mineralized salt, and steamed bone meal) on relative acceptability and palatability by mature lactating beef cows. Eighteen lactating cows were allotted to three 2.9- ha plots in six groups of three animals each. Each group was offered the mineral mixes in thirteen consecutive 10 d periods as a cafeteria style, allowing for 1 kg of each of the 4 mineral mixes in a feeder daily. In each of the thirteen periods cows consumed more of the dry molasses mixture than any of the other three mixtures. Cows consumed an average of 46.3 g/d of the dry molasses mixture, 13.3 g/d of the cottonseed meal mixture, 12.6 g/d of the bonemeal mixture, and 2.4 g/d of the trace mineralized salt mixture. In experiment 2, mineral preference was removed by only allowing the cows access to only one of the four mineral mixtures for three successive 15 d periods. Cows consumed higher levels of the cottonseed meal and dry molasses mineral mixtures (170.9 and 103.6 g·hd·d-1, respectively) than the control or steamed bonemeal mineral mixtures (94.0 and 91.8 g·hd·d-1, respectively). Results indicated that when minerals were offered separately mineral intakes increased in all four mineral mixtures, and preference for the cottonseed meal mixture increased.

Coppock et al. (1972) evaluated the relationship of ration on free choice consumption of calcium-phosphorus supplements relative to calcium-phosphorus

requirements in dairy cattle. In experiment 1, the four diets fed were hay supplemented with corn silage, corn and alfalfa silage, corn silage, and grass hay supplemented with high moisture corn. Daily individual mineral consumption was highly variable between animals and ranged from 0 to 1000 g/hd across all diets. Diet had no effect on the amount of supplement consumed, and there was no relationship between mineral consumption and the animals metabolic requirements for the minerals (Coppock et al., 1972). In experiment two, the 3 diets fed were alfalfa hay, alfalfa hay plus a 16% crude protein supplement, and corn silage plus 0.45 kg of supplemental soybean meal per heifer per day. Each group was offered two free-choice mineral supplements (dicalcium phosphate or defluorinated phosphate) daily. Type of ration had no effect on the amount of total supplement consumed. However, 82.4% of the total mineral consumed was the dicalcium phosphate-based supplement indicating that heifers preferred dicalcium phosphate to defluorinated phosphate. The results further suggest that when the diet provides adequate amounts Ca and P, cattle do not have nutritional wisdom and will consume free-choice supplements in excess of requirements.

A follow up study conducted by Coppock et al. (1976) examined the effects of free-choice mineral consumption by dairy cows fed Ca and P deficient diets. Cows were fed Ca and P in excess for 8 wks prior to the initiation of the study in an effort to decrease individual mineral variation between cows. Results showed that feeding low Ca and P diets did not increase the free-choice intakes of Ca and P supplements. In fact, free choice mineral consumption was higher during the initial 8 wk period where cows were fed excess Ca and P in the diet than during the Ca and P deprivation period.

CHAPTER 3

MATERIALS AND METHODS

Experiment 1

Objectives

The objectives of experiment 1 were to determine the effects of increasing the tetany risk ratio on DM and fiber digestion; N, Mg, Ca, K and P balance; and changes in blood serum Mg levels.

Animals

All research procedures were approved by the Montana State University Institutional Animal Care and Use Committee (Permit # 2009-AA07). Twenty four Targhee crossbred wether lambs were transported from the Fort Ellis Experiment Station in Bozeman, Montana to the O. O. Thomas Nutrition Center at the Bozeman Agricultural Research and Teaching Farm, Montana State University, Bozeman, MT. Wethers (avg. wt. 40 kg) were individually housed and maintained in stainless steel metabolism crates (141 x 62.5 cm) with a light:dark cycle of 10:14 h and allowed ad libitum access to water.

Design and Treatments

The experimental design utilized was a randomized complete block where wethers were blocked by initial body weight and initial serum Mg levels. Wethers were randomly assigned to one of four treatments within blocks (6 wethers/treatment). The tetany risk ratio (TRR) was calculated using the equation, TRR = [(%K * 255.74) ÷

((%Ca * 499) + (%Mg * 822.64))]. The tetany risk ratio dietary treatments were increased using increasing levels of K (KCO_3) to allow for a tetany risk ratio of 1.6 (TRR 1.6), 2.3 (TRR 2.3), 2.9 (TRR 2.9), and 3.5 (TRR 3.5). All diets contained chopped (10cm) barley hay and supplement and the diet was fed at a target rate of 3.0% of BW once daily at 0800 h (Table 3.1). The treatments were formulated to meet or exceed NRC energy and CP maintenance requirements for growing wethers (NRC, 1985). Wethers were adapted to the dietary treatments for a 10-d period followed by 5-d collection of urine and feces. Daily orts were removed, weighed and recorded before the next days ration was offered.

Table 3.1. Composition and analysis of treatment diets (DM basis) formulated to provide tetany risk ratios (TRR) of 1.6, 2.3, 2.9, and 3.5[1] in experiment 1.

Item	TRR 1.6	TRR 2.3	TRR 2.9	TRR 3.5
Ingredients		% DM		
Barley hay	77.0	75.1	73.7	72.4
Soy bean meal	13.9	13.9	13.9	13.9
Cracked corn	7.60	7.57	7.55	7.54
Potassium carbonate		1.94	3.35	4.65
NaCl	1.52	1.51	1.51	1.51
Nutrients				
CP	18.7	17.8	17.7	17.8
TDN	65.9	66.4	67.1	67.2
K	2.21	3.22	3.86	4.36
Mg	0.21	0.19	0.19	0.19
Ca	0.41	0.42	0.39	0.39
P	0.45	0.37	0.42	0.42
Cl	0.98	0.98	0.98	0.98
DCAB ratio, meq[2]	44	73	94	113

[1] Tetany risk ratio calculated using the equation, ((%K * 255.74) ÷ ((%Ca * 499) + (%Mg * 822.64))).
[2] DCAB ratio: Dietary Cation Anion Balance calculated using the equation, [(Na + K) - Cl]/l00 g diet DM.

Measurements and Collections

Orts, water disappearance, and total fecal and urinary excretions from each wether were collected daily during the 5-d collection period. Water disappearance was measured using graduated marks on the watering pan in each individual crate at 0800, 1200, and

0500 h to calculate average daily water consumption. Wethers were fitted with fecal collection bags on d-9 before the initiation of the 5-d total fecal collection. Fecal collection bags were emptied once daily at 0800 h. Total fecal output was weighed and mixed after the 5-d collection and a 200 g subsample was taken and dried in a 60˚ oven for 72 h for subsequent analysis. Total daily urine output was collected through a funnel into a vessel containing 30 mL of HCl to prevent N volatilization. Urine output was measured daily, and a 10% subsample was collected and combined for a total 5 d urine composition and frozen for later analysis. Blood samples were collected via jugular venipuncture on d-0, 5, 10, and 15. Samples were placed in the centrifuge 20 min post bleeding and spun for 15 min at 2000 rpm. Serum was decanted off into serum tubes and analyzed for Mg concentrations using a QuantiChrom™ Magnesium Assay Kit (DIMG-250).

Forage, fecal, and urine samples were analyzed at the O.O. Thomas Nutrition Center Bozeman, MT for CP (% N x6.25; Truspec-CN LECO Corporation, ST. Joseph, MI 49085), NDF (Ankon Tech Corp, Fairport, NY) using methods by Van Soest et al. (1991), and DM digestibility.

Feed samples were sent to Midwest Laboratories in Omaha, NE and analyzed for CP, DM, Mg, Ca, K, and P concentrations. Blood, fecal, and urine samples were analyzed at the Bozeman Fish Technology Center Bozeman, MT by use of the Inductively Coupled Plasma Mass Spectrometer (ICP-MS) using methods described by Anderson et al. (2010) to determine Mg, Ca, K, and P concentrations.

Statistical Analysis

Each wether was considered as an experimental unit. Dry matter, N, and NDF digestibilities, N retention, Mg, Ca, K, P, and Na retention were analyzed by treatment with ANOVA using the PROC MIXED model of SAS (SAS Inc. Cary, NC). Treatment was fit as fixed effects with DM, N, and NDF digestibilities, and N, Mg, Ca, K, P, and Na retentions considered random effects. Least square means were separated using LSD procedures when $P < 0.05$.

Experiment 2

Objectives

The objectives of experiment two were to determine the effects of adding supplemental Mg to diets with a high tetany risk ratio on DM N, and NDF digestibilities, N, Mg, Ca, K and P balance, and changes in blood serum Mg levels. A secondary objective was to determine the effects of maintaining a constant dietary cation anion balance (DCAB) on mineral balance.

Animals

All research and procedures were approved by the Montana State University Institutional Animal Care and Use Committee (Permit # 2009-AA07). Twenty four Targhee cross wether lambs were transported from the Fort Ellis Experiment Station in Bozeman, Montana to the O. O. Thomas Nutrition Center at the Bozeman Agricultural Research and Teaching Farm, Montana State University, Bozeman, MT. Wethers (avg.

wt. 48 kg) were individually housed and maintained in metabolism crates (141 x 62.5) with a light:dark cycle of 10:14 h and allowed ad libitum access to water.

Design and Treatments

The experiment was a randomized complete block design where wethers were blocked by initial body weight and initial serum Mg level. Wethers were randomly assigned to one of four treatments within blocks (6 wethers/treatment). The tetany risk ratio treatments were tetany risk ratio of 1.5 (TRR 1.5), tetany risk ratio of 2.6 (TRR 2.6), tetany risk ratio of 1.5 plus MgO (TRR 1.5 + MgO), and tetany risk ratio of 1.5 plus MgCl (TRR 1.5 + MgCl). The tetany risk ratio of 2.6 was achieved by the addition of potassium carbonate to the diets. The two Mg supplemented treatments were originally formulated at a tetany risk ratio of 2.6, and the ratio was brought down to 1.5 with Mg supplementation. The DCAB ratio was maintained at 37 and 38 meq by the addition of Ammonium chloride to the TRR 1.5, TRR 2.6, and TRR 1.5 + MgO treatments and by the addition of MgCl to the TRR + MgCl treatment. All diets were formulated at to contain chopped barley hay (10cm) and supplement to be fed at 3.0% of BW once daily at 0800 h (Table 3.2). The diets were formulated to meet or exceed energy and CP maintenance requirements as described by the NRC guidelines for growing wethers (NRC, 1985). Wethers were adapted to the treatments for a 10-d period followed by a 5-d collection period. Excess feed was removed, weighed and recorded before the next days feed was offered.

Table 3.2. Composition and analysis[1] of experiment 2 diets (DM basis) formulated to provide tetany risk ratios (TRR) of 1.5, 2.6, 1.5 with MgO supplementation, and 1.5 with MgCl supplementation.

Item	TRR 1.5	TRR 2.6	TRR 1.5 + MgO	TRR 1.5 + MgCl
Ingredients			% DM	
Barley hay	76.8	72.8	72.3	71.6
Soy bean meal	14.8	14.0	13.9	13.8
Cracked corn	5.91	5.60	5.56	5.51
Ammonium chloride	0.30	2.41	2.39	0.83
Potassium carbonate		3.08	3.06	3.03
Magnesium oxide			0.56	
Magnesium chloride				3.03
Vegetable oil	0.74	0.70	0.83	0.83
NaCl	1.48	1.40	1.39	1.38
Nutrients				
CP	19.3	21.1	21.8	19.0
TDN	69.8	67.7	66.7	67.4
K	2.22	3.79	4.20	4.40
Mg	0.25	0.24	0.69	0.78
Ca	0.43	0.40	0.42	0.44
P	0.36	0.35	0.33	0.35
Cl	0.79	2.65	2.64	2.62
DCAB ratio, meq	38	37	37	37

[1] Tetany risk ratio calculated using the equation, ((%K * 255.74) ÷ ((%Ca * 499) + (%Mg * 822.64))).
[2] DCAB ratio: Dietary Cation Anion Balance calculated using the equation, [(Na + K) - Cl]/l00 g diet DM.

Measurements and Collections

Body weights were determined on d 0 and d 15. Orts, water disappearance, and total fecal and urinary excretions from each wether were collected daily during the 5-d collection period. Water disappearance was measured as described in experiment 1. Wethers were fitted with fecal collection bags on d-9 before the 5-d total fecal collection. Fecal collection bags were emptied once daily at 0800 h. Total fecal output was weighed and mixed after the 5-d collection and a 200 g subsample was taken and dried for later analysis. Total daily urine output was collected through a funnel into a vessel containing 30 mL of HCl to prevent N volatilization. Urine weights were measured daily, and a 10% subsample was collected and frozen for later analysis. Blood samples were collected via jugular venipuncture on d-0, 5, 10, 15, and 20. Samples were placed in the

centrifuge 20 min post bleeding and spun for 15 min at 2000 rpm. Serum was decanted off into serum tubes and analyzed for Mg concentrations using a QuantiChrom™ Magnesium Assay Kit (DIMG-250).

Forage, fecal, and urine samples were analyzed at the O.O. Thomas Nutrition Center Bozeman, MT for CP (% N x6.25; Truspec-CN LECO Corporation, ST. Joseph, MI 49085), NDF (Ankon Tech Corp, Fairport, NY) using methods by (Van Soest et al., 1991), and DM digestibility.

Feed samples were sent to Midwest Laboratories in Omaha, NE and analyzed for CP, DM, Mg, Ca, K, and P concentrations. Fecal and urine samples were digested and analyzed at the Bozeman Fish Technology Center, Bozeman, MT on the Inductively Coupled Plasma Mass Spectrometer (ICP-MS) using methods described by Anderson et al. (2000) to determine Mg, Ca, K, P, and Na retention.

Statistical Analysis

Each wether was considered the experimental unit. Dry matter, N, NDF digestibilities, N, Mg, Ca, K, P, and Na retention were analyzed by ANOVA using the PROC MIXED model of SAS (SAS Inc. Cary, NC). Treatment was fit as fixed effects with DM, N, and NDF digestibilities, and N, Mg, Ca, K, P, and Na retention's considered random effects. Least square means were separated using LSD procedures when $P < 0.05$.

Experiment 3

Objectives

The objective of experiment 3 was to examine the effects of feeding two levels of supplemental Mg (0.0 and 10.0%) on feed intake and mineral consumption between two locations (drylot and pasture) by third trimester beef heifers.

Animals

All research and procedures were approved by the Montana State University Institutional Animal Care and Use Committee (Permit # 2009-AA07). Twenty three Angus cross heifers were maintained at the Bozeman Agricultural Research and Teaching Farm, Montana State University, Bozeman, MT.

Design and Treatments

In December 2010, twenty-three primiparious heifers were weighed (513 kg BW) and individually identified using electric identification tag (Alflex, HD) placed in the middle two thirds of the left ear to measure individual intakes with the use of GrowSafe® Feed Intake Feeders (GrowSafe Systems Ltd., Airdrie, Alberta, Canada). Heifers were randomly assigned to one of two locations (11 heifers in the drylot, and 12 heifers on the pasture) to measure individual loose mineral consumption (g/d), feeder attendance (trips/d), and feeding duration (s/d). Groups were rotated between locations after 15 d for 30 d of measurements. The drylot measured 22.5 x 11.0 m and contained 6 GrowSafe feeders, and two automatic waters located 10 m from the feeders. Heifers were fed barley hay (15.0% CP, 56.6% TDN, 0.39% Ca, 0.21% Mg, and 1.27% K) at a rate of

15.4 kg DM·hd·d^{-1} in the drylot. Barley hay was chopped to a length of 10 cm through a hammer mill, and fed twice daily at 0800 and 1500 using a Roto-Mix TMR Mixer/Feeder (Dodge City, KS). Heifers were allowed ad libitum access to hay, supplements, and water.

The pasture measured 3.0 ha and contained two GrowSafe feeders, and one automatic water located 30 m from the feeder. The pasture composition was primarily a mixture of timothy grass (*Phleum pretense),* orchard grass (*Dactylis glomerata* L.), smooth brome grass (*Bromus inermis* L.), red clover (*Trifolium pratase* L.), and weeds. Forage availability was predicted at 2930 kg/ha at the initiation of the study. However, the pasture was covered with snow for the entire study, so heifers were fed chopped barley hay (15.0% CP, 56.6% TDN, 0.39% Ca, 0.21% Mg, and 1.27% K) at a rate of 20.5 kg DM·hd·d-1. All GrowSafe feeders were covered by an open sided barn to prevent scale disturbances from wind or precipitation.

Supplements containing 0.0% or 10.0% Mg (Table 3.3) were provided in two separate GrowSafe feeders at each location. Supplements were rotated between feeders every 5 d to reduce the effect of feeder and supplement location. Supplement availability was observed daily, and additional supplement was added if needed. Due to high supplement intakes on the first two days, 50% salt was added to both mineral mixtures at the beginning of d-3 and for the remainder of the experiment to reduce supplement intakes. Hay intake was measured in the drylot with four GrowSafe feeders.

Table 3.3. Composition mineral supplements containing 0.0% or 10.0% Mg for the first 2 days and the for the remaining 27 days.

	Day 0 – Day 2		Day 3 – Day 30	
Item	0.0% Mg	10.0% Mg	0.0% Mg	10.0% Mg
Ca	12.0	12.0	8.3	8.3
P	6.0	6.0	4.1	4.1
Mg		10.0		6.9
NaCl			50.0	50.0

Measurements and Collections

Individual DM hay and preference for supplement (g/d), feeder attendance (trips/d), and feeding duration (s/d) were recorded daily using the GrowSafe® system. Body weight measures were taken on d 0, d 15, and d 30.

Statistical Analysis

Each heifer was considered as an experimental unit, with individual mineral intakes and feeding behavior measured. Mineral consumption preference, feeder attendance, and feeding duration were analyzed by location, period, and location x period interaction with ANOVA using the PROC MIXED model of SAS (SAS Inc. Cary, NC). Location and period were fit as fixed effects with mineral consumption, feeder attendance, and feeding duration considered as random effects. Least square means were separated using LSD procedures when $P < 0.05$.

CHAPTER 4

RESULTS AND DISCUSSION

Experiment 1

Increasing the tetany risk ratio from 1.6 to 2.9 had no effect ($P = 0.27$) on DM, NDF, or N digestibilities (Table 4.1) but N retention decreased ($P < 0.05$) as the tetany risk ratio increased. The negative N retention for the TRR 2.3 treatment was due primarily to increased urinary N (Figure 4.1). Urinary Mg concentrations decreased ($P < 0.05$) as the tetany risk ratio increased due to increased K intakes (Table 4.2). Fecal Mg and K concentrations ($P < 0.10$) tended to be higher for the TRR 2.3 treatment when compared to all other treatments. Fisher et al. (1994) observed linear increases in the concentrations of N, Mg, and K in the feces as K levels increased (1.6, 3.1, and 4.6% of the diet) in the diet. Likewise, Newton et al. (1972) reported increases in fecal Mg with the addition of K to the diet. While Greene et al. (1983) found that a high K diet (4.8%) caused a 39% decrease in ruminal Mg absorption, and increased the amount of fecal K and Mg.

There were no differences in Mg, Ca, K, or P balance due to treatment ($P = 0.25$; Table 4.2). Increasing the tetany risk ratio through the addition of K to the diet did not affect Mg balance. However, increasing the levels of K in the diet did show a numerical but not statistical decrease in urinary Mg and an increase in urinary K. Similar decreases in urinary Mg and increases in urinary K excretion were reported with increases of K to the diet in previous studies (Fisher et al., 1994; Jittakhot et al., 2004). Fisher et al. (1994)

reported increased water intake and urine output with increasing levels of K in the diet, which decreased the concentration and total excretion of Mg and increased the excretion of K in the urine with the addition of higher levels of K (Fisher et al., 1994). Jittakhot et al. (2004) fed increasing levels of Mg to dry cows and found that as Mg concentration increased in the diet, Mg absorption decreased through increased Mg excretions. Similar to the present study Jittakhot et al. (2004) fed Mg above NRC requirements, which may have caused the increase in Mg excretion. However, when feeding a high and low concentration of Mg (1.9 and 4.3 g/kg DM) and three levels of K (19, 28, and 37 g/kg DM) to lactating dairy cows no differences were recorded in urinary Mg excretion , Mg balance, or plasma Mg concentrations with the addition of K to the ration (Holtenius et al., 2008).

Table 4.1. One way ANOVA for DM, N, and NDF digestibilities on treatment diets with a tetany risk ratio (TRR) of 1.6, 2.3, 2.9, and 3.5.

Item	TRR[1]	Intake, g/d	Digestibility, %	Balance, g/d	Balance % Intake
DM	1.6	1152.5	68.5		
	2.3	1161.3	69.6		
	2.9	1163.1	69.2		
	3.5	1112.9	68.5		
	SE	56.0	1.1		
N	1.6	40.3	44.3	13.1[a]	32.5[a]
	2.3	37.7	38.6	-0.63[b]	-0.81[b]
	2.9	37.2	38.7	4.09[ab]	11.0[ab]
	3.5	36.7	43.2	5.58[ab]	15.2[ab]
	SE	1.5	2.5	0.03	0.03
NDF	1.6	636.0	64.3		
	2.3	632.3	66.0		
	2.9	634.0	65.2		
	3.5	638.2	65.6		
	SE	23.7	1.0		

[1] TRR – Tetany risk ratio calculated using the equation, [(%K * 255.74) ÷ ((%Ca * 499) + (%Mg * 822.64))].

[a, b] Within a column, means that do not have a common superscript differ, $P < 0.05$.

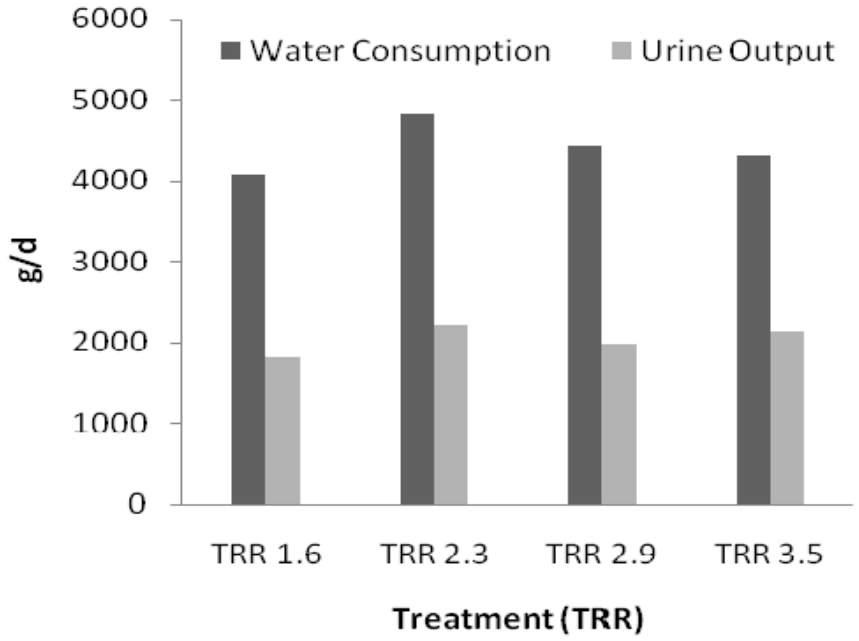

Figure 4.1. Comparison of average water intake and urine output by wethers fed a TRR of 1.6, 2.3, 2.9, or 3.5.

Table 4.2. One way ANOVA for average balance data of Mg, Ca, K, and P on treatment diets consisting of a tetany risk ratio (TRR) of 1.6, 2.3, 2.9, and 3.5.

			Excretion		
Element	TRR[1]	Intake, g/d	Fecal, g/d	Urinary, g/d	Balance, g/d
Mg	1.6	2.42	2.47	1.87[a]	-1.92
	2.3	2.21	2.93	1.53[ab]	-2.26
	2.9	2.21	2.56	0.99[bc]	-1.34
	3.5	2.20	2.69	0.72c	-1.21
	SE	0.09	0.37	0.16	0.40
Ca	1.6	4.73	3.87	0.07	0.79
	2.3	4.88	4.20	0.07	0.61
	2.9	4.54	3.82	0.06	0.66
	3.5	4.52	3.70	0.04	0.78
	SE	0.18	0.55	0.01	0.51
K	1.6	25.47[a]	1.95	40.22	-16.69
	2.3	37.39[b]	3.22	50.94	-16.77
	2.9	44.89[c]	2.69	74.38	-32.18
	3.5	50.48[c]	2.40	70.02	-21.94
	SE	1.52	0.39	15.71	15.73
P	1.6	5.19[a]	4.97	0.04	0.18
	2.3	4.30[b]	5.50	0.03	-1.24
	2.9	4.88[ab]	4.76	0.13	-0.01
	3.5	4.81[ab]	4.49	0.30	0.02
	SE	0.20	0.68	0.12	0.63

[1] TRR – Tetany risk ratio calculated by the equation, [(%K * 255.74) ÷ ((%Ca * 499) + (%Mg * 822.64))].

[a, b, c] Within a column and mineral, means that do not have a common superscript differ, $P < 0.05$.

Serum Mg levels decreased in all four treatments after 5 d and increased after 10 d (Figure 4.2). The data suggests that the wethers began mobilizing Mg from the bone after 5 d. Serum Mg levels decreased ($P < 0.05$; Figure 4.3) from the TRR 1.6 to TRR 2.3 treatments on d -15, but was not different in the remaining two treatments. Other investigators (Fisher et al., 1994; Kunkel et al., 1953; Newton et al., 1972; Suttle and Field, 1967, 1969) have reported decreases in serum Mg levels with the addition of K to the diet within the first 15 d, but show no further decreases in serum Mg levels beyond 15 d. Blood serum Mg was numerically lower in the TRR 2.3 treatment when compared to

all other treatments on d-5, d-10, and d-15 (Table 4.3). This is contradicting to Ritter et al. (1984), who reported that supplementing Mg prior to exposure of tetany prone forages provided little long-term protection against tetany in lactating cows with no additional Mg supplementation. Ruminants depend on daily intakes of Mg to meet metabolic requirements and to aid in the prevention of tetany (Ritter et al., 1984). In the present study wethers fed the two highest tetany risk ratio treatments (2.9 and 3.5) had higher blood serum Mg levels than the TRR 2.3 treatment. The reported increases in serum Mg levels in the highest two tetany risk ratio treatments may be due the stage of growth in the wethers, and their ability to mobilize bone Mg. Ritter et al. (1984) used mature lactating cows which are highly susceptible to tetany because of their inability to mobilize large amounts of bone Mg and due to Mg and Ca losses in the milk. In this study, young growing wethers were used which would be less susceptible to tetany because of their ability to mobilize bone Mg and may explain the increases in the blood serum Mg with the two highest tetany risk ratio treatments (Kvasnicka and Krysl., 1992).

Table 4.3. Changes in blood serum Mg (mg/dL)[2] on treatment diets consisting of a tetany risk ratio[1] (TRR) of 1.6, 2.3, 2.9, and 3.5.

Item	TRR 1.6	TRR 2.3	TRR 2.9	TRR 3.5	SE
No. of Lambs	6	6	6	6	
Day 0	1.88	1.88	1.88	1.88	0.11
Day 5	0.99	0.79	0.93	0.83	0.11
Day 10	1.50	1.33	1.50	1.46	0.07
Day 15	1.40 [a]	1.02 [b]	1.30[ab]	1.24[ab]	0.09

[1] TRR – Tetany risk ratio calculated using the equation, ((%K * 255.74) ÷ ((%Ca * 499) + (%Mg * 822.64))).
[2] Blood serum Mg concentrations of 1.7 to 3.0 mg/dL are normal ranges.
[a,b] Within a row, means that do not have a common superscript differ, $P < 0.05$.

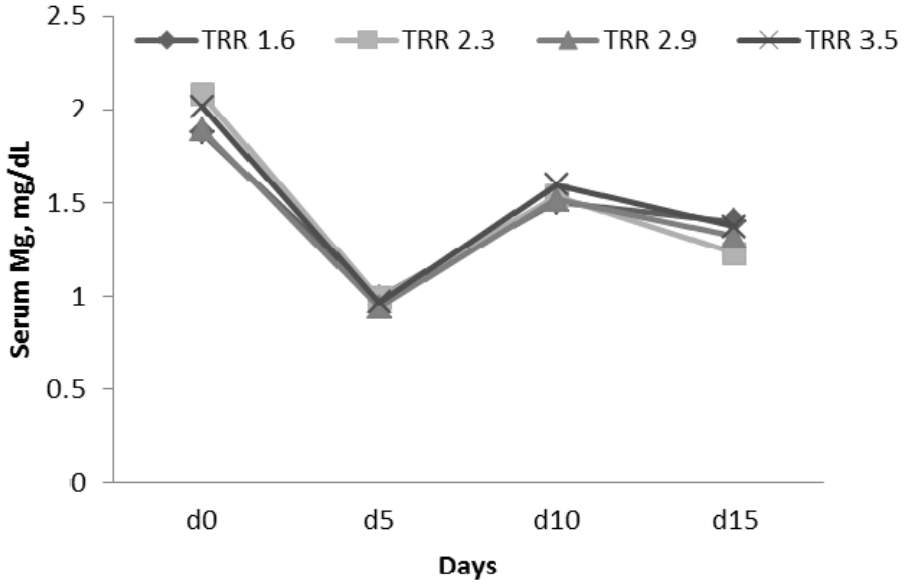

Figure 4.2. Comparison of blood serum Mg levels on d0, d5, d10, and d15 by wethers fed a tetany risk ratio (TRR) of 1.6, 2.3, 2.9, or 3.5.

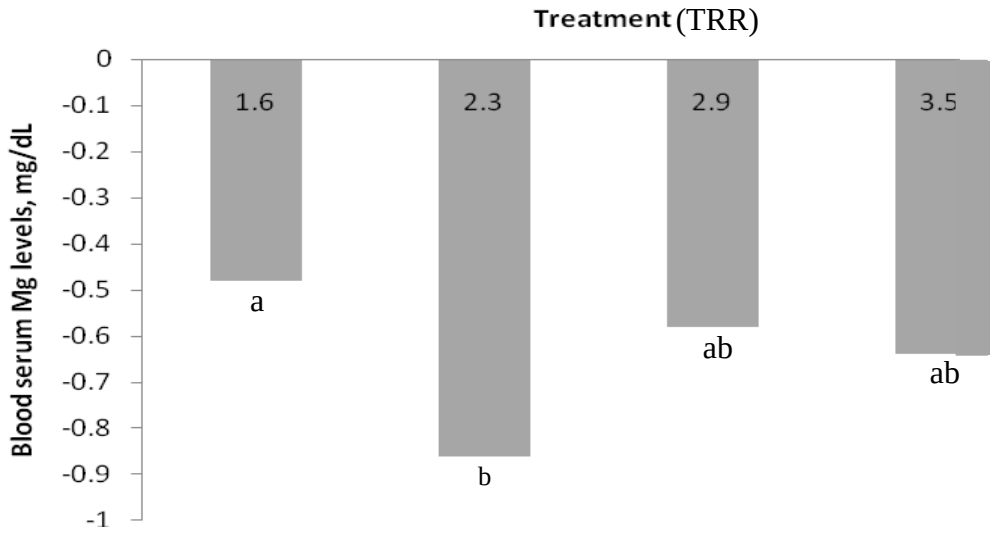

Figure 4.3. Comparison of average changes in blood serum Mg levels over the first 15d by wethers fed a tetany risk ratio of 1.6, 2.3, 2.9, or 3.5. Means that do not have a common superscript differ, $P < 0.05$.

In conclusion, increasing the tetany risk ratio through the addition of K on young growing wethers caused a decrease in N retention, and serum Mg levels in the TRR 2.3

treatment. Serum Mg levels decreased in all four treatments by d-5, and Mg balance was negative. However, it appears that wethers began to mobilize bone Mg after d-5, and serum Mg level recovered in all four treatments after 15 d.

Experiment 2

Maintaining a constant DCAB ratio resulted in increased ($P < 0.05$) DM, NDF, and N digestibilities for the TRR 2.6 treatment when compared to all other treatments (Table 4.4). Nitrogen digestibility decreased ($P < 0.05$) with the addition of supplemental Mg. Nitrogen retention was negative in wethers supplemented with Mg when compared to the high tetany risk ratio treatment and the low tetany risk ratio treatment with no Mg supplementation. Chester-Jones et al. (1989) reported linear decreases in apparent DM, ADF, and CP digestibilities with the addition of increasing levels of dietary Mg to the diet. Water consumption and urine outputs were lower ($P < 0.05$) in the TRR 2.6 treatment when compared to all other treatments. The increased DM, NDF, and N digestibilities recorded in the TRR 2.6 treatment may be the result of decreased water consumption and urine output in the TRR 2.6 treatment. Fisher et al. (1994) reported that increased water consumption dilutes rumen digesta and rate of passage which increases urine volume and may cause a greater disruption in mineral and nutrient digestibility.

There were no differences ($P > 0.16$; Table 4.5) in Mg, Ca, K, or P balance between treatments. Magnesium and Ca balance were negative in all treatments, but tended to be more negative in the Mg supplemented treatments. Additionally, fecal and urinary Mg excretions were higher ($P < 0.05$) in the Mg supplemented treatments.

Chester-Jones et al. (1989) reported similar results as fecal and urinary Mg excretions increased with increasing levels of dietary Mg. This may also be the result of increased water intakes and urine outputs recorded in the Mg supplemented treatments (Figure 4.4). Fisher et al. (1994) also reported increased water intakes on diets containing high levels of K when compared to low K diets.

Table 4.4. One way ANOVA for DM and N digestibilities on treatment diets consisting of a tetany risk ratio of 1.5, 2.6, 1.5 with MgO supplementation, and 1.5 with MgCl supplementation.

Item	TRR[1]	Intake, g/d	Digestibility, %	Balance, g/d	Balance as % of Intake
DM	1.5	1300.4	65.5[a]		
	2.6	1281.8	69.0[b]		
	1.5 + MgO	1289.7	66.4[a]		
	1.5 + MgCl	1291.4	66.5[a]		
	SE	35.5	0.79		
N	1.5	45.2	53.4[ab]	5.55[ab]	12.3
	2.6	46.3	56.8[a]	9.68[a]	20.9
	1.5 + MgO	47.6	49.0[b]	-2.69[ab]	5.2
	1.5 + MgCl	41.8	41.0[c]	-3.97[a]	9.6
	SE	1.2	1.92	4.54	4.54
NDF	1.5	602.7	47.14[a]		
	2.6	589.5	52.94[b]		
	1.5 + MgO	594.9	49.15[ab]		
	1.5 + MgCl	616.9	50.19[ab]		
	SE	16.0	1.38		

[1] TRR – Tetany risk ratio calculated using the equation, ((%K * 255.74) ÷ ((%Ca * 499) + (%Mg * 822.64))).

[a, b, c] Within a column and item, means that do not have a common superscript differ, $P < 0.05$.

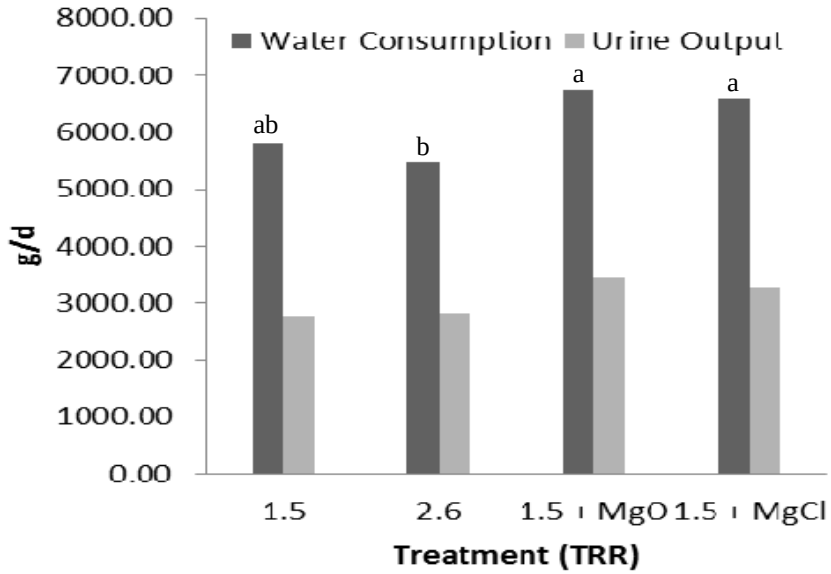

Figure 4.4. Comparison of average water intake and urine output by wethers fed a TRR of 1.5, 2.6, 1.5 + MgO, or 1.5 + MgCl. Means that do not have a common superscript differ, $P < 0.05$.

Table 4.5. One way ANOVA for average balance data of Mg, Ca, K, and P on treatment diets consisting of a tetany risk ratio[1] of 1.5, 2.6, 1.5 with MgO supplementation, and 1.5 with MgCl supplementation.

			Excretion		
Element	Treatment	Intake, g/d	Fecal, g/d	Urinary, g/d	Balance, g/d
Mg	1.5	3.25[a]	4.88[a]	1.33[a]	-2.96
	2.6	3.08[a]	4.27[a]	0.74[b]	-1.93
	1.5 + MgO	8.09[b]	12.64[b]	1.38[a]	-5.15
	1.5 + MgCl	10.07[c]	12.58[b]	1.85[a]	-4.35
	SE	0.21	1.02	0.14	1.04
Ca	1.5	5.59	6.35	0.14	-0.89
	2.6	5.13	5.03	0.18	-0.08
	1.5 + MgO	5.42	6.73	0.15	-1.46
	1.5 + MgCl	5.68	6.58	0.14	-1.04
	SE	0.15	0.70	0.05	0.71
K	1.5	28.87[a]	1.97[ab]	21.79	5.10
	2.6	48.58[b]	2.06[a]	20.58	22.93
	1.5 + MgO	54.17[c]	1.35[ab]	47.44	5.38
	1.5 + MgCl	56.82[c]	1.15[b]	44.92	10.75
	SE	1.37	0.21	6.97	7.03
P	1.5	4.68	5.58	0.00	-0.90
	2.6	4.49	4.59	0.01	-0.11
	1.5 + MgO	4.26	5.53	0.00	-1.28
	1.5 + MgCl	4.52	5.31	0.00	-0.79
	SE	0.12	0.57	0.03	0.57

[1] TRR – Tetany risk ratio calculated using the equation, ((%K * 255.74) ÷ ((%Ca * 499) + (%Mg * 822.64))).

[a, b, c] Within a column and mineral, means that do not have a common superscript differ, $P < 0.05$.

Blood serum Mg was lower ($P < 0.05$; Figure 4.5) in the TRR 2.6 treatment when compared to the TRR 1.5 and both Mg supplemented treatments on d -5. Blood serum Mg was not different between treatments on d-10 or d-15 (Table 4.6). Maintaining the DCAB ratio did not alter the effects on serum Mg as found in the first experiment, where the DCAB ratio was not held constant. This data disagrees with Goff et al. (1991) results as they reported an increase in plasma Mg concentrations after calving in dairy cows fed two separate DCAB ratios (-228 meq/kg or 978 meq/kg). Suggesting that

lowering the DCAB ratio allowed the animal to produce more 1,25-dihydroxyvitamin D_3 and increase bone Ca resorption. This supports data by Fontenot et al. (1989) which described the relationship between Ca regulating hormones and subsequent interactions with Mg. Increases in PTH and 1,25-dihydroxyvitamin D_3 within the animal promotes bone mineral resorption and the release of bone Ca and Mg ions into the extracellular fluid (Fontenot et al., 1989). However, in the present study growing wethers were used instead of lactating dairy cattle. This may be the cause of the differences in serum Mg concentrations.

Table 4.6. Changes in serum Mg[2] on treatment diets consisting of tetany risk ratios[1](TRR) of 1.5, 2.6, 1.5 + MgO, and 1.5 + MgCl.

Item	TRR 1.5	TRR 2.6	TRR 1.5 + MgO	TRR 1.5 + MgCl	SE
No of Lambs	6	6	6	6	
DCAB ratio	38	37	37	37	
Day 0	1.61	1.61	1.61	1.61	
Day 5	1.36[ab]	1.28[b]	1.49[a]	1.53[a]	
Day 10	1.63	1.57	1.64	1.46	
Day 15	1.85	1.73	1.74	1.82	

[1] TRR – Tetany risk ratio calculated using the equation, [(%K * 255.74) ÷ ((%Ca * 499) + (%Mg * 822.64))].
[2] Blood serum Mg concentrations of 1.7 to 3.0 mg/dL are considered normal.
[a,b] Within a row, means that do not have a common superscript differ, $P < 0.05$.

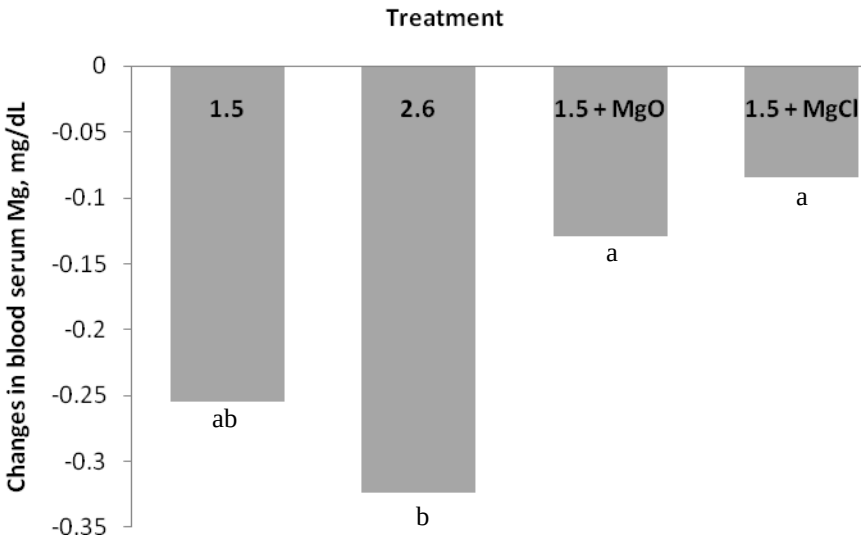

Figure 4.5. Comparison of average changes in blood serum Mg levels after 5 d by wethers fed diets with a tetany risk ratio of 1.5, 2.6, 1.5 + MgO, or 1.5 + MgCl, and a DCAB ratio of 37. Means that do not have a common superscript differ, $P < 0.05$.

In conclusion, supplementing high tetany risk ratio (TRR 2.6) diets with Mg (MgO and MgCl) helped maintain serum Mg levels when compared to the high tetany risk ratio treatment diet without Mg after 15 d. However, Mg balance was still negative in all four treatments. Maintaining the DCAB ratio through the addition of Chloride (Ammonium and Magnesium) decreased DM, NDF, and N digestibilites due to increased water intakes and urine outputs.

Experiment 3

There was no difference (*P*=0.33) in daily gain between animals or periods. Daily mineral consumption was variable among animals, supplements, and location. However, no interactions were detected among animals, supplements, and location. Mineral consumption in the drylot ranged from 14 to 384 g·hd·d-1 and 0 to 106 g·hd·d-1for the

0.0% Mg and 10.0 % Mg supplements, respectively (Table 4.7). Pasture supplement intakes ranged from 0 to 1100 g·hd·d-1for the 0.0% Mg supplement and from 0 to 274 g·hd·d-1 for the 10.0% Mg supplement. Total mineral intakes were 87.3% greater ($P <$ 0.01) for heifers on the pasture (230.8 g/d) when compared to drylot heifers (123.4 g/d). Coefficients of variation (CV) were calculated to evaluate the GrowSafe location and intake variability. The CV's for the drylot compared to the pasture were not different (P=0.59) for either supplement. Although the CV's were not different, the large range and variability of consumption of 0.0% Mg on the pasture may be the cause of the large numerical CV. On average, heifers consumed 119% more (Figure 4.6; $P < 0.01$) 0.0% Mg supplement each day (121.6 g/d) than the 10.0% Mg (55.5 g/d). Coppock et al. (1972) reported similar variation in daily mineral consumption (0 to 1000 g·hd·d-1) by lactating dairy cattle offered free-choice dicalcium phosphate. Other investigators (Cunha, 1987; McDowell, 1996) have reported increased supplemental mineral intakes during the winter or dry season as the result of decreases in forage quality and mineral availability. However, in the present study there was not a decrease in mineral availability as hay plus supplemental Mg intakes accounted for 185% of the daily NRC requirements for 513 kg gestating beef heifers. Other research found no differences in total mineral consumption between cattle supplemented with four mineral blocks which contained differing Ca to P ratios during the grazing months when compared to the winter months (Chladek and Zapletal, 2007). Total daily mineral intakes were higher ($P < 0.01$; Table 4.8) during the first 15 d when compared to the second 15 d (221.9 g/hd vs. 132.2 g/hd). Garossino et al. (2001) reported greater mineral supplement intake by calves

during the second 14 d when compared to the first 14 d. In the present study heifers were not adapted to the hay or supplements prior to the initiation of the study, which may account for increased intakes in the first 15 d. The observed CV of supplement intakes for the first 15 d compared to the second 15 d were not different (*P*=0.59) for either supplement. However, the large numerical difference observed in the CV between the 0.0% Mg and 10.0% Mg supplement in both the first 15 d and the second 15 d is most likely was the result of high mineral intakes before the addition of 50% salt to both supplements on d 2. Similarly, Cockwill et al. (2000) reported that increasing the level of salt from 9.8% to 22.5% decreased daily mineral intakes from 241.6 g/d to 183.5 g/d.

Table 4.7. Average daily intakes, range, and coefficient of variation of mineral supplements containing 0.0% or 10.0% Mg by heifers offered in drylot or on pasture.

	Drylot[a]					Pasture				
Item	Avg.	Min.	Max	CV%	SE	Avg.	Min.	Max	CV%	SE
0.0% Mg[b]	87.8	14.0	384.0	79.2	76.6	155.2	0.0	1108.0	120.0	76.6
10.0% Mg	35.5	0.0	106.0	76.4	22.9	75.5	0.0	274.0	68.0	22.9

[a] Main effect due to location , P < 0.05.
[b] Main effect due to level of Mg, P < 0.05.

Table 4.8. Average daily intakes, range, and coefficient of variation of mineral supplements containing 0.0% or 10.0% Mg by heifers measured for the first 15 d or the second 15 d of a 30 d experiment.

	d0 – d15[a]					d16 – d30				
Item	Avg.	Min.	Max	CV%	SE	Avg.	Min.	Max	CV%	SE
0.0% Mg[b]	151.9	14.0	1108.0	123.7	76.6	91.2	0.0	384.0	75.0	76.6
10.0% Mg	70.0	2.0	274.0	74.0	22.9	41.0	0.0	154.0	80.1	22.9

[a] Main effect due to 15 d period, P < 0.01.
[b] Main effect due to level of Mg, P < 0.01.

Heifers made almost twice as many (*P* < 0.01; Figure 4.7) trips to the feeder (3.1 vs. 1.8 trips/d), and spent an additional 91.3 s (*P* < 0.01; Figure 4.8) consuming the 0.0% Mg than the 10.0% Mg (186.4 vs. 95.1 s/d). The amount of 0.0% Mg consumed was correlated (*P* < 0.01) with feeder attendance (r = 0.72) and duration (r = 0.60), but no

correlation of 10.0% Mg with these variables were detected. Consumption differences and behavior between the two mineral supplements may be the result of decreased palatability with the addition of Mg to the mineral. Greene (2000) reported that addition of Mg, P, and other inorganic mineral salts to supplemental minerals tended to reduce free-choice mineral consumption due to decreased palatability. Decreased palatability and consumption of MgO mixed in a 1:1 ratio with trace mineralized salt was also reported by Frye et al. (1977) when compared to MgO combined with trace mineralized salt and dry molasses in a 1:1:1 ratio.

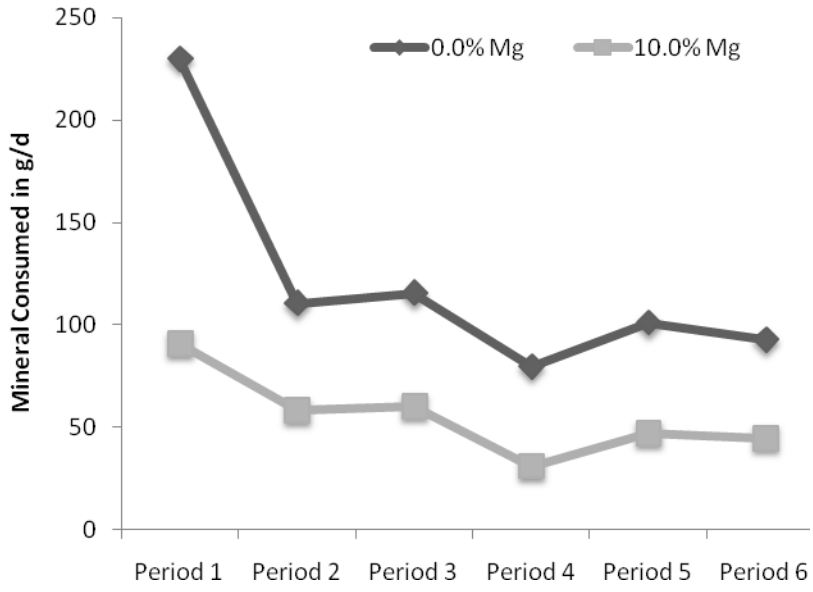

Figure 4.6. Comparison of preference for mineral supplements containing either 0.0% or 10.0% Mg by heifers. Main effects were measured due to period and level of Mg, ($P < 0.01$).

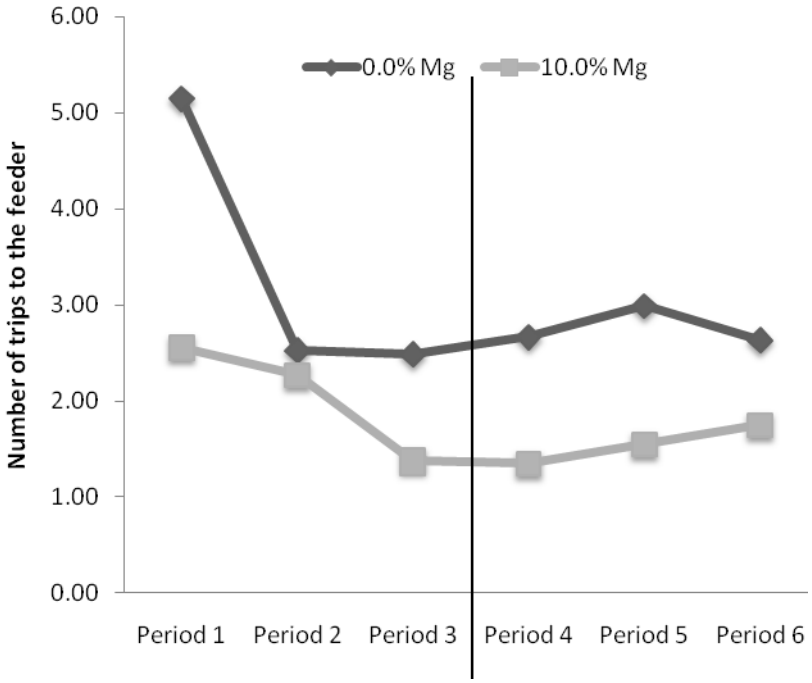

Figure 4.7. Comparison of the average number of trips by heifers to the mineral feeder when supplements contained either 0.0% or 10.0% Mg. Main effects measured were due to period and level of Mg, ($P < 0.01$).

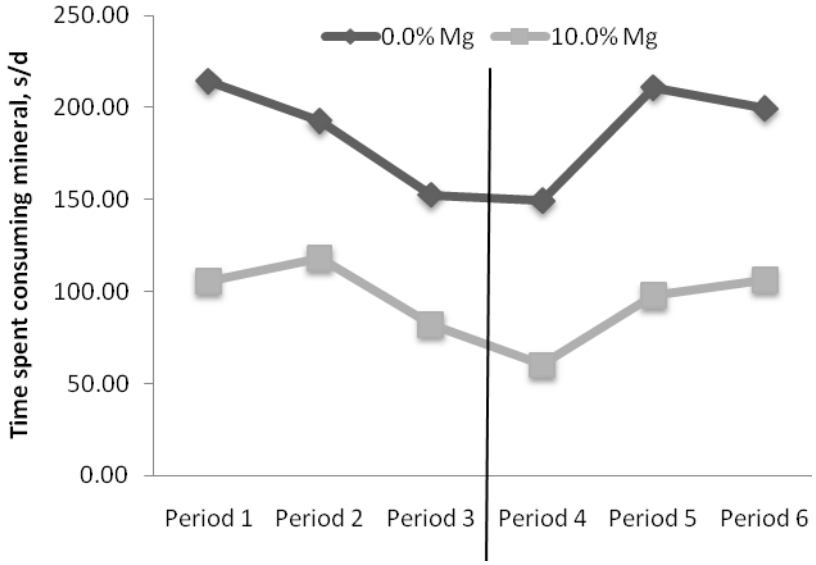

Figure 4.8. Comparison of the average number of seconds spent consuming mineral when supplements contained either 0.0% or 10.0% Mg by heifers. Main effects were due to period and level of Mg, ($P < 0.01$).

CHAPTER 5

CONCLUSION

The literature states that when computing the tetany risk ratio, a value of 2.3 or greater indicates an increased tetany risk for ruminants with higher values indicating a higher risk for tetany. We concluded in experiment one that increasing the tetany risk ratio through the addition of K to the diet caused decreased serum Mg levels and N retention by wethers. With the greatest decreases in serum Mg and N retention recorded in the tetany risk ratio of 2.3 treatment. The higher serum Mg levels in the TRR 2.9 and TRR 3.5 treatments when compared to the TRR 2.3 treatment may be a result of the ability of young growing ruminants to mobilize bone Mg. As mature lactating ruminants are more susceptible to tetany due to their inability to mobilize large amounts of bone Mg and due to Mg and Ca losses in the milk. The results of this experiment suggest that the tetany risk ratio indicative value of risk of may need to be reexamined in ruminants at different stages of production due to differences in liable Mg reserves.

Experiment two suggests that Mg supplementation helped maintain blood serum Mg levels when compared to the TRR 2.6 treatment after 15 d. The results of the experiment suggest that the addition of chloride to the diet to lower the DCAB ratio caused reduced DM, NDF, and N digestibilities due to increased water intakes and urine outputs. More research is needed to understand the interactions between the DCAB ratio and tetany at animals at different stages of production.

In experiment three when given a choice of consumption, results indicate that the addition of MgO to the mineral supplement decreased overall mineral consumption,

feeding attendance, and feeding duration. Heifers consumed more mineral on the pasture than in the drylot and during the first 15 d compared to the second 15 d. The relationship between salt and MgO concentration in mineral supplements warrants further investigation

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