COMPARISON OF ORGANIC VS. INORGANIC TRACE MINERALS ON RATE AND EFFICIENCY OF GAIN AND CONCEPTION RATES IN BEEF HEIFERS

by

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ABSTRACT

Objectives of this experiment were to compare rate and efficiency of gain, and conception rates of yearling heifers supplemented with Cu, Zn and Mn as either methionine chelated trace mineral (**CTM**) or the same minerals in SO_4 form. The experimental design utilized 3 ranches, each having 2 replications per treatment with pen as the experimental unit for ADG, DMI and G:F. Heifer was the experimental unit for pregnancy rates. Ranch 1 contained 498 Angus heifers, ranch 2, 236 Red Angus cross heifers, and ranch 3, 1,742 Angus cross heifers. All heifers were fed silage based diets that contained approximately 13.5% CP, 64% TDN (DM basis) and had low levels of SO_4, Mo or Fe in feed or H_2O. Diets contained 24 ppm Cu, 70 ppm Zn and 64 ppm Mn. Supplements were fed for 181 d (Ranch 1), 149 d (Ranch 2) and 151 d (Ranch 3) prior to breeding. Heifers were weighed at trial initiation (BW 270 kg ± 2.8), end of drylot feeding, at breeding and at pregnancy diagnosis. Ranch 1 heifers were bred by AI followed by natural service (45 d breeding), Ranch 2 heifers were bred by natural service (50 d breeding) and Ranch 3 heifers were bred by AI once. Pregnancy was determined via ultrasound. Ranch effects were significant ($P < 0.001$) for gain, ADG, G:F and overall pregnancy rate, but not for conception in the first 21 d. No ranch x treatment interactions were detected for any measurements ($P \geq 0.47$) and no differences ($P \geq 0.46$) were detected between treatments for total gain, ADG, G:F or the number of heifers that conceived during the first 21 d on Ranches 1 or 2. Conception rate increased ($P = 0.03$) for CTM heifers from ranch 3 with one AI breeding. Across ranches, conception rates during the first 21 d of breeding did not differ ($P = 0.12$) between treatments but overall pregnancy rate was greater ($P = 0.05$) for heifers supplemented with CTM. Under the conditions of this experiment results suggest that supplementation with CTM contributed to greater pregnancy rates in heifers.

INTRODUCTION

The Importance of First Service Conception in Beef Heifers

Primiparous heifers have the lowest conception rates among all age groups of cows (Bellows et al. 1982). Heifers must calve by 24 mo of age in order to achieve maximum lifetime productivity because heifers that calve later are more likely to breed later in subsequent yr or perhaps not even rebreed (Patterson et al. 1992). Lesmeister et al. (1973) determined that primiparous heifers calving early in the calving period will have lifetime average weaning weights that are 20% greater than those heifers calving late in the calving season. Due to growth and lactation requirements, heifers may have a longer post partum interval than mature cows (Funston and Geary 1999). Due to the longer post partum interval experienced by primiparous heifers it has become a common practice among many producers to breed heifers to calve 28 d earlier than multiparous cows.

Negative financial ramifications exist due to lower conception rates by heifers. American Marketing Service data indicates the mean sale price of bred heifers on 2/14/2011 at Billings, MT was $1,435/hd. On 2/16/2011 AMS data indicates that similar weight non-pregnant heifers demanded a price of only $890/hd. This is indicative of a monetary price differential of approximately $545. The cash cost, exclusive of any economic opportunity cost (as of February 2011) to retain a heifer to first calving date at 24 mo of age was approximately $1,210 per heifer (Table 1).

Table 1. Cost to retain and support a heifer to first calving date at 24 mo as of Feb. 2011.

Item	Cost US $
Heifer Calf[1]	800.00
Hay[2]	170.00
Mineral[3]	43.00
Vaccine and Wormer[4]	30.00
Pasture[5]	144.00
Breeding Cost[6]	25.00
Total Cost	1210.00

[1]Cost of heifer calf based on AMS Billings 2/14/2011 report, 293kg calf at $0.55/kg.
[2]Hay cost based on AMS Billings 2/11/2011 report, $70/ton.
[3]Mineral supplement cost of $950/ton, 3oz daily consumption for 486d.
[4]Vaccine and wormer cost based on local vet estimate.
[5]Pasture rent based on MT Ag Statistics 2010, $18/month for 7 mos.
[6]Breeding cost based on ABS representative estimate.

Factors Limiting First Service Conception

Ferrell (1982) found that age at first puberty was one of the most important factors in heifer conception. Short et al. (1990) determined that it is ideal for heifers to reach puberty 1 to 3 mo prior to breeding as early estrous cycles are often infertile. Short and Bellows (1971) and Patterson et al. (1992) determined that when intake was restricted it resulted in lesser weight at breeding, delayed estrus, and lesser pregnancy rates compared to heifers that were fed on an adequate nutritional plane. Feuz (1991) determined that it is most profitable over the life of the heifer for 62.5% of mature BW to be obtained by breeding. Funston and Deutscher (2004) determined that heifers could be developed to 53% of mature BW with no adverse effects on reproduction or calf production traits. Later Funston et al. (2011) determined that heifers can be developed to a range of 50 to 57% of mature BW because puberty was more a result of age than BW. It is still common practice in the industry to feed to a target weight of 60 to 66% of mature BW at breeding.

Mineral deficiencies, both macro and micro minerals, can cause delayed estrus, decreased conception, abnormal estrus, depressed immunity, and reduced intake (Paterson and Engle 2005). Given that each of the aforementioned symptoms of mineral deficiencies could adversely affect pregnancy rates in heifers and thus have negative financial impacts to producers, much research has been conducted and continues to be conducted in micro mineral nutrition and its relationship with reproductive performance. Three minerals that are heavily studied are Cu, Zn, and Mn.

LITERATURE REVIEW

Introduction to Trace Minerals and Their Role in Ruminant Nutrition

Chemical elements other than C, H, O and N are referred to as minerals (Taylor and Field, 1998). Minerals themselves are inorganic as they contain no carbon (Taylor and Field, 1998) and are needed in the body of both ruminants and non-ruminants to ensure proper nutrition (NRC, 1996). Macro minerals are needed in larger quantities, which vary by mineral, and micro minerals are needed in trace amounts (Taylor and Field, 1998). Trace minerals are essential to numerous functions in biological beings (Suttle, 2010). Some trace minerals such as Cu and Zn are needed in enzymes and proteins that support immunological mechanisms (Shim and Harris, 2003). Some trace minerals are needed in the oxidation of other minerals, such Fe being dependant on Cu for oxidation (Shim and Harris, 2003). Some micro minerals work in tandem with vitamins in the prevention of disease, such as Se and vitamin E which have an interdependency in the prevention of white muscle disease (Taylor and Field, 1998). Cobalt, which is a micro mineral, is a part of vitamin B_{12} (Taylor and Field, 1998). Micro minerals are commonly attached to either organic compounds such as the amino acid lysine or methionine, or to inorganic compounds such as sulfates, chlorides, or oxides in mineral supplements to be included in the diets and rations of both ruminants and non-ruminants. While micro minerals are not the largest component of ruminant diets, the need for them within the body to continue biological processes is essential. The focus of this research investigates the nutrition of micro minerals Cu, Zn, and Mn.

The Role of Copper in Ruminant Physiology and Reproduction

Copper is an essential trace mineral for ruminant animals which is absorbed in much lower quantities in ruminants than non-ruminants (Spears, 2003) and is primarily stored in hepatic tissue after being absorbed from the intestinal lumen (Shim and Harris, 2003) and is excreted in bile and feces. Free Cu rarely exists in vivo as it has multiple specific chaperones to transport it between cellular compartments (Shim and Harris, 2003). Copper is essential for many functions and is a component of numerous enzymes, supports growth and immunity, as well as reproduction (NRC, 1996). Copper is necessary for proper Fe oxidation (Shim and Harris, 2003). It comes as no surprise that one symptom of a Cu deficiency in ruminants can include anemia; others are reduced growth, and delayed or depressed estrus (NRC, 1996 and Paterson and Engle, 2005). As early as 1933 Cu deficiency was found to cause illness in cattle, and was termed Lechsucht, a wasting disease common to the Netherlands (Gilbert, 1949). Later, Stabel et al. (1993) determined that a Cu deficiency can have negative effects on immunological defense mechanisms. In this study, 14 steer calves 30 d of age were fed diets that contained either 1.5 mg·kg or 11.5 mg·kg $CuSO_4$. Calves fed the higher level of Cu responded to an infectious bovine rhinotracheitis virus (IBRV) challenge with blood plasma Cu levels of approximately 1.0 µg/mL while the calves fed the lower level of Cu only demonstrated approximately 0.35 µg/mL. Blood serum ceruloplasmin levels after the IBRV challenge were approximately 23.5 IU/L greater in the calves fed the higher level of Cu than those on the lower level of

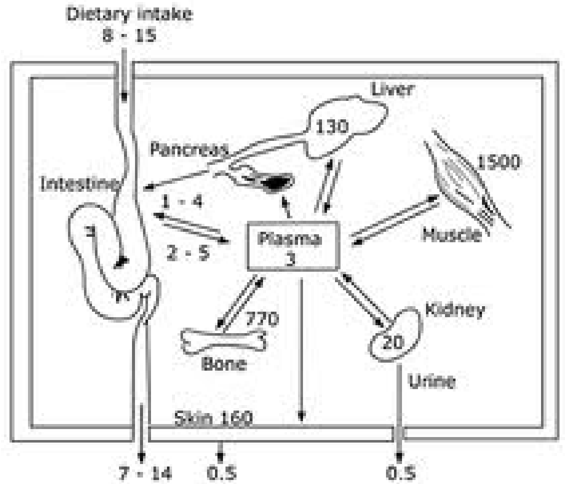
Cu. Arthington et al. (1996) determined Cu deficiency in heifers could alter the acute-phase protein response to viral infection and can also have a negative effect on lymphocyte response to pathogens. In another report Arthington et al. (1996) noted that Cu deficiency resulted in an increased number of neutrophils in the blood, indicating an acute inflammation.

Different breeds of cattle utilize Cu with different levels of efficiency. Gooneratne et al. (1994) determined that Simmental cattle excrete more Cu in the urine than do Angus cattle. Ward et al. (1995) determined that Angus cattle retain higher levels of blood plasma Cu than do Simmental and Charolais cattle. These data indicates that different breeds may metabolize Cu differently and thus may have differing Cu requirements. Gestational status can affect Cu absorption and retention as pregnant cattle have higher uptake and retention of Cu. (Vierboom et al. 2002). Mineral interactions can have an impact on the metabolism and bio-availability of Cu.

The Role of Zinc in Ruminant Physiology and Reproduction

Zinc is an essential nutrient in cattle that is critical to enzyme systems and is involved in protein synthesis and carbohydrate metabolism as well as other biochemical reactions (Miller, 1970). Zinc is primarily absorbed through the duodenum in cattle and is also re-excreted through the distal GI tract and in feces; very little Zn is excreted in urine. Zinc is stored in most tissues with the largest reserve being in the liver (Miller, 1970).

Figure 1. Uptake and Mobilization of Zn



Dietary factors and Zn levels already present in the animal have much to do with volume and rate of Zn absorption (Spears, 2003). Pregnant cattle have greater uptake and retention of Zn compared to non-pregnant cows. (Vierboom et al. 2002). Patterson et al. (1992) determined that at restricted DMI there are adverse effects on reproductive performance. If Zn deficiency exists it can result in depressed DMI and similar adverse effects on reproduction could occur. This is likely because a deficiency of Zn will force a change in enzymatic activity since Zn is such a critical component of many enzymes (Miller, 1970). Chirase et al. (1991) found that steers fed a low or unavailable form of Zn exhibited a decrease in DMI when stressed with IBRV. Suttle and Jones (1989) found that Zn deficient sheep had a greater instance of morbidity than those that had adequate levels of Zn stored in the body. Pinchak et al. (2004) noted lower conception rates among heifers experiencing a high rate of morbidity as opposed to heifers that stayed healthy in a trial utilizing 633 heifers in a stocker setting grazing on southern US plains native range. While Zn does not directly impact the reproductive system, the main functions it supports, such as immunity, have great impacts on reproduction potential and overall animal performance, thus making Zn a critical mineral in the ruminant diet.

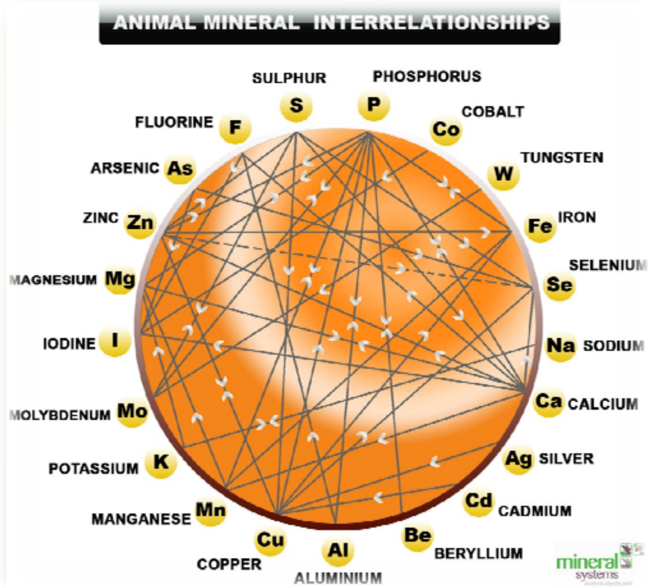
The Role of Manganese in Ruminant Physiology and Reproduction

Manganese is necessary for normal enzymatic activity, immunity, and reproduction (NRC, 1996). Manganese is typically found in the liver, kidney, skeletal tissues, and the gonads (NRC, 1996 and Tuormaa, 1996). Manganese is poorly absorbed (via the small intestine) in ruminants and some research suggests that high concentrations of Ca and P in the diet can inhibit Mn absorption (Spears, 2003). Some symptoms of a Mn deficiency include reduced birth weights, shortened tendons in new borns, skeletal deformities, and impaired reproductive performance (NRC, 1996 and Tuormaa, 1996). Manganese deficiency can also lead to alterations in all tissue cells including the liver, kidneys, pancreas, and heart (Tuormaa, 1996). Early research indicated that Mn deficient rats exhibited estrus at a lower rate than rats fed a diet with sufficient Mn levels (Waddell et al., 1931). When 19 female rats were observed over a 50 week period, estrus was erratic, delayed, and depressed for the first 28 weeks. When Mn was added to the diet in the form of $MnSO_4$, the rats began to exhibit regular estrus cycles immediately and continued to have regular cycles for the remaining 22 weeks of the experiment. When an all milk diet that was low in Mn was fed to rats by Orent and McCollum (1932) there was a reported decrease in gains compared to Mn supplemented rats but no numeric differences were reported. Bently and Phillips (1951) fed different levels of Mn to 12 dairy heifers which were assigned to one of four treatment diets over a period of 2 yr. The control treatment diets was Mn deficient with only 7 to 10 ppm Mn the other treatment diets had 30, 40 and 60 ppm Mn. Those heifers assigned the 40 ppm Mn treatment exhibited up to 30% greater pregnancy rates in year 1 and up to 15% greater pregnancy in yr 2. Heifers that were fed the Mn deficient diet reached puberty approximately 2 mo later and required more services per conception than heifers that the Mn supplemented treatments. Heifers fed the 60 ppm Mn treatment showed similar estrus and pregnancy rates to those that were deficient, indicating that excessive amounts of Mn were as detrimental as deficiency. Hidiroglou (1975) examined ovarian tissues from normal and anestrous ewes and determined that Mn was critical for proper corpus luteum function. These data indicate that Mn is an essential mineral in diet of the ruminant in order to maintain proper health and biological functions.

Mineral Interactions and the Necessity of Considering More Than One Mineral in Reproductive Performance

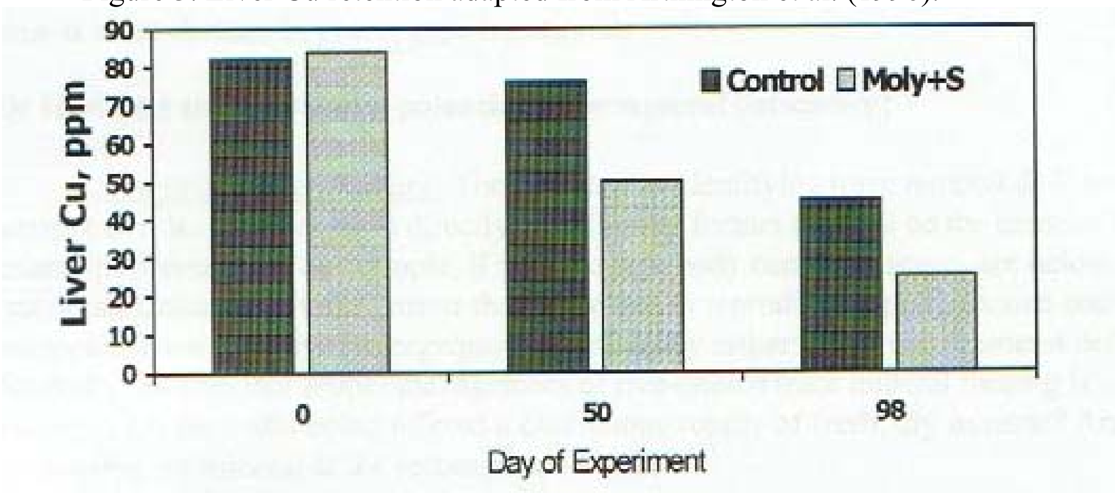
Analyzing the effect of only one mineral's effect on reproduction can be both difficult and perhaps misleading. Copper interacts with seven minerals, Zn interacts with 6 minerals, and Mn interacts with 4 minerals (Fig. 2).

Figure 2. Mineral Interaction (Mineral Systems)



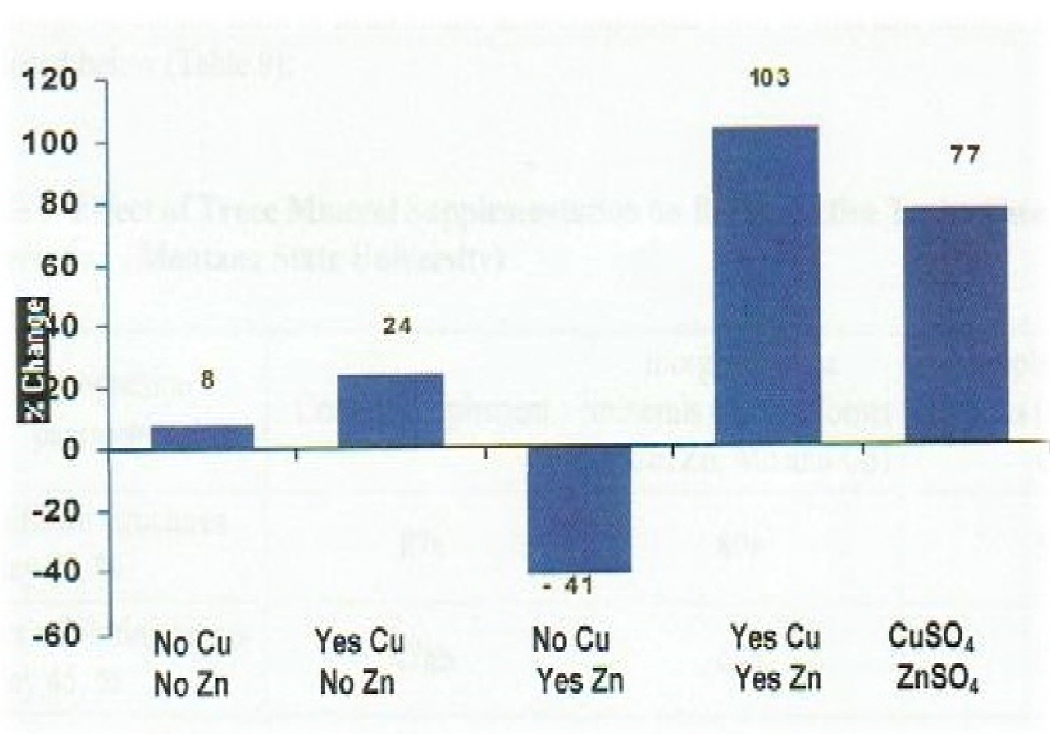
It is known that S, Mo, and Fe have an antagonistic relationship with Cu (Suttle, 1974). When the presence of these antagonists exists Cu is bound into insoluble compound, referred to as thiomolybdates, in the rumen (Davis and Mertz, 1987 and Suttle, 1991). The antagonistic interaction between Cu, S, and Mo are well illustrated in an experiment conducted by Arthington et al. (1996). In this experiment 12 heifers were used in which 6 were fed a control diet without the presence of antagonists and 6 were fed an antagonistic diet for 129 d. At 100 d of the trial, heifers fed the antagonistic diet had approximately half of the hepatic Cu concentration than those in the control group with no antagonists present (Fig. 3). By d 129, heifers fed the antagonistic diet exhibited Cu deficiency based on liver biopsies. This experiment demonstrates the intensity that antagonistic interactions can induce.

Figure 3. Liver Cu retention adapted from Arthington et al. (1996).



Bailey et al. (2000) found that the Cu antagonists can still be stored in the liver 75 d after removal from a high antagonist diet. That experiment used 60 heifers that were previously consuming the antagonists S, Fe, and Mo. During the 75 d study the heifers were separated into 3 treatments and fed Cu and Zn from different sources or were fed no supplemental Cu and Zn. By the end of the 75 d trial, heifers that received copper supplementation had less Mo stored in the liver. This suggests that Cu supplementation is needed for cattle coming off of a diet containing significant levels of antagonist. Ratios of minerals ingested can also have an effect on liver retention of minerals. In a study conducted by Wellington et al. (1998) it was found that heifers supplemented with both Zn and Cu retained higher levels of hepatic Cu than those supplemented with only Cu. It was also determined that when Zn was supplemented in the absence of Cu that hepatic Cu depleted by 41% over the 90 d experiment as illustrated in Figure 4. This experiment was conducted in the presence of high levels of the antagonist Mo. Thirty heifer calves utilized in this experiment were individually fed one of four treatment diets, the first being a control diet with no additional Cu or Zn supplementation, second being a high Cu supplemented diet, third being a high Zn supplemented diet, and the fourth being a high Cu and Zn supplemented diet. Molybdenum was added to all treatment diets in an effort to deplete liver Cu. Liver biopsies were taken on d 1, 15, 58, and 90 of the experiment. The hepatic Cu concentration at the conclusion of the trial showed that when Cu alone was supplemented liver Cu concentration increased 24%, when Zn alone was supplemented liver Cu went into a state of depletion and decreased by 41% from d 1 of the trial. When Cu and Zn were supplemented together, the liver Cu concentration increased 103% over the 90 d trial (Fig. 4). Results illustrate that there is a strong interaction between dietary Cu and Zn levels.

Figure 4. Cu and Zn interaction adapted from Wellington et al. (1998)



Hatfield et al. (2001) noted a similar response in ewes in regards to hepatic Zn concentrations. It was found that when ewes were supplemented with both Zn and Cu hepatic Zn was higher than in ewes supplemented with Zn alone, illustrating that there appears to be a synergistic relationship between Cu and Zn. Stabel et al. (1993) conducted an experiment in which 14 calves were fed a basal diet containing 1.5 mg Cu/kg in which half of the calves in the experiment were supplemented with an additional 10 mg/kg Cu while the remainder were only fed the basal diet. Those supplemented at the higher Cu rate also exhibited higher levels of Zn retention. These examples underscore the importance of mineral interactions, ratios, and the interdependency minerals have upon other minerals and are not intended to be an exhaustive list of all mineral interactions that may take place, but rather, ones appurtenant to this research.

Bio-availability and Metabolism of Organic/Chelated Minerals vs. Inorganic Minerals

Research comparing the bio-availability of Cu proteinate to $CuSO_4$ is very mixed (NRC, 1996). The majority of research indicates that chelated minerals are more bio-available when antagonists are present or special circumstances exist, but overall, research has failed to produce consistent or sustained advantages for organic minerals (Suttle, 2010). Suttle (1974) supplemented ewes with organic and inorganic forms of S to examine the effect on plasma Cu. Four experiments were performed and each concluded that organic forms of S would increase the Cu depletion in blood plasma as more thiomolydates were formed in the rumen which did not allow as much dietary Cu to be absorbed as when the inorganic forms of S were fed. Kincaid et al. (1986) found that

CuLy was more available than $CuSO_4$ when the antagonist Mo was present after analyzing Cu levels in blood plasma of Holstein calves fed differing levels of Cu in the diet for 12 wks.

One proposed method of overcoming the negative effects of antagonists is the use of Cu injections. Wood et al. (1989) injected Cu glycinate into young pre-weaned calves grazing pastures with a heavy Mo concentration. This was ineffective and in some cases calves that were injected with CuGly did not perform as well as those who were orally supplemented with $CuSO_4$. These results were similar to previous work conducted by Bohman et al. (1983) in which Cu EDTA injections were compared to CuGly injections. This experiment showed that Cu EDTA injections resulted in a higher blood Cu plasma spike than CuGly, but both effects were short lived and injections are not an effective means of assisting cattle in overcoming a chronic Mo antagonist problem. Furthermore, the problem of short lived injection response was supported by other research of Bull et al. (1986) and Edmiston and Bull (1988). Deutscher et al. (1982) were able to overcome high S antagonistic effects in the form of sulfates in the water for range cattle in South Dakota with the use of CuGly injections. Prior to injections cows were demonstrating clinical signs of anemia, diarrhea, and low blood and liver Cu levels. Calves were performing poorly with low gains. By the end of the experiment, cattle injected with CuGly or a combination of oral supplement with $CuSO_4$ and CuGly injection demonstrated blood Cu levels within normal ranges and calves demonstrated better BW gains. Spears (1989) performed four experiments with lambs and heifers and reported that blood plasma Zn was higher in lambs dosed with ZnMet 24 hr post dosing than in lambs dosed with ZnO. Heifers showed significantly greater gain and better G:F ratio at d 56 of the trial. However, by d 126 gains were similar between the ZnO treatment and the ZnMet treatment, even though the heifers fed the ZnMet treatment tended ($P < 0.19$) to have faster rates of gain. Spears (1989) summarized that Zn, when provided either as Zn Oxide (ZnO) or ZnMet appeared to be absorbed to a similar extent, but appeared to be metabolized differently.

Nockels et al. (1993) determined that CuLy and ZnMet supplementation to stressed steer calves resulted in higher blood plasma levels of Cu and Zn as well as less excretion in the urine and feces than when steers were supplemented with $CuSO_4$. Nockels et al. randomly assigned eight steers to two treatment groups, one receiving an organic supplement of Cu and Zn and one receiving Cu and Zn in sulfate form. Steers were fed their respective treatment diets for 29 d at which time a stress, depletion, and repletion regimen was imposed upon the steers. At trial conclusion, which was marked by the end of the repletion phase, steers fed the CuLys and ZnMet showed an apparent 53% higher Cu absorption than those fed $CuSO_4$ treatment. No differences were noted in apparent Zn absorption; however, Zn retention was 58% higher among those steers in the organic treatment group. It should be noted in this trial that the Zn levels between treatments were the same, but the Cu supplemented in the organic treatment group was 1.2 ppm higher than in the SO_4 treatment group. Most research indicates that supplementation with organic forms of minerals can result in better animal performance than supplementation with inorganic forms in the presence of antagonists; however, Nockel et al. (1993) experiment was conducted with no significant levels of antagonists present. Ward et al. (1993) conducted a study that had the opposite conclusion as Nockels et al (1993). Ward et al. (1993) study found that when freshly weaned steers were supplemented with either CuLy or $CuSO_4$ in the presence of S and Mo, no difference in blood plasma Cu was observed. Similarly, Kegley and Spears (1994) fed Cu deficient calves diets that contained the antagonists Fe and Mo and determined that CuLy and $CuSO_4$ had similar bio-availabilities based on blood plasma Cu. Eckert et al. (1999) determined that when ewes were fed Cu protienate in levels near requirement, higher hepatic Cu concentrations were evident. This experiment was conducted in the absence of any significant levels of antagonists. Rabiansky et al. (1999) determined that in Cu depleted heifers CuLy was more beneficial for repleting hepatic Cu than was $CuSO_4$ when the antagonists Fe, S, and Mo were present. This experiment was a 211 d trial that involved forty heifers assigned to one of five treatment groups. The control group received no supplementation while the other four treatments were 8 mg/kg CuLys, 8 mg/kg $CuSO_4$, 16 mg/kg CuLys, and 16 mg/kg $CuSO_4$. The heifers were fed a Cu depletion diet for 70 d before treatments were imposed. On d 71 the treatments were imposed with no changes to the dietary antagonists until d 169. On d 169 the antagonists were removed from the diet. At conclusion of the trial it was noted that while growth and performance remained constant across treatments, the higher level of CuLys supplementation increased liver Cu in cattle and tended to keep blood plasma Cu higher than the inorganic form of Cu at the same level of supplementation. This suggests that in the case of a deficiency, the organics may be more beneficial to the animal. Figure 5 summarizes the relative bio-availability from multiple experiments by various researchers and compiled by Greene (2000). In this figure Green placed a sulfate form of minerals as the benchmark level of availability and demonstrated the comparison as a percentage of the sulfate benchmark. The figure is not to imply 100% bio-availability of a sulfate form of mineral, but places sulfate at a comparison level of 100 to facilitate comparisons between multiple forms of mineral supplements.

Figure 5. Relative bio-availability adapted from Greene (2000)

Mineral	Sulfate form	Oxide form	Carbonate	Chloride form	Organic form (Complexed, chelate, etc)
Cu	100	0	-	105	130
Mn	100	58	28	-	176
Zn	100	-	60	40	159-206

More recently, Bailey et al.(2001) determined that a 50% organic:50% inorganic combination of mineral supplements resulted in higher hepatic Cu retention in beef heifers when heifers were consuming the antagonists Mo, S, and Fe as compared to heifers supplemented with 100% inorganic sources of Cu. In this experiment 60 heifers were assigned to one of five treatment groups with a control group, one group supplemented 5X the NRC recommendation for Cu via a SO_4 form, a SO_4 group at twice the NRC recommendation for Cu, a group of 50/50 CuLys and $CuSO_4$ at twice the NRC Cu recommendation, and a group of 25/50/25 $CuSO_4$/CuLys/CuO at twice the NRC recommendation for Cu. During the 112 d trial Mo, S, and Fe were fed to place antagonists in the diets. At trial conclusion heifers in the two treatment groups that contained organic forms of Cu showed both significance and tendencies to have higher liver Cu and lower Mo concentrations than the diets that contained only the SO_4 forms of Cu.

Research of organic minerals bio-availability has also been conducted for the trace mineral Mn. Henry et al. (1992) determined that MnMet had a bioavailability of 120% of $MnSO_4$ based on a 21 d trial where bone, kidney, and liver Mn concentrations were measured. In this research two experiments were conducted in which 42 lambs were divided into seven treatments and fed a basal ration with no Mn supplementation, and one treatment each of MnMet or $MnSO_4$ at added levels of 900, 1800, and 2700 ppm. For experiment 2 different levels of $MnSO_4$ were compared to the same level of two types of MnO and MnMet. At the end of the 21 d trial lambs were sacrificed and Mn levels in the bone, kidney, and liver were analyzed. Results indicated that at each level of Mn fed, the methionine form of Mn resulted in greater concentrations in all tissues when compared to the two inorganic types of Mn.

These experiments do support the conclusion that in the presence of antagonists, organic minerals have a greater bio-availability than inorganic varieties, but results should not be construed as having hyper-availability (Suttle, 2010).

Organic Minerals Effect on Immunity and Feedlot Performance

Ward et al. (1993) found that when freshly weaned steers were supplemented with either CuLy or $CuSO_4$ in the presence of S and Mo, no differences in immune response, growth, feed efficiency, or DMI were observed. Spears (1989) heifer experiment showed significantly greater gain and better G:F ratio at d 56 for heifers supplemented with ZnMet, but by d 126 gains were similar between the ZnO treatment and the ZnMet treatment. Chirase et al. (1991) found that steers fed a low or oxide form of Zn exhibited a greater decrease in DMI and a longer recovery period when stressed with IBRV compared to steers supplemented with ZnMet. Later, Chirase et al.(1994) conducted another experiment three groups of steers in which one group was not given supplemental Zn or Mn, one group was supplemented with ZnMet, and one with both ZnMet and MnMet. Those supplemented with ZnMet and MnMet demonstrated a better immune response with significantly lower rectal temperature and less decrease in BW change following the stress of weaning, shipping, and IBRV challenge upon arrival and during the first 62d in the feedlot. These results suggest that an interaction could be occurring between Mn and Zn that has yet to be explored.

Dorton et al. (2002) determined that level and type of Cu supplementation could improve feedlot performance and increase blood antibody titers to combat disease. In this experiment 48 steers were individually fed one of 5 treatment diets, a basal diet with no supplementation, one treatment each of 10mg/kg Cu from either a SO_4 source or an organic source, and one treatment each of 20mg/kg from the same two SO_4 and organic source as in treatments two and three. Results indicated that steers fed the higher levels of Cu from either form of Cu had greater liver Cu, greater gains, greater levels of immunoglobulin G and antibody titers to ovalbumin in the blood. The data also showed that the highest liver Cu, highest gains, and highest antibody titers were found in those steers fed the higher level of organic Cu. These experiments indicate that organic minerals can have a positive effect on feedlot performance and immune response in cattle.

Organic Minerals Effect on Reproductive Performance

Manspeaker et al. (1987) reported improved reproductive performance in dairy cows supplemented with organic minerals over cows given no mineral supplementation. While this study only demonstrated that organic mineral supplementation increased reproduction as opposed to no supplementation, Olson et al. (1999) conducted an experiment where cows were given supra natural levels of both organic and inorganic minerals and found that levels far above requirement could have a negative impact on reproductive performance. Barone et al (1998) noted that excessive levels of Zn and Cu in rats resulted in deformed fetuses. The indication is that both low levels and ultra high levels can have negative impacts on reproduction.

Ansotequi et al. (1999) determined that heifers being supplemented with a 50% organic and 50% inorganic form of Cu and Zn exhibited higher ovulation rates than those that received only SO_4 form of Cu and Zn. This was determined by individually feeding three treatment groups of heifers totaling 60 animals, a control group with only a basal diet, and treatment group with an inorganic mineral supplement, and a treatment group with a 50/50 mix of organic and inorganic Cu and Zn. Liver biopsies were taken on days 0, 25, 50, and 75 to determine trace mineral status in the animals. After 47 d estrus synchronization was started and on day 65 the heifers started a super ovulation regimen. Following ovulation induction the heifers were bred AI three times and then flushed to determine the number of ova and fertilized embryos. While there was no difference in fertilization, ovulation rates were significantly higher for heifers fed the organic supplement. Stanton et al. (2000) utilized 300 Angus cows in a 209 d trial that started prior to calving where cows were supplemented with three mineral treatments, a low level inorganic mineral supplement of Cu, Zn, Mn, and Co, a high level of inorganic supplement of Cu, Zn, Mn, and Co, and a high level organic supplement of Cu, Zn, Mn, and Co. Cow body condition, liver Cu, liver Zn, and liver Mn were not affected by treatment at any time during the trial. Cows on the high level of inorganic minerals lost more weight ($P < 0.05$) than other treatments, but again, this did not change BCS of the cattle. Calf performance was greater ($P < 0.05$) among the cows in the high level of organic supplementation. Cattle in the organic mineral treatment exhibited better pregnancy rates to AI ($P < 0.05$) than the other two inorganic treatments, but overall pregnancy rates did not differ. Ahola et al. (2004) conducted a study in which 178 crossbred multiparous cows were fed one of three treatment groups, a control with no mineral supplementation, a 100% inorganic mineral containing Cu, Zn, and Mn, and the third treatment being a 50 /50 mix of organic and inorganic mineral supplement containing Cu, Zn, and Mn. At the end of the first year the cattle receiving the organic mix treatment had higher liver Cu, but plasma Cu and Zn, liver Zn, BCS and weight did not differ among treatments. By the end of year two there were no detectable differences among treatments in these areas. In year 1 overall reproductive performance did not differ, but the trend ($P = 0.08$) was for those cows supplemented with the organic mineral mix to have a higher rate of pregnancy to AI. Cows supplemented with the organic mineral mix exhibited a 67% pregnancy rate to AI when estrus was observed whereas cows provided with the inorganic minerals on had a 52% pregnancy rate to AI. In year 2 of the trial (148 of the cows were retained in year 2) cows fed the organic mineral mix treatment showed no difference in conception rates to AI when mass AI breeding was conducted. When both years of the trial were pooled, the indication was that the cattle provided the organic mix treatment tended ($P = 0.13$) to have better pregnancy rates to AI than the control cows or cows in the 100% inorganic mineral treatment only if estrus was observed in the cow, mass breeding showed no differences. Though both Stanton et al. (2000) and Ahola et al. (2004) reported greater pregnancy rates to AI breeding due to the organic mineral treatments, neither reported or speculated a possible reason that only pregnancy to AI breeding was affected by the treatment. Arthington and Swenson (2004) conducted an experiment using 160 Braford cows over a three year period where S antagonism was present. Cows were assigned to one of four treatments, which included a treatment using organic forms of Cu, Zn, and Mn supplement and an inorganic form of Cu, Zn, and Mn. The other two treatments compared free choice versus hand fed supplementation. The results indicated that the organic forms of Cu, Zn, and Mn did not overcome the S antagonism and cows supplemented with the organic minerals actually had a lower hepatic concentration of Cu after the winter feeding periods than those cows fed inorganic minerals. Zinc and Mn concentrations did not differ regardless of which type of mineral the cattle were fed. Over the course of the trial it was determined that mineral source had no effect on cow BW, cow BCS, or calf weaning weight. However, pregnancy rates were higher in year two ($P < 0.05$) and calving intervals were shorter in years one and three for young cows that were fed the organic forms of Cu, Zn, and Mn, but older cows did not differ regardless of mineral type or source.

Summary

It seems that the single largest factor in obtaining the desired levels of Cu, Zn, and Mn concentrations within cattle is the amount of minerals ingested in the diet regardless of form, be it organic or inorganic (Suttle, 2010). There have been those who, through poor trial design have fed higher levels of organics and compared measures to treatments fed low levels of inorganic minerals, which have given misleading results to indicate that organic forms of minerals will always result in better mineral nutrition (Suttle, 2010). Even in well designed experiments, the apparent difference in absorption and availability of Cu, Zn, and Mn by organic vs. inorganic forms is highly variable and inconsistent (Suttle, 2010). Kegley and Spears (1994) determined that oxide forms of minerals are far less available than sulfate forms, which could add to the inconsistent results between bio-availability of organic and inorganic mineral forms as there is not consistency in availability within inorganic forms. Supra natural levels have been imposed for short specified periods of time and have resulted in positive responses in reproduction (Stanton et al., 2000), but effects are often short lived (Edmiston and Bull, 1988 and Woods et. al, 1989). Interactions with some macro minerals, such high levels of Ca inhibiting Mn absorption (Tuormaa, 1996) or the antagonistic relationship between Cu and S, Mo and Fe (Suttle, 1974) effect the needed levels of trace minerals in the diet. The general conclusion among well designed experiments seems to indicate that organic forms of minerals tend to improve growth, feedlot performance, immunity, and reproductive aspects particularly in young cattle under specific circumstances such as the presence of high levels of antagonists, depleted or physically stressed animals, and those that are nutritionally stressed. This indicates that supplementation with organic forms of minerals may be more beneficial under the aforementioned circumstances.

MATERIALS AND METHODS

Objectives

The objectives of this research were to determine if heifers supplemented with an organic, methionine chelated form of Cu, Zn, and Mn would gain at a different rate or with differences in efficiency in the feedlot and if pregnancy rates would be greater than heifers supplemented with an inorganic, sulfate form of Cu, Zn, and Mn.

Animals Care and Use

This experiment utilized 2,484 yearling heifers. All research and procedures were in accordance with the ranch protocol on which the animals were housed and all animal handling was conducted in accordance with Beef Quality Assurance guidelines in a humane manner.

Design and Treatments

The experimental design was a randomized block utilizing three blocks (ranches). Two replications of each treatment were applied at each block. Pen was the experimental unit for feedlot performance measures. Performance measures were total gain, ADG, and G:F ratio. Heifer was the experimental unit when comparing pregnancy rates between treatments. This is a similar experimental design to Stanton et al. (2000). Pens of cattle cannot be pregnant, thus the individual heifer must be the experimental unit. This design does not guarantee individual consumption of the treatment diets, but rather guarantees that the diet was offered and available to the heifers. This method will allow the treatment diets to be applied in the most common manner that diets are fed in production settings. Treatment diets were formulated based on NRC (1996) recommendations for heifers to achieve 65% of mature body weight at the time of breeding. The basal diets were silage-based and contained approximately 13.5% CP, 64% TDN (Table 2). When supplements were included diets provided an average of 24 ppm Cu, 70 ppm Zn and 64 ppm Mn per heifer daily (Tables 2 and 3). The NRC (1996) recommended levels for Cu, Zn, and Mn are 10, 40 and 40 ppm, but the levels fed in the experiment are more similar to the industry practice in the region where the experiment was conducted even though there are some scientist who feel the NRC (1996) recommendations are more than adequate (Suttle, 2010). Treatment diets contained very low levels of the antagonists SO_4, Mo, or Fe (Tables 2, 3 and 4).

Table 2**.** Analysis of diets fed to heifers by ranch

Item	Ranch 1	Ranch 2	Ranch 3
CP,%	12.67	13.28	15.20
ADF,%	37.83	25.22	34.78
TDN,%	59.42	67.55	63.95
NE_l, (Mcal/lb)	0.61	0.70	0.61
NE_m, (Mcal/lb)	0.58	0.68	0.64
NE_g, (Mcal/lb)	0.35	0.41	0.36
S, %	0.23	0.23	0.21
P, %	0.30	0.39	0.32
K, %	1.89	1.43	1.50
Mg, %	0.31	0.26	0.31
Ca, %	1.55	0.92	1.53
Na, %	0.18	0.20	0.20
Fe, ppm	309	416	184
Mn, ppm	70	59	64
Cu, ppm	20	23	28
Zn, ppm	62	69	80

Table 3. Analysis of treatment supplements

Item	Ranch 1		Ranch 2		Ranch 3	
	Sulfate	Organic	Sulfate	Organic	Sulfate	Organic
CP, %	22.9	23.2	9.86	9.92	9.86	9.92
Sulfur, %	0.38	0.45	0.27	0.35	0.20	0.27
Phosphorus,%	0.85	1.23	0.54	0.58	0.44	0.38
Potassium,%	1.06	1.17	0.68	0.74	0.57	0.55
Magnesium,%	0.90	0.85	0.29	0.28	0.28	0.25
Calcium,%	5.89	4.93	7.57	7.88	8.09	7.80
Sodium,%	1.03	1.43	1.98	2.59	2.26	2.33
Iron,ppm	359	502	182	321	302	196
Manganese, ppm	510	412	414	507	468	551
Copper, ppm	257	305	300	374	311	373
Zinc, ppm	599	569	550	728	688	747

Table 4. Analysis of water consumed by heifers by Ranch

Item, ppm	Ranch 1	Ranch 2	Ranch 3
Na	9.05	311.0	2.94
Ca	45.8	0.40	65.9
Mg	27.3	0.08	22.0
NO_3-N	0.30	0.00	0.00
SO_4	31.0	1.00	64.0
Fe	0.00	0.10	0.03
Mn	0.00	0.00	0.00
Cl	19.0	41.0	0.00
Cu	0.00	0.00	0.00

The supplements were fed either as a pellet or meal as part of a total mixed ration and were delivered by a mixer-mounted feed truck. All heifers had adequate bunk space with a minimum of fourteen inches at one block and a maximum of twenty four inches at another block. Nine to twelve inches of bunk space is considered to be adequate for growing and finishing cattle in a feedlot (Harner and Murphy, 1998).

Measurements and Collections

Diets (Table 3), supplements (Table 4) and water (Table 5) were analyzed at a commercial laboratory (MidWest Labs, Omaha, NE).

Ranch One, Reminisce Ranch Feedlot

Ranch one was located near Dillon, Montana in the southwestern part of the state. At this ranch 502 Angus heifers were used for the feedlot and performance data collection. Initial BW of heifers was collected on December 11, 2010 (BW 257 kg ± 2.0). Heifers were randomly assigned to pens of approximately 125 head per pen. Pens were randomly assigned treatments. Supplements were fed as part of a total mixed ration via a truck mounted feed mixer (Table 5).

Table 5. Ingredients of diet fed at Ranch 1 (Reminisce Ranch, Dillon, MT)

Item	
Cooked potato silage,%	33
Chopped oat or barley hay,%	30
Chopped alfalfa and grass hay,%	35
Supplement,%	≤2

Heifers had *ad libitum* access to water provided in frost free water dispensers located in each pen. All pens had adequate drainage and were equipped with concrete feed bunks along one wall of the pen to facilitate feed delivery. The heifers remained in the feedlot for 181 d and weighed 341 kg ± 2.6. Some heifers were removed from the experiment after the feedlot phase which left 473 heifers remaining to be used in the reproductive part of the experiment. Heifers in this block were bred just prior to exiting the feedlot via

AI by trained AI technicians and were exposed to bulls starting on June 15, 2011 for approximately 45 days while on range during the summer. After breeding, the heifers were shipped to summer pasture near Fishtail, Montana. Pregnancy diagnosis took place in Fishtail, Montana on August 22, 2011.

Ranch Two, Harding Land and Cattle Co.

Ranch two was located in Terry, Montana in the eastern part of the state. In this block 240 fixed composite (50% Red Angus x 25% Charolais x 25%Tarentaise) heifers were used for the drylot and performance data collection. Heifers were randomly assigned to four pens of 60 head per pen with pens then randomly assigned to treatments. Initial BW of heifers was collected on December 15, 2010 (BW 269 kg ± 2.8). Supplements were fed as part of a total mixed ration via a truck mounted feed mixer (Table 6).

Table 6. Ingredients of diet fed at Ranch 2 (Harding Land and Cattle Co, Terry, MT)

Item	
Corn silage,%	63
Chopped hay,%	20
Cracked corn,%	10
Dried distiller's grain,%	5
Supplement,%	≤2

Heifers had *ad libitum* access to water provided in frost free water dispensers located in each pen. All pens had adequate drainage and were equipped with concrete feed bunks along one wall of the pen to facilitate feed delivery. One fatality occurred during the feedlot phase of the experiment thus 239 heifers completed the feedlot phase of the trial. The heifers remained in the feedlot 149 d and were weighed prior to removal on May 19, 2011 (BW 390 kg ± 3.9). Some heifers were removed from the experiment after the feedlot phase due to sickness or death during the breeding period, leaving 236 heifers to be used in the reproductive part of the experiment. Upon removal from the drylot in Terry, Montana, the heifers were shipped to summer pasture nearby. Heifers in this block were bred natural service by bulls while on range starting on May 20, 2011 for approximately 50 days. A bull to heifer ratio of 1:20 was maintained throughout the breeding season. Pregnancy diagnosis took place at their summer range near Terry, Montana on August 10, 2011.

Ranch 3, Padlock Ranch Co.

Ranch three was located near Dayton, Wyoming just south of the Montana border. In this block 1753 Angus x Composite heifers were used for the feedlot and performance data collection. Initial BW of heifers was collected on February 8-11 and 14, 2011 (BW 295 kg ± 1.5). Heifers were randomly assigned fours pens of 333 to 537 head per pen depending on pen size and pens were randomly assigned treatments. Supplements were fed as part of a total mixed ration via a truck mounted feed mixer (Table 7).

Table 7. Ingredients of diet fed at Ranch 3 (Padlock Ranch Co, Dayton, WY)

Item	
Corn silage,%	64
Chopped hay,%	34
Supplement,%	≤2

Heifers had *ad libitum* access to water provided in frost free water dispensers located in each pen. All pens had adequate drainage and were equipped with concrete feed bunks along one wall of the pen to facilitate feed delivery. By the end of the drylot phase of the trial eleven heifers were removed from the trial due to death or sickness leaving 1,742 total heifers to complete the feedlot phase. Final BW was recorded on d77-81 (348 kg ± 1.6). Upon leaving the feedlot the heifers remained divided by treatment and were placed on pasture immediately adjacent to the feedlot where they continued to receive their assigned mineral supplement while on range until breeding commenced. During this period on pasture heifers within treatments were commingled as logistics did not allow for replications to remain split. While on pasture, mineral supplements were offered to the heifers via mineral feeding stations located within the pastures. The mineral supplements were offered ad libitum while feeders were full of mineral supplements, however, feeders were only filled as needed to allow the same average daily consumption of mineral supplement as was offered in the feedlot. The heifers were then comingled in the feedlot to facilitate breeding. Heifers (BW 400 kg ± 0.0) were bred via AI one service only from July 17-August 1. The heifers were shipped to summer range near Decker, Montana and were not exposed to bulls while on summer range. Some heifers were removed from the experiment after the feedlot phase due to sickness, death, or disappearance while on summer range, leaving 1,621 heifers to be used in the reproductive part of the experiment. Pregnancy diagnosis took place on their summer range on September 12-16, 2011.

Statistical Analysis

For rate and efficiency of gain measurements, ANOVA was performed using Statistix 9 (Analytical Software, Tallahassee, FL) with variables of total gain, ADG, and G:F with treatment being the model statement for each block individually and when all pens in the experiment were combined as whole. Analysis of variance for the 12 total observations (4 pens at 3 ranches) was performed for treatment, ranch and ranch x treatment interaction. Pregnancy differences between treatments for blocks one and two were analyzed using Chi-square with Statistix 9 (Analytical Software, Tallahassee, FL) with counts variable being first cycle bred, row variable being heifer, and column variable being treatment. For pregnancy differences between treatments, Chi-square was performed using SAS (SAS Inc. Cary, NC) for block three analysis and when ranches were combined. Analysis of variance for percentage bred within each treatment was performed with Statistix 9 (Analytical Software, Tallahassee, FL) when ranches were combined to determine ranch effects and ranch x treatment interactions for pregnancy rates.

RESULTS AND DISCUSSION

Ranch One

Feedlot Performance

There were no differences between treatments in feedlot performance. Comparisons were made for gain ($P = 0.91$), average daily gain ($P = 0.92$), and G:F ($P = 0.90$), (Table 8).

Reproductive Performance

Ranch one heifers were bred AI and then were exposed to bulls while on range in the summer. There were no differences between treatments for first service conception rates ($P = 0.47$) or for conception rates overall ($P = 0.48$), (Table 8).

Table 8. Ranch 1(Reminisce Ranch Feedlot) summary of differences in feedlot performance and conception of heifers fed CuMet, ZnMet, and MnMet or $CuSO_4$, $ZnSO_4$, and $MnSO_4$

	Repetition 1		Repetition 2		SE	P-value
Treatment	Sulfate	Organic	Sulfate	Organic		
No. heifers	122	124	129	122		
Days on Test	181	181	181	181		
Initial BW,kg	238	238	264	262	2.03	
End BW,kg	331	328	350	352	2.61	
Gain,kg	93	89	85	90	4.04	0.91
ADG,kg	0.51	0.49	0.51	0.49	0.02	0.92
G:F,kg	0.18	0.16	0.15	0.16	0.05	0.90
% Pregnant	86	89	84	84	0.03	0.48
% Preg 1st 21d	54	56	63	58	0.05	0.47

Ranch Two

Feedlot Performance

There were no differences between treatments in feedlot performance. Comparisons were made for gain ($P = 0.92$), average daily gain ($P = 0.98$), and G:F ($P = 0.93$), (Table 9).

Reproductive Performance

Ranch two heifers were not bred AI but were exposed to bulls while on range during the summer. There were no differences between treatments for conception rates in the first 21 d of the breeding season ($P = 0.46$) or for conception rates overall ($P = 0.47$), (Table 9).

Table 9. Ranch 2 (Harding Land and Cattle Co.) summary of differences in feedlot performance and conception of heifers fed CuMet, ZnMet, and MnMet or $CuSO_4$, $ZnSO_4$, and $MnSO_4$

	Repetition 1		Repetition 2		SE	P-value
Treatment	Sulfate	Organic	Sulfate	Organic		
No. heifers	60	60	59	60		
Days on Test	149	149	149	149		
Initial BW,kg	275	277	262	263	2.82	
End BW,kg	395	401	383	380	4.11	
Gain,kg	121	124	120	118	3.07	0.92
ADG,kg	0.84	0.84	0.82	0.80	0.02	0.98
G:F,kg	0.26	0.27	0.26	0.26	0.01	0.93
% Pregnant	88	88	97	93	0.04	0.47
% Preg 1^{st} 21d	54	44	54	58	0.07	0.46

Ranch Three

Feedlot Performance

There were no differences between treatments in feedlot performance. Comparisons were made for gain ($P = 0.59$), average daily gain ($P = 0.58$), and G:F ($P = 0.63$), (Table 10).

Reproductive Performance

Ranch three heifers were bred AI one service only, for this reason conception in the first 21 d and overall conception are one and the same. There were significant differences between treatments for pregnancy rates ($P = 0.03$), (Table 10). Repetition 1 showed a 6% greater pregnancy rate in heifers supplemented with organic minerals and repetition 2 demonstrated a 4% greater pregnancy rate in heifers supplemented with organic minerals.

Table 10. Ranch 3 (Padlock Ranch Co) summary of differences in feedlot performance and conception of heifers fed CuMet, ZnMet, and MnMet or $CuSO_4$, $ZnSO_4$, and $MnSO_4$

	Repetition 1		Repetition 2		SE	P-value
Treatment	Sulfate	Organic	Sulfate	Organic		
No. heifers	537	410	333	462		
Days on Test	77	77	77	77		
Initial BW,kg	289	290	301	298	1.46	
End BW,kg	342	349	351	349	1.64	
Gain,kg	53	59	50	50	4.49	0.59
ADG,kg	0.72	0.75	0.69	0.67	0.06	0.58
G:F,kg	0.24	0.27	0.22	0.23	0.03	0.63
% Pregnant	57	63	62	66	0.02	0.03

Overall with Ranches Combined

Feedlot Performance

When the three ranches were combined, there were no differences between treatments in feedlot performance. Comparisons were made for gain (P = 0.60), ADG (P = 0.57), and G:F (P = 0.91), (Table 11). Ranch proved to have a highly significant effect for each of the three comparisons of total gain, ADG, and G:F (P<0.001). This indicates that any differences were due to the specific ranch location and not the form of minerals supplemented. There was no significant ranch by treatment interaction detected (P ≥ 0.76).

Table 11. Summary of differences in feedlot performance of heifers fed organic form of Cu, Zn and Mn or SO_4 form of Cu, Zn and Mn.

	Ranch 1		Ranch 2		Ranch 3		SE	P-value Trt[1]	P-value Ranch	P-value R[2] X Trt
Trt	SO_4	ORG[3]	SO_4	ORG	SO_4	ORG				
No. hfs[4]	251	246	120	119	870	872				
DoT[5]	181	181	149	149	77	77				
IBW,kg[6]	249	251	268	270	288	294	2.82			
EBW,kg[7]	341	340	389	391	347	349	4.11			
Gain,kg	91	89	121	121	59	54	4.49	0.60	<0.001	0.88
ADG,kg	0.50	0.49	0.81	0.81	0.76	0.70	0.06	0.57	<0.001	0.76
G:F,kg	0.16	0.16	0.26	0.26	0.23	0.25	0.04	0.91	<0.001	0.85

[1]Trt=treatment
[2]R=Ranch
[3]ORG=organic
[4]hfs=heifers
[5]DoT=days on test
[6]IBW=Initial BW
[7]EBW= BW at end of feeding in the drylot

Reproductive Performance

When the three ranches were combined, there were no significant differences between treatments for number of heifers that became pregnant during the first 21 d of breeding (P = 0.12). There were significant differences between treatments for overall conception rates (P = 0.05), (Table 12). Ranch proved to be an insignificant factor (P = 0.10) in number of pregnancies attributed to the first 21 d of breeding, but was significant for overall pregnancy rate (P < 0.001). This indicates that not only was form of mineral a significant factor in pregnancy rate differences, but also the ranch location. Surprisingly, there was no significant ranch x treatment interaction detected (P ≥ 0.47).

Table 12. Summary of differences in pregnancy rates of heifers fed organic form of Cu, Zn and Mn or SO_4 form of Cu, Zn and Mn.

								P-value		
	Ranch 1		Ranch 2		Ranch 3		SE	Trt[1]	Ranch	R[2] X Trt
Trt	SO_4	ORG	SO_4	ORG	SO_4	ORG				
% Pregnant	85	86	92	91	59	66	0.02	0.05	<0.001	0.47
% P 1st 21d[2]	58	57	54	51	59	66	0.02	0.12	0.10	0.54

[1]ORG=organic
[2]%P 1st 21d=% pregnant in the first 21d of breeding season

Discussion of Results

Feedlot Performance

In this experiment it appears that ranch management is the single biggest factor in any differences in feedlot performance as ranch proved to be of great significance (P ≤ 0.001). The theory that ranch is the most significant factor in feedlot performance under the conditions of this experiment is supported by the fact that there was no ranch x mineral treatment interaction (P ≥ 0.76) and that there were no differences in gains, ADG, or G:F during the feedlot phase of the experiment due to mineral treatment ($P \geq 0.57$). Past organic mineral research has rarely showed positive advantages due to organic minerals in feedlot performance, especially when antagonists were not present. Spears (1989) experiments with lambs and heifers comparing ZnO to ZnMet reported that heifers showed significantly greater gain and better G:F ratio at d 56 of the trial, but by trials end on d 126, gains were similar between the ZnO treatment and the ZnMet treatment. Like this experiment, Nockel et al. (1993) experiment was conducted with no significant levels of antagonists present. And while Nockel et al. (1993) experiment with steers did indicate a greater bioavailability for CuLy over $CuSO_4$, there were no differences in the steer's gains between the two treatments. Ward et al. (1993) study found that when freshly weaned steers were supplemented with either CuLy or $CuSO_4$ both in the presence and absence of S and Mo, early gains were significantly greater for steers fed $CuSO_4$, but by trial conclusion, no significant differences existed between steers supplemented with either CuLy or $CuSO_4$. Rabiansky et al. (1999) determined that in Cu depleted heifers CuLy was more beneficial for repleting hepatic Cu than was $CuSO_4$ when the antagonists Fe, S, and Mo were present, but at trial conclusion it was noted that growth and performance remained constant across treatments. Conversely, Dorton et al. (2002) determined that level and type of Cu supplementation could improve feedlot performance. The results of that experiment indicated that steers fed high levels of Cu from either form of Cu (CuLy or $CuSO_4$) had greater liver Cu, greater gains, greater levels of immunoglobulin G and antibody titers to ovalbumin in the blood. The data also showed that the highest liver Cu, highest gains, and highest antibody titers were found in those steers fed the higher level of organic Cu. While specific instances do exist where supplementation with organic minerals in the feedlot did result in greater or more efficient gains, the majority of the research found similar results to the subject experiment and indicated that form of minerals had no significant effect on feedlot performance in young steers or heifers.

Reproductive Performance

The results of this trial support Suttle's (2010) statement that research has failed to produce consistent advantages due to organic minerals. Two of the three ranches showed no significant differences ($P \geq 0.46$) in pregnancy rates either in the first 21 d or overall, and yet one ranch showed a significantly ($P = 0.03$) greater pregnancy rate (to AI breeding) due to supplementation of organic minerals. Based on prior research (Ahola et al. 2004 and Stanton et al. 2000) it could be speculated that if bulls were introduced as well at Ranch 3, overall conception could possibly have been equal. When ranches were combined, there was a significant difference ($P = 0.05$) due to the supplementation of organic minerals. The ANOVA also indicated that ranch was also a significant ($P \leq 0.001$) factor in overall pregnancy rates. This supports the theory that management at Ranch 3 contributed to the organic mineral's ability to aid in the achievement of greater pregnancy rates to AI breeding. It is surprising, given these statistical data, that there was no ranch x treatment interaction ($P \geq 0.47$). Past research has also produced inconsistent results in regards to organic mineral's effects on pregnancy rates. Stanton et al. (2000) utilized 300 Angus cows in a 209 d trial that started prior to calving where cows were supplemented with three mineral treatments consisting of different levels of inorganic and organic Cu, Zn and Mn. Cattle in the organic mineral treatment exhibited better pregnancy rates to AI ($P < 0.05$) than the other two inorganic treatments, but overall pregnancy rates did not differ. The subject experiment shows some similarities to Stanton et al. (2000) in that Ranch 3 showed a significantly higher pregnancy rate to AI. Ranch 3 was the only ranch among the three utilized in this experiment that used only AI breeding and heifers were only bred one time. While Ranch 3 showed similar results to Stanton et al. (2000), Ranch 1 of the subject experiment also used AI breeding at the beginning of the breeding season and showed no differences ($P = 0.47$) between treatments in the number of pregnancies occurring due to AI. At both Ranch 1 and 2, overall conception did not differ ($P \geq 0.46$) which shows similarity to Stanton et al. (2000). Since Ranch 3 heifers were only bred one time by AI, comparisons between first service pregnancy and overall pregnancy are one and the same. Similarities exist between the subject experiment and research conducted by Ahola et al. (2004) as well. Ahola et al.'s 2004 experiment utilized 178 crossbred cows which were supplemented with either inorganic or a mix (1: 1 ratio) of organic and inorganic forms of Cu, Zn, Mn and Co. In year 1 overall reproductive performance did not differ, but the trend ($P < 0.08$) was for those cows supplemented with the organic mineral mix to have a higher rate of pregnancy when bred by AI. Cows supplemented with the organic mineral mix exhibited a 67% pregnancy rate to AI whereas cows provided with the inorganic minerals demonstrated a 52% pregnancy rate to AI. Like Ahola et al. (2004) experiment, the subject experiment showed greater conception to AI breeding (Ranch 3), but the subject experiment was considered significant ($P = 0.03$) with only 7% difference between treatments and Ahola et al. (2004) showed only a trend ($P = 0.08$). Perhaps the reason for this is that the subject experiment had the statistical power of 1,620 observations whereas the Ahola et al. (2004) experiment had only 110 observations. Stanton et al. (2000) and Ahola et al. (2004) both found no differences in overall pregnancy rates, but the subject experiment results showed significantly greater ($P = 0.05$) overall pregnancy rates due to supplementation of organic forms of Cu, Zn and Mn; however it must be noted that a large percentage of the heifers were only bred one time, which was an AI breeding. In both Ahola et al. (2004) and Stanton et al. (2000) cows were bred by AI and were exposed to bulls as well. There was no reported reason or speculation as to the reason that organic minerals had greater effect on pregnancy due to AI breeding, nor was a reason determined at this point for greater pregnancy rate to AI among heifers supplemented with organic minerals in the subject experiment. Perhaps if Ranch 3 had exposed heifers to bulls, the results would be more similar to prior research.

Further Research

This experiment was conducted in the absence of significant levels of antagonists. The majority of research related to organic minerals where organic minerals have proved more beneficial than inorganic forms has been in the presence of antagonists. A repeat of this study with the introduction of antagonists would be an appropriate sequel to this experiment. Since Ranch 3 proved to have a significant treatment difference and ranch was also a significant factor, the experiment should be repeated at Ranch 3 to ascertain the reason that supplementation with organic minerals resulted in greater pregnancy rates at that location. It is known that there are some areas of Ranch 3 that have a high SO_4 and Mo concentrations which could have possibly resulted in some carryover hepatic SO_4 and Mo that the organic minerals were better able to combat than the sulfate form. The subject experiment indicates strong similarity to Stanton et al. (2000) and Ahola et al. (2004) in that organic minerals appear to aid in greater pregnancy to AI breeding, but there has yet to be a strong conclusion as to the reason why. Further research to answer this question should also be considered.

Implications and Summary

Given the inconsistency of past research (Suttle, 2010) on the effect of form of minerals on feedlot performance and pregnancy rates in cattle, supplementation with organic forms of minerals should not be considered as hyper available or as a guarantor of higher levels of performance (Suttle, 2010). Management remains a key factor in determining the proper mineral supplementation (Greene, 2000) as is supported by the results of this experiment. If greater pregnancy rates can be achieved through the supplementation of chelated minerals, management and economies of scale within the production setting will determine financial feasibility of supplementation as organic forms of minerals cost approximately $200 more per ton than do sulfate forms (Cenex Harvest States, Great Falls, MT, Westfeeds, Inc, Billings, MT and Ranchway Feeds, Fort Collins, CO). While the results of this experiment suggest that feedlot performance may not be enhanced by supplementation of organic minerals in the absence of antagonists, it does indicate that under certain conditions using AI breeding, supplementing heifers with a methionine chelated form of Cu, Zn and Mn may result in increased pregnancy rates in yearling replacement heifers.

REFERENCES CITED

Ahola, J. K., D. S. Baker, P.D. Burns, R.G. Mortimer, R.M. Enns, J.C. Whittier, T.W. Geary and T. E. Engle. 2004. Effect of copper, zinc, and manganese supplementation and source on reproduction, mineral status, and performance in grazing beef cattle over a two-year period. J Anim. Sci. 82:2375-2383.

Ansotequi, R. P., J. D. Bailey, J. A. Paterson, P. G. Hatfield, and C. K. Swenson. 1999. Effects of supplemental trace mineral form of copper on status, estrus, ovulation rate, and fertility in beef heifers. Proc. West. Sec. Amer. Soc. Anim. Sci. 50:189-192.

Arthington, J. D. and C. K. Swenson. 2004. Effects of trace mineral source and feeding method on the productivity of grazing braford cows. Prof. Anim. Sci. 20:155-161.

Arthington, J. D., L. R. Corah and F. Blecha. 1996. The effects of molybdenum-induced copper deficiency on acute-phase protein concentrations, superoxide dismutase activity, leukocyte numbers, and lymphocyte proliferation in beef heifers inoculated with bovine herpesvirus-1. J Anim. Sci. 74:211-217.

Arthington, J. D., A. R. Spell, L. R. Corah and F. Blecha. 1996. Effect of molybdenum-induced copper deficiency on in vivo and in vitro measures of neutrophil chemotaxis both before and following an inflammatory stressor. J Anim. Sci. 74:2759-2764.

Bailey, J. D., R. P. Ansotequi, J. A. Paterson and C.K. Swenson. 2000. Feedlot performance and hepatic trace mineral status of beef heifers previously consuming dietary copper antagonists. Proc. West. Sec. Amer. Soc. Anim. Sci. 51:128-131.

Bailey, J. D., R. P. Ansotequi, J. A. Paterson, C.K. Swenson and A. B. Johnson. 2001. Effects of supplementing combinations of inorganic and complexed copper on performance and liver mineral status of beef heifers consuming antagonists. J Anim. Sci. 79:2926-2934.

Barone, A. O Ebesh, R. G. Harper and R. A. Wapnir. 1998. Placental copper transport in rats: effects of elevated dietary zinc on fetal copper, iron, and metallothionein. J Nutr. 0022-3166/98:1037-1041.

Bellows, R.A., R.E. Short and G.V. Richardson. 1982. Effect of sire, age of dam and gestation feed level on dystocia and post partum reproduction. J Anim. Sci. 55:18.

Bentley, O.G. and P.H. Phillips. 1951. The effects of low manganese rations upon dairy cattle. J. Dairy Sci. 34:396.

Bohman, V. R., E. L. Drake and W. C. Behrens. 1983. Graded levels of copper EDTA and copper glycinate on plasma and liver copper levels in Holstein calves. Proc. West. Sec. Amer. Soc. Anim. Sci. 34:277-279.

Bull, R. C., J. J. Ney and J. D. Mankin. 1986. Evaluation of copper and selenium supplementation on reproductive and growth performance of beef cattle. Proc. West. Sec. Amer. Soc. Anim. Sci. 37:67-70.

Chirase, N. K., D. P. Hutcheson and G. B. Thompson. 1991. Feed intake, rectal temperature, and serum mineral concentrations of feedlot cattle fed zinc oxide or zinc methinonine and challenged with infections bovine rhinotracheitis virus. J. Anim. Sci. 69:4137-4145.

Chirase, N. K., D. P. Hutcheson, G. B. Thompson and J. W. Spears. 1994. Recovery rate and plasma zinc and copper concentrations of steer calves fed organic and inorganic zinc and manganese sources with or without injectable copper and challenged with infections bovine rhinotracheitis virus. J. Anim. Sci. 72:212-219.

Davis, G.K. and W. Mertz. 1987. Copper in W. Mertz (Ed.) Trace elements in human and animal nutrition p. 312. Academic Press. San Diego, California.

Deutscher, G. H., J. R. Johnson, R. J. Emerick, R. E. Moul and D. L. Whittington. 1982. Copper injections and supplementation for range beef cows and calves. Proc. West. Sec. Amer. Soc. Anim. Sci. 33:235-238.

Dorton, K. L., T. E. Engle, D. W. Hamar, P. D. Siciliano, and R. S. Yemm. 2002. Effects of copper source and concentration on performance, copper status, and immune function in growing and finishing feedlot steers. Proc. West. Sec. Amer. Soc. Anim. Sci. 53:515-518.

Eckert, G.E., L.W. Greene, G.E. Carstens and W.S. Ramsey. 1999. Copper status of ewes fed increasing amounts of copper from copper sulfate or copper proteinate. J Anim. Sci. 77:244-249.

Edmiston, F. L. and R. C. Bull. 1988. Evaluation of selenium reticular pellets and injectable copper edentate for yearling replacement heifers. Proc. West. Sec. Amer. Soc. Anim. Sci. 39:111-114.

Ferrell, C. L. 1982. Effects of postweaning rate of gain on onset of puberty and productive performance of beef heifers of different breeds. J Anim. Sci. 55:1272.

Feuz, D.M. Replacement Beef Heifer Economics. 1991. South Dakota Beef Report. South Dakota State University, Agricultural Experiment Station and Cooperative Extension Service. August.

Funston, R. N. and G. H. Deutscher. 2004. Comparison of target breeding weight and breeding date for replacement beef heifers and effects on subsequent reproduction and calf performance. J Anim. Sci. 82:3094-3099.

Funston, R. N. and T. W. Geary. 1999. Optimizing reproductive performance. Accessed Feb.10,2011.http//www.msuanimalrangeextension.montana.edu/articles/beef/.../optimizing.htm

Funston, R. N., J. L. Martin, D. M. Larson and A. J. Roberts. 2011. Nutritional aspects of developing replacement heifers. J Anim. Sci. doi:10.2527/jas.2011-4569.

Gilbert, F. A. 1949. Mineral Nutrition of Plants and Animals. 1st ed. University of Oklahoma Press. Norman, OK.

Gooneratne, S. R., J. V. Bailey, H. W. Symonds and D. A. Christensen. 1987. Effect of dietary Cu, Mo, and S levels on bile and urine Cu excretion in breeds of cattle. Can, J. Anim. Sci. 67:1188 (Abstr.).

Greene, L. W. 2000. Designing mineral supplementation of forage programs for beef cattle. Proc. An. Soc. Anim. Sci.

Harner III, J. P. and J. P. Murphy. 1998. Planning cattle feedlots. Kansas State University Extension. MF-2316.

Hatfield, P. G., C. K. Swenson, R. W. Kott, R. P. Ansotequi, N. J. Roth, and B. L. Robinson. 2001. J Anim. Sci. 79:261-266.

Henry, P. R., C. B. Ammerman and R. C. Littell. Relative bioavailability of manganese from a manganese-methionine complex and inorganic sources for ruminants. 1992. J Dairy Sci. 75:3473-3478.

Hidiroglou, M. 1975. Manganese uptake by the ovaries and reproductive tract of cycling and anestrous ewes. Can. J Physiology and Pharmacology. 53:969-972.

Kegley, E.B. and J.W. Spears. 1994. Bioavailability of feed-grade copper sources (oxide, sulfate, or lysine) in growing cattle. J Anim. Sci. 72:2728-2734.

Kincaid, R.L., R.M. Blauwiekel, and J.D. Cronrath. 1986. Supplementation of Copper Sulfate or Copper Proteinate for Growing Claves Fed Forages Containing Molybdenum. J Dairy Sci. 69:160-163.

Lesmeister, J.L., P.J. Burfening and R.L. Blackwell. 1973. Date of first calving in beef cows and subsequent calf production. J Anim. Sci. 36:1-6.

Manspeaker, J. E., M. G. Robl, G. H. Edwards and L. W. Douglass. 1987. Chelated minerals: The role in bovine fertility. Vet. Med. 82:951-952.

Miller, W. J. Zinc nutrition of cattle: a review. 1970. J Dairy. Sci. 53:1123-1135.

Nockels, C.F., J. DeBonis and J. Torrent. 1993. Stress induction affects copper and zinc balance in calves fed organic and inorganic copper and zinc sources. J. Anim. Sci. 71:2539-2545.

Nutrient Requirements of Beef Cattle 7th Revised Edition, 1996. National Academy Press. Washington D.C.

Olson, P. A., D. R. Brink, D. T. Hickok, M. P. Carlson, N. R. Schneider, G. H. Deutscher, D. C. Adams, D. J. Colburn and A. B. Johnson. 1999. Effects of supplementation of organic and inorganic combinations of copper, cobalt, manganese, and zinc above nutrient requirement levels on postpartum two-year-old cows. J Anim. Sci. 77:522-532.

Orent, E.R. and E.V. McCollum. 1932. The estrual cycle in rats on a manganese-free diet. J. Biol. Chem. 98: 101-102.

Paterson, J.A. and T.E. Engle. 2005. Trace mineral nutrition in beef cattle. Nutr. Conf. Univ. Tenn., Knoxville, TN.

Patterson, D. J., R. C. Perry, G. H. Kiracofe, R.A. Bellows, R.B. Staigmiller and L.R. Corah. 1992. Management considerations in heifer development and puberty. J Anim. Sci. 70:4018-4035.

Pinchak, W.E., D.R. Tolleson, M. Mcloy, L.J. Hunt, R.J. Gill, R.J. Ansley and S.J. Bevers. 2004. Morbidity effects on productivity and profitability of stocker cattle grazing in the Southern Plains. J Anim. Sci. 82:2773-2779.

Rabiansky, P. A., L. R. Mcdowell, J. Velasquez-Pereira, N. S. Wilkinson, S. S. Percival, F. G. Martin, D. B. Bates, A. B. Johnson, T. R. Batra and E. Salgado-Madriz. 1999. Evaluating copper lysine and copper sulfate sources for heifers. J Dairy Sci. 82:2642-2650.

Shim, H. and Z. L. Harris. 2003 Genetic defects in copper metabolism. J Nutr. 133:1527S-1531S.

Short, R. E. and R. A. Bellows. 1971. Relationships among weight gains, age at puberty and reproductive performance in heifers. J Anim. Sci. 32(1):127-131.

Short, R. E., R. B. Staigmiller, R. A. Bellows and R. C. Greer. 1990. Breeding heifers at one year of age: Biological and economic considerations. In: Proc. 39th Annu. Beef Cattle Short Course. Pp93-106. Univ of Florida, Gainesville.

Spears, J. W. 1989. Zinc methionine for ruminants: relative bio-availability of zinc in lambs and effects of growth and performance of growing heifers. J Anim. Sci. 67:835-843.

Spears, J. W. 2003. Trace mineral bioavailability in ruminants. J Nutr. 133(5):1506S-1509S.

Stabel, J. R., J. W. Spears and T. T. Brown, Jr. 1993. Effect of copper deficiency on tissue, blood characteristics, and immune function of calves challenged with infectious bovine rhinotracheitis virus and Pasteurella hemolytica. J Anim. Sci. 71:1247-1255.

Stanton, T.L., J.C. Whittier, T.W. Geary, C.V. Kimberling and A.B. Johnson. 2000. Effects of trace mineral supplementation on cow-calf performance, reproduction, and immune function. Prof. Anim. Sci. 16:121-127.

Suttle, N.F. 1974. Effects of organic and inorganic sulphur on the availability of dietary copper to sheep. Br. J. Nutr. 32:559.

Suttle, N.F. 1974. Recent studies of the copper-molybdenum antagonism. Proc. Nutr. Soc. 33:299.

Suttle, N.F. 1991. The interaction between copper, molybdenum, and sulfur in ruminant nutrition. Annual Review of Nutrition. 11:121.

Suttle, N.F. and D. G. Jones. 1989. Recent developments in trace element metabolism and function: trace elements, disease resistance and immune responsiveness in ruminants. J. Nutr. 119:1055.

Suttle, N.F. 2010. Mineral Nutrition of Livestock. 4th. ed. CAB International. Oxforshire, UK. P284, 545.

Taylor, R. E. and T. G. Fields. 1998. Scientific Farm Animal Production. 6th. ed. Prentice Hall. Upper Saddle River, NJ.

Tuormaa, T. E. The adverse effects of manganese deficiency on reproduction and health: a literature review. 1996. J. Orthomolecular Med. 11:69-79.

Underwood, E. J. 1971. Trace Elements in Human and Animal Nutrition. 3rd. ed. Academic Press. New York, NY.

Vierboom, M. M., T. E. Engle, P. D. Sciliano, and C. V. Kimberling. 2002. Effects of gestational status on apparent absorption and retention of copper and zinc in cows and ewes. Proc. West. Sec. Amer. Soc. Anim. Sci. 53:519-522.

Waddell, J., H. Steenbock and E. B. Hart. 1931. Growth and reproduction on milk diets. J. Nutr. 4:53-65.

Ward, J.D., J.W. Spears and G.P. Gengelbach. 1995. Differences in copper status and copper metabolism among Angus, Simmental, and Charolais cattle. J Anim. Sci. 73:571-577.

Ward, J.D., J.W. Spears and E.B. Kegley. 1993. Effect of copper level and source (copper lysine vs copper sulfate) on copper status, performance, and immune response in growing steers fed diets with or without supplemental molybdenum and sulfur. J. Anim. Sci. 71:2748-2755.

Wellington, B.K., J.A. Paterson, C.K. Swenson, R.P. Ansotequi, P.G. Hatfield and A.B. Johnson. 1998. The influence of supplemental copper and zinc on beef heifer performance and changes in liver copper. Proc. West. Sec. Amer. Soc. Anim. Sci. 49:323-326.

Woods, L. B., J. R. Carpenter, C. H. Campbell, and J. C. Nolan, Jr. 1989. Oral vs. oral plus injectable copper supplementation of beef cattle grazed on high molybdenum, copper deficient pasture. Proc. West. Sec. Amer. Soc. Anim. Sci. 40:272-276.