EFFECT OF COPPER LEVEL AND ZINC LEVEL AND SOURCE ON FINISHING CATTLE PERFORMANCE AND CARCASS TRAITS

By

LEVI JOEL MCBETH

Bachelor of Science
Kansas State University
Manhattan, Kansas
1997

Master of Science
University of Arkansas
Fayetteville, Arkansas
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Dissertation Approved:

Dr. Clint Krehbiel - Dissertation Adviser

Dr. Donald R. Gill

Dr. Gerald W. Horn

Dr. Hebbie T. Purvis

Dr. James A. Breazile

Dr. A. Gordon Emslie - Dean of the Graduate College

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NOMENCLATURE

ADF	acid detergent fiber
ADG	average daily gain
BW	body weight
^{o}C	degrees centigrade
CP	crude protein
DM	dry matter
DMI	dry matter intake
DOF	days on feed
GF	gain:feed ratio
HCW	hot carcass weight
KPH	kidney, pelvic and heart fat
MP	metabolizable energy
NEm	net energy for maintenance
NEg	net energy for gain
QG	quality grade
REA	longissimus muscle area

YG	yield grade
cm	centimeter
d	day
h	hour
kg	kilogram

CHAPTER I

INTRODUCTION

Zinc (Zn) and copper (Cu) are both transition molecules positioned at number 29 and 30, respectively, in the periodic table of elements. Zinc, first identified as an essential nutrient for animals in 1934 (Pond et al., 1995), is widely utilized in biologic systems in cell proliferation, particularly for protein and nucleic acid synthesis (Underwood, 1977). Similarly, Zn is a constituent of a wide variety of metalloenzymes that include carbonic anhydrase, alkaline phosphatase and pancreatic carboxypeptidase, as well as a cofactor in several proteolytic enzymes, and is a binding component in the storage of insulin (Underwood, 1977; Aspinwall et al., 1997). Because Zn is necessary for formation of proteins (Pond et al., 1995), it has been implicated as a requirement for proper function of both growth hormone and insulin-like growth factor-1 (MacDonald, 2000). Zinc is absorbed throughout the small intestine at 5 to 40% of intake, and absorption is regulated by the enterocyte (Pond et al., 1995). Deficiency of Zn is generally characterized by growth retardation (Underwood, 1977; Pond et al., 1995) postulated to be caused by a decrease in thymidine kinase activity and subsequent DNA synthesis and cell division (Underwood, 1977). This phenomenon is explained very well by Underwood (1977), and it is also suggested that this can be further exacerbated by the reduction in appetite common with Zn deficiency in laboratory animals.

Copper, first identified as an essential nutrient in 1928 (Pond et al., 1995), is also utilized in a wide variety of physiological functions such as immune response, lipid metabolism, oxidative stress, cardiovascular disorders and glucose metabolism (Davis and Mertz, 1987). Both Cu and Zn have been implicated in the impairment of keratinization during deficiency (Underwood, 1977; Davis and Mertz, 1987), and hence the formation of hair, fur, wool and skin, which is the first line of defense for the immune system.

Supplementation of Zn and Cu has been implicated as advantageous in a wide range of beef production settings. The purpose of the research conducted for the present dissertation was to evaluate the effects of Cu level and Zn level and source on performance and carcass merit of cattle fed high-concentrate diets.

CHAPTER II

REVIEW OF LITERATURE

Zinc and Copper Status

Knowledge of mineral status is important for any study designed to evaluate the effects of the mineral(s) in question. Measurement of Zn and Cu status has focused primarily on blood and hepatic indices of Zn and Cu concentration. While hepatic Cu concentration is influenced by dietary Cu levels and specific disease factors, modifications of dietary Zn cause only small changes in hepatic Zn concentration (Cousins, 1985). Although the previous statement is characteristic of hepatic Cu and Zn for nonruminant species, aspects of hepatic mineral concentrations may differ for ruminants.

The liver cytosol contains Zn- and Cu-binding proteins (Underwood, 1977). Ruminants appear to have a high capacity to bind Cu in the liver, as well as a low capacity for excretion (NRC, 1996). Consequently, blood Cu levels do not rise in ruminants in response to the same extent as in rats (Davis and Mertz, 1987). This fact is important to understand in experimental settings where blood levels are neither borderline for deficiency nor toxicity. However, Cu concentrations consistently below 0.6 μg/mL in whole blood or plasma are generally considered indicative of Cu deficiency in cattle and sheep. Zinc is also largely stored for metabolism in the liver. While

measurements of blood or plasma Zn concentrations change reflective of oral Zn intake, their reliability as an index of Zn status is suspect, similar to Cu (NRC, 1996).

Both Zn and Cu absorption are affected by dietary levels, and hence Zn and Cu status are influenced by diet. When Zn and Cu status are low uptake is increased (Underwood, 1977; Davis and Mertz, 1987). When Cu and Zn are needed by peripheral tissues they are released from the liver bound primarily to ceruloplasmin and albumin (Cousins, 1985). Efflux of Cu and Zn from the liver depends specifically on intracellular factors that might favor retention of Cu and Zn within the cells, and the availability of ligands circulating to bind with these minerals from the liver (Cousins, 1985). It is not clear which ligands are responsible for control of these changes, but albumin and amino acids in response to muscle catabolism have been implicated for Zn (Cousins, 1985). In addition, glucocorticoids exert control over Cu metabolism. Glucocorticoids increase Cu uptake by liver cells and increase Cu excretion from the liver bound to ceruloplasmin (Cousins, 1985).

Immune Function

Zinc has long been implicated in parakeratosis in animals reared in practical feeding operations, and likely led to intensive research of minerals in animal nutrition (Lueke, 1966). Zinc and copper have been shown to play a major role in disease resistance and immune responsiveness in stressed feeder cattle. For example, Chirase et al. (1994) found that an organic source of Zn reduced the recovery time for cattle challenged with an infectous bovine rhinotracheitis virus (**IBRV**). Moreover, Ward and Spears (1997) showed that supplemental Cu (5 mg/kg of dry matter [**DM**]) increased DM

intake (**DMI**) during the receiving period, which is a critical time for shipping stressed calves. During this receiving period it is imperative that calves are stimulated to establish adequate DMI. Cole (1996) stated that although proper nutrition cannot prevent infection, proper nutrition can decrease the adverse effects of stress and enhance recovery from stressful periods. Both Zn and Cu have been implicated in basic operation of immune function.

Zinc. Because Zn is required by more than 200 enzymes as a functional component, and these enzymes affect most metabolic processes (MacDonald, 2000), it is inherent that function of the immune system will be affected by Zn status. Protein formation is imperative for adequate immune status in times of infection for production of antibodies, lymphocytes and acute phase proteins. Zinc is associated with the process of protein formation via the Zn finger domains that are used in the formation of a bridge between cysteine and histidine residues in the process of binding to specific DNA sequences (MacDonald, 2000).

Zinc requirement for growth is listed by the NRC (1996) as 30 mg Zn/kg of DM; however, this requirement may be increased during stress to 75 to 100 mg Zn/kg of DM (NRC, 1996). Orr et al. (1990) reported that serum Zn concentration decreased in response to market-transit stress and to challenge with IBRV. While the decrease in serum Zn concentration corresponded with a reduction in DM (and thus Zn) intake that commonly occurs during periods of stress or infection, the decrease in serum Zn concentration after IBRV challenge was still present when DMI was held constant. Similar results were reported by Chirase et al. (1990, 1994), who reported lower serum Zn concentrations in response to IBRV challenge with both organic and inorganic Zn

sources. In contrast, Nockels et al. (1993) reported an increase in serum Zn concentration when stress was simulated by administration of ACTH (every 8 h for 72 h) and removal of feed and water for 36 h. The increase in serum Zn concentration, in contrast to previous work, was postulated to be caused by increased Zn released from catabolized muscle during the fasting period (Nockels et al., 1993). During this period of elevated stress, when the requirement for Zn appears to be slightly elevated, retention of ingested Zn appears to be lowered. Nockels et al. (1993) reported that although there was lower urinary and fecal excretion of Zn, retention of Zn was negative when fasting was followed by ACTH-induced stress. These experimental conditions were designed to simulate those encountered by feeder calves that are purchased and transported to growing or finishing facilities. The consequences of this type of management are not only a removal of feed and water, but also an increase in stress incurred by the animal, which could lead to increased morbidity and the need for increases in at least dietary Zn concentrations, if not absolute Zn requirements.

It has been reported that during the acute phase response Zn is redistributed from the plasma to the liver and to lymphocytes (Beisel, 1995). Zinc has been postulated to reduce localized infections via its high concentration in mucosal secretions, and during deficiency, barrier and nonspecific immunity are compromised (Shankar and Prasad, 1998). Nonspecific immunity can be of great importance in respiratory infection of stressed cattle due to the manifestation of infection via binding of viruses in the upper pulmonary tract. These viruses subsequently cause damage to the pulmonary epithelium allowing potential bacterial pathogens access to the lung (Griffin, 1996). In humans, Zn has been directly implicated in inhibiting the binding of the common cold virus to the

upper respiratory epithelium (Novick et al., 1996). This is accomplished by administration of either Zn lozenges or nasal spray. Zinc ions bind to the virus at the sites it would normally bind to the epithelium, and reduces the viruses' ability to bind to the epithelium (Novick et al., 1996). In steers, Galyean (1995) reported supplementation with 100 mg Zn/kg of DM from organic or inorganic sources resulted in half as many steers treated for BRD than those receiving 30 mg Zn/kg of DM from $ZnSO_4$, or those receiving 65 mg Zn/kg of DM (30 mg Zn/kg of DM from $ZnSO_4$ plus 35 mg Zn/kg of DM from Zn methionine). Similarly, Kegley et al. (2001) reported that calves fed 360 mg of supplemental Zn/d had greater response to intradermal injection of phytohemagglutinin (**PHA**), suggesting greater cell-mediated immune response. Engle et al. (1997) also observed greater response to PHA when calves were fed 40 mg Zn/kg of DM (from $ZnSO_4$) vs.17 mg Zn/kg of DM (from the basal diet).

Copper. Similar to Zn, Cu has been implicated in the effectiveness of immunity. Copper has been suggested to have a strong anti-inflammatory effect (Davis and Mertz, 1987) and to support the integrity of the host defense system (Failla and Hopkins, 1998). Ceruloplasmin is a Cu-containing acute phase protein whose secretion is increased by infection, inflammation, and ACTH and, it has been postulated to assist in oxidative stress (Cousins, 1985). Due to the role of ceruloplasmin in Cu transport, it may play an important role in transport of Cu to inflammation sites for use as an antioxidant to prevent tissue damage (Stabel et al., 1993). Stabel et al. (1993) reported lower ceruloplasmin activities in preruminant calves fed a milk replacer with < 1.0 mg Cu/kg of DM during a 30-d challenge period with IBRV and *Mannheimia haemolytica*. Another Cu-containing enzyme of oxidative importance is Cu, Zn-superoxide dismutase

(**CuZnSOD**). This enzyme catalyzes superoxide radicals to the less oxidative hydrogen peroxide molecule and hence lessens the oxidative burden (Fridivich, 1975). Normal respiration and the activity of phagocytic leukocytes increase the accumulation of superoxide radicals and SOD becomes important in reducing the damage to tissue that occurs during inflammation (Arthington, 1996). Stabel et al. (1993) reported decreased liver CuZnSOD activity in calves supplemented with milk replacer that contained < 1.0 mg Cu/kg of DM vs. Cu supplemented controls after a 30-d disease challenge.

An early sign of Cu deficiency is neutropenia (Percival, 1995), in which the number of neutrophils are reduced in the circulating blood. This can be of great importance because neutrophils are important for innate cell mediated immunity and initiating the inflammatory response, particularly in response to bacterial infection (Parham, 2000). In contrast, Arthington et al. (1996) reported increased neutrophil numbers in response to bovine herpes virus-1 challenge in heifers supplemented with adequate levels of Mo to reduce Cu status, suggesting that even in periods of compromised Cu status, immune challenge will increase neutrophil concentration. Impairment of immunity has been observed in humans when indexes of Cu status are normal (Percival, 1998). Similar situations exist in cattle when liver and blood indexes of Cu status are normal, but immune function on some level is impaired. Xin et al. (1991) reported decreased bactericidal capacity of polymorphonuclear neutrophils when Cu status was decreased by Mo and S addition to the diet. Polymorphonuclear neutrophils are among the most important phagocytes for defending the body against pathogenic microorganisms, and a reduction in Cu status can lead to increased susceptibility to disease (Xin et al., 1991).

While plasma Zn concentration is decreased in periods of immune challenge or stress, the opposite appears to be true for Cu. Serum Cu has been reported to increase in response to disease challenge (Orr et al., 1990; Nockels et al., 1993; Chirase et al., 1994) and in steers that had experienced market-transit induced stress (Ward and Spears, 1999). These increases in serum Cu concentrations are likely due to the increase in ceruloplasmin and neutrophils that are present in the early stages of infection.

Effects on Growth Performance – Zinc

In addition to their positive effects for stressed cattle, Zn and Cu have been shown to influence performance of finishing cattle. While it is common place for nutritionists to formulate supplements with Zn and Cu concentrations that exceed those suggested by the 1996 NRC for both receiving and finishing cattle (Galyean, 2002), reported results for performance variables with these supplementation strategies are inconsistent. As previously discussed, a relatively strong case has been made for Cu supplementation above recommended levels for enhancing immune function. Supplementation of Zn above NRC (1996) appears to be due to the perceived performance or carcass advantages that can be gained.

The NRC (1996) recommends 30 mg Zn/kg of DM consumed to satisfy requirements in most situations. In situations that compare Zn deficient diets to controls or Zn repleted diets, there is generally a noticeable increase in DMI with Zn adequate diets or increased Zn levels in the diet for laboratory animals (Underwood, 1977). This response, however, is not consistently observed in ruminants. Several authors have reported no difference in DMI over a wide range of Zn concentrations and sources when

fed in pen-fed situations (Greene et al., 1988; Spears, 1989; Berrie et al., 1995; Engle et al., 1997; George et al., 1997). Beeson et al. (1977) reported increases in DMI with supplemental Zn (0, 20, 40, 60, and 80 mg Zn/kg of DM) when cattle were fed on an individual basis, but no difference when cattle were group fed (0, 20, 60, 140, 320, and 600 mg Zn/kg of DM). Malcolm-Callis et al. (2000) reported a linear decrease in DMI with Zn concentrations from $ZnSO_4$ at 20, 100, and 200 mg Zn/kg of DM, and higher intakes of DM when Zn methionine was fed vs. Zn polysaccharide complex during the initial 28-d of the feeding period. When steers were fed Zn, Cu, Mn, and Co at 1 and 1.5 times the NRC (1996) recommendations from organic minerals (Availa-4®, Zinpro, Eden Prairie, MN), or 1.5, 3 and 6 times the NRC (1996) recommendations from inorganic sources, DMI was decreased only when these minerals were fed at 6 times the recommended level (Rhoads et al., 2003). This instance was also present during the first 28-d of the feeding period when cattle should be at the greatest risk for respiratory infection (Rhoads et al., 2003). The link to supplemental Zn source and stress or immune challenge is further illustrated by Chirase et al. (1991, 1994). When steers were fed ZnO versus Zn methionine and challenged with IBRV, the decrease in DMI due to challenge with IBRV was lesser for steers supplemented with Zn methionine than for steers fed ZnO (Chirase et al., 1991; Chirase et al., 1994). Longer-term differences in DMI were reported by Galyean et al. (1995) when steers were fed control (30 mg Zn/kg from ZnO), control + 35 mg Zn/kg from Zn methionine, control + 70 mg Zn/kg from $ZnSO_4$, or control + 70 mg/kg Zn from Zn methionine. The authors noted greater DMI throughout the finishing period for all Zn supplemented treatments vs. controls (Galyean et al., 1995). The maintenance of Zn intake is particularly important in the initial phase of the

feeding period and coincides with intake responses when stress or illness is prevalent, leading to an assumption of better health status due either to increased DMI or more closely meeting the absolute requirement for Zn. The maintenance of greater intakes throughout the finishing period seems to be harder to explain and much less consistent in its occurrence.

Average daily gain (**ADG**) has also met with inconsistency when measured over a range of Zn levels and sources. Several authors have reported no differences for body weight (**BW**) or ADG over a range of Zn concentrations and sources and production situations (Beeson et al., 1977; Pond, 1983; Green et al., 1988; Berrie et al., 1995; Engle et al., 1997; Rhoads et al., 2003). Few authors have reported significant differences for ADG that last the entire feeding period attributable to Zn source or concentration. In a series of trials, Perry et al. (1968) reported greater ADG in steers fed ZnO supplemented diets (ranging from 124 to 346 mg Zn/kg of diet) vs. control diets with no supplemental Zn (ranging from 18 to 29 mg Zn/kg of diet) for feeding periods ranging from 84 to 202 d. In contrast, in an effort to define toxicity of Zn, Ott et al. (1966) reported a linear decrease in ADG with supplemental ZnO at 100, 500, 900, 1,300, 1,700, and 2,100 mg Zn/kg of diet. Similarly, Malcolm-Callis et al. (2000) reported a linear decrease in ADG when Zn was supplemented at 20, 100, or 200 mg Zn/kg of DM from $ZnSO_4$.

Several authors have reported increases in BW and ADG in the initial portion of the feeding period, which could speak to the enhanced immune status of experimental animals and a potential decrease in maintenance energy requirements. Kegley et al. (2001) reported greater ADG for calves supplemented with a Zn amino acid complex vs. $ZnSO_4$ or no supplemental Zn from d 14 to 28 of a receiving study. Spears (1989)

reported higher ADG from d 0 to 56 of a 126-d feeding period for heifers supplemented with ZnO or Zn methionine at 25 mg Zn/kg of DM (basal diet contained 23.8 mg Zn/kg of DM). In a study comparing level and source of Zn supplementation, Galyean et al. (1995) reported no difference in ADG during the receiving period (28 d) or the finishing period (161 d), but differences were noted when cattle were changed from a 65% concentrate diet to a 90% concentrate diet during the step-up protocol. Steers that were supplemented with 70 mg Zn/kg of DM (from $ZnSO_4$ or Zn methionine) had greater ADG than controls or those supplemented with 35 mg Zn/kg of DM from $ZnSO_4$ (Gaylean et al., 1995). The same steers that experienced increased ADG experienced half as much morbidity as those supplemented at lower levels of Zn concentration in the diet (Galyean et al., 1995). Malcolm-Callis (2000) reported that steers supplemented with a Zn amino acid complex had greater ADG than those that consumed a Zn polysaccharide complex during the last 15 d of the feeding period. Although not significant, Zn amino acid complex diets elicited 24% greater ADG than diets containing $ZnSO_4$ (Malcolm-Callis, 2000). This increase in weight gain late in the feeding period could be linked to the ability of Zn to increase uptake of insulin-dependent metabolites (Shisheva et al., 1992; Xioa-han et al., 2001), and the reduction in insulin sensitivity that occurs with increasing age, degree of fatness, and BW (Eisemann et al., 1997).

A large body of research has been conducted in murine models in an effort to define the interaction of Zn and insulin with respect to uptake of substrates by adipocytes. Sensitivity to insulin decreases in beef cattle with increasing age and fatness (Eismann et al., 1997), and could contribute to decreased gain efficiency typically observed in the late portion of the finishing phase. Interestingly, Droke et al. (1993) reported serum insulin

levels were lowered in lambs fed a Zn deficient diet. Insulin stimulates fatty acid synthesis by two direct mechanisms: increasing glucose transport through the cell membrane, and decreasing activity of hormone sensitive lipase (Beitz, 1993). Recently, Zn has been shown to increase the uptake of glucose and lipogenesis in murine models in vitro (Shisheva et al., 1992; Tang and Shay, 2001). Shisheva et al. (1992) reported that the combination of Zn and insulin in media preparations exhibited an additive effect on glucose incorporation into lipids. Additionally, Zn was effective in stimulating glucose oxidation by both glycolysis and the pentose phosphate pathway (Shisheva et al., 1992). Zinc appears to circumvent some effects of lowered insulin sensitivity in streptozocin induced diabetic rats by increasing glucose conversion into lipids to a greater degree than can be attributed solely to insulin (Shisheva et al., 1992). Ilouz et al. (2002) reported that Zn ions at physiological concentrations (~15 μM) act as uncompetitive inhibitors of glycogen synthase kinase -3β, which attenuates insulin signaling, and further suggested that the increased glucose uptake is likely mediated through the insulin sensitive transporter GLUT 4. Therefore, the insulin mimetic action of Zn substantiates the additive effect of Zn on increased fat deposition where glucose is a major precursor to fat synthesis in the adipocyte in the nonruminant.

Similar to ADG, diverse results have been reported for Zn levels and sources in reference to measurements of gain efficiency. Several authors have reported no differences is gain efficiency over a range of Zn levels and sources (Beeson et al., 1977; Greene et al., 1988; Berrie et al., 1995). In contrast, Rhoads et al. (2003) reported greater kg ADG/kg DMI (gain efficiency) over the entire feeding period for steers that were fed inorganic mineral sources at 1.5 and 3 times NRC (1996) recommendations vs. those fed

inorganic mineral sources at NRC (1996) recommended levels. The same authors noted no difference between organic and inorganic mineral sources fed at 1.5 times NRC (1996) recommendations (Rhoads et al., 2003). Spears (1989) reported greater gain efficiency in response to Zn supplementation during the first 56 d, and that heifers supplemented with Zn methionine had lower plasma urea N concentrations than animals consuming ZnO on d 42. The author suggested greater utilization of amino acids by heifers consuming Zn methionine as a potential cause for increased gain efficiency, but could not attribute this phenomenon strictly to Zn suggesting that increased dietary methionine might also elicit this response (Spears, 1989). Malcolm-Callis et al. (2000) reported a linear increase in gain efficiency from d 56 to 84 as Zn concentration increased in the diet (20, 100, 200 mg Zn/kg of DM from $ZnSO_4$), and increased gain efficiency from d 112 to 126 for steers fed a Zn amino acid complex vs. $ZnSO_4$. Interestingly, fat thickness for steers supplemented with Zn amino acid complexes was greater than for steers supplemented with $ZnSO_4$ (Malcom-Callis et al., 2000). Although inconsistent, performance results in response to Zn source and level appear to be evident at either the beginning or the end of the feeding period. These results suggest that performance enhancement near the beginning of the feeding period are likely linked to enhanced immune status during stress or disease challenge, and the associated decrease in maintenance energy requirement. Conversely, the increase in performance, particularly gain efficiency, near the end of the feeding period might be linked to increased substrate utilization for fat deposition.

Effects on Carcass Merit – Zinc

The effects of Zn on carcass characteristics have met with more consistent results. Although Zn is highly involved in protein synthesis, the majority of carcass results with increasing dietary Zn concentration or availability suggests that Zn has the greatest effect on fat deposition. Galyean et al. (1995) reported no differences in carcass characteristics when cattle were fed no supplemental Zn, 35 mg Zn/kg of DM from Zn methionine or 70 mg Zn/kg of DM from either $ZnSO_4$ or from Zn methionine. However, Malcolm-Callis (2000) reported greater external fat and yield grade for steers fed 20 vs. 100 mg Zn/kg of DM, and greater kidney, pelvic and heart fat (**KPH**) and external fat for calves fed organic (Zn amino acid complex and Zn polysaccharide complex) vs. those fed $ZnSO_4$ with no effects on intramuscular fat deposition. Greene et al. (1988) and Spears and Kegley (2002) reported increases in marbling and external fat thickness when organic Zn vs. control was fed. Although ZnO and Zn methionine are apparently absorbed at similar rates (Spears, 1989), there appears to be differences in the way organic and inorganic sources of Zn are metabolized. Spears (1989) reported that there was lower urinary excretion of Zn and a slower rate of decline in plasma Zn concentration for lambs given an oral dose of Zn methionine vs. those given ZnO. The author further suggested that Zn absorbed as Zn methionine without modification may behave differently than the pool of Zn that is transported bound to albumin (Spears, 1989). This difference in metabolism of Zn could partially explain enhanced gain efficiency and fat deposition in the late stages of the finishing period for cattle fed organic Zn.

The increase in both ADG and gain efficiency late in the finishing period could be due to the interaction of Zn in enhancing the ability of adipose cells to incorportate

substrates into stored fatty acids and triglycerides. The primary substrates utilized as lipogenic precursors are lactate, acetate and glucose (Smith and Crouse, 1984). Although glucose is not traditionally considered a highly utilized substrate in ruminants, it does appear to have importance in fat deposition, particularly in intramuscular adipocytes. Smith and Crouse (1984) reported that glucose was incorporated at a higher percent in intramuscular fat than in subcutaneous fat tissue when evaluated quantitatively. The same authors stated that on an absolute basis there was more glucose incorporated into subcutaneous adipose tissue than intramuscular adipose tissue (Smith and Crouse, 1984). In in vitro models with rat adipocytes, concentrations of 10 μM of Zn have been reported to increase hexose uptake threefold over non-treated controls (Ilouz et al., 2002). In murine models, Zn has been shown to increase glucose uptake in adipose cells both alone and additively in the presence of insulin. Shisheva et al. (1992) reported that in vitro conversion of glucose to lipids was 138% of maximal stimulation when Zn and insulin were present in the media, and 71% of maximal stimulation when Zn alone was present in the media. These comparisons were made considering media with no Zn or insulin to be 0%, and media with insulin only to be 100% (Shisheva et al., 2002). Of particular importance was that Zn had a stimulatory affect on glucose utilization by rat adipocytes (both via glycolysis and the pentose phosphate pathway), with the greatest response of Zn via the pentose phosphate pathway (Shisheva et al., 2002). When the same measurements were taken on rats that had streptozocin induced diabetes the effect of Zn alone was fivefold that of insulin (Shisheva et al., 2002). Similarly, Tanaka et al. (2001) reported that Zn promoted adipogenesis in 3T3-L1 adipocytes with or without insulin using measurements of glycerol phosphate dehydrogenase activity as an indicator of

adipogenesis. Although glucose has been established as an important substrate in adipogenesis for beef cattle, and the relationship with Zn can be clearly established, the greatest responses were observed when organic Zn sources were compared to ZnO. It is also important to note that acetate and lactate are major contributors to carbons in deposited fatty acids, and current research does not illustrate the relationship between Zn and these substrates incorporation into fat depots.

Effects on Growth Performance – Copper

As with Zn, performance responses in relation to Cu concentration in the diet or Cu source used in the diet have produced inconsistent results. Multiple authors have reported no difference in DMI in response to varied levels and sources of dietary Cu during both growing and finishing periods (Galyean et al., 1995; George et al., 1997; Engle and Spears, 2000a; Engle and Spears 2001; Lee et al., 2002). Engle et al. (2000b) reported a decrease in DMI for steers fed 20 mg Cu/kg of DM from $CuSO_4$, Cu citrate, Cu proteinate, or Cu chloride and for steers fed 40 mg Cu/kg from $CuSO_4$ vs. control diets. The authors attributed this decrease in DMI and subsequent decrease in ADG and gain efficiency to inhibition of ruminal fermentation from high dietary Cu. Essig et al. (1972) reported decreased acetic, propionic, butyric, and total volatile fatty acid (**VFA**) concentrations 2 h after feeding in response to supplementation with 1,600 mg Cu/kg of DM. In contrast, when in vitro dry matter disappearance (**IVDMD**) was measured on diets with concentrations of 0, 10, or 20 mg Cu/kg of DM, no differences were reported in IVDMD, or concentrations of acetate, propionate, isobutyrate, butyrate, isovalerate, or valerate (Engle and Spears, 2000a). Engle et al. (2000b) fed $CuSO_4$ and reported greater

DMI over a 112-d finishing period when 10 and 40 mg Cu/kg of DM were supplemented vs. no supplemental Cu. When Cu was fed below the NRC (1996) recommendation of 10 mg Cu/kg of DM, Ward and Spears (1997) reported increased DMI during a 28-d receiving period in response to Cu supplementation of 5 mg Cu/kg of DM vs. no copper supplementation (the basal diet contained 5.2 mg Cu/kg of DM). It appears from these data that increases in dietary Cu concentrations above NRC (1996) recommendations might increase DMI if the basal diet does not satisfy the animal's requirements. However, it appears that high levels of Cu can inhibit ruminal function, especially if the Cu source is readily available to ruminal microbes.

Several studies have reported no differences for ADG when $CuSO_4$ or Cu lysine was supplemented over controls in both receiving and finishing trials (Essig et al., 1972; Galyean et al., 1995; Engle and Spears, 2000a; Engle and Spears, 2001). In contrast, Ward and Spears (1997) reported a tendency for 5 mg Cu/kg of DM from $CuSO_4$ to increase ADG when supplemented to a diet below the NRC (1996) recommendation for Cu. Engle and Spears (2000b) reported a decrease in ADG with 20 mg Cu/kg of DM from $CuSO_4$, Cu citrate, Cu proteinate, or Cu chloride, and with 40 mg Cu/kg of DM from $CuSO_4$ vs. unsupplemented controls. The basal diet in this study contained 10.2 mg Cu/kg of DM. The authors attributed the decreased performance to potential inhibition of ruminal fermentation due to high-dietary levels of Cu (Engle and Spears, 2000b). Researchers from the same laboratory (Engle et al., 2000) reported a tendency towards increased ADG for steers fed 10 or 40 mg Cu/kg of DM from $CuSO_4$ vs. control diets with no supplemental Cu. The basal diet in this study contained 9.9 mg Cu/kg of DM (Engle et al., 2000). Lee et al. (2002) observed a tendency for higher ADG for steers

consuming 10 mg Cu/kg of DM from a Cu amino acid complex than for steers supplemented with 10 mg Cu/kg of DM from $CuSO_4$, when the basal diet contained 7.1 mg Cu/kg of DM.

Gain efficiency follows the same pattern of inconsistency with regard to Cu supplementation. In several instances Cu supplementation has not affected gain efficiency over a range of Cu levels and sources in diets for both receiving and finishing cattle (Essig et al., 1972; Galyean et al.,1995; Engle et al., 2000b; Engle and Spears, 2000b; Engle and Spears, 2001; Lee et al., 2002). Engle and Spears (2000b) reported a decrease in gain efficiency when Cu was supplemented at 20 mg Cu/kg of DM from $CuSO_4$, Cu citrate, Cu proteinate, and Cu chloride or 40 mg Cu/kg of DM from $CuSO_4$ vs. non-supplemented controls. The authors postulated inhibition of ruminal fermentation caused by high dietary Cu levels for lowered performance (Engle and Spears, 2000b). When researchers from the same laboratory conducted a similar trial with $CuSO_4$ supplementation at 10 or 20 mg Cu/kg of DM, no differences were observed with respect to performance (Engle and Spears, 2000a). While performance responses to Cu supplementation are not consistent and their mechanisms are not clear, Lee et al. (2002) suggested that dietary Cu agonists (S, Mo, Zn, and Fe), environmental and health factors, and breed differences could possibly affect an animal's response to Cu supplementation.

Effects on Carcass Merit – Copper

Copper supplementation at approximately 1.5 to 2 times NRC (1996) recommended levels has generally decreased the deposition of external fat (Ward and

Spears, 1997; Engle et al., 1998; Engle and Spears 2000a; Engle et al., 2000a; Engle et al., 2000b; Engle and Spears, 2001; Lee et al., 2002). Engle and Spears (2000a) reported a decreased dressing percentage as well as a reduction in external fat with supplemental Cu, and postulated a reduction in fatty acid synthase as a potential causative factor. Research in poultry has indicated a decrease in fatty acid synthase with elevated levels of Cu (Konjufca et al., 1997). Ward and Spears (1997) observed larger longissimus muscle areas and lower USDA Yield Grades with inclusion of levels of Cu to basal diets that were below NRC (1996) recommendations. Engle et al. (2000a, 2000b) reported increased serum cholesterol concentrations and increased cholesterol concentrations in longissimus muscle of finishing cattle at both 10 and 20 mg Cu/kg of DM from $CuSO_4$. Supplemental Cu has also been observed to alter the fatty acid profile of longissimus muscle sections. Concentrations of 18:2, 18:3, and total polyunsaturated fats have been increased with supplemental dietary Cu in finishing steers (Engle et al., 2000a, 2000b). Although Cu has been shown to clearly reduce subcutaneous fat deposition, there appears to be little if any effect on intramuscular fat deposition, marbling or USDA Quality Grade (Ward and Spears, 1997; Engle et al., 1998; Engle et al., 2000a; Engle et al., 2000b; Engle and Spears 2000a; Engle and Spears, 2001; Lee et al., 2002). The mechanism of the effect of Cu on fat metabolism is still unproven and warrants further research.

Conclusions

Both Zn and Cu have been shown to influence beef cattle performance. While both are intricately involved in immune function, the requirements recommended by NRC (1996) are set with animal growth as a goal. Although this should encompass some

aspects of immune function, inherently the requirements for neutrophils immune response may be greater than those for maximal growth. This is evidenced by reductions in immune function at levels of dietary or serum Zn and Cu that are not sufficiently low to cause a deficiency by current measurements. Performance results for both Zn and Cu have met with varied response, and seem to reflect either the previous mineral status or how close the basal diet is to the animal's requirement for the respective mineral. If either Zn or Cu are marginally deficient in either the animal or the diet, supplementation will likely increase indices of performance. It is plausible that high levels of Cu can inhibit ruminal function due to its microbicidal potential, but levels of Cu commonly included in diets should not have this negative effect. Both Zn and Cu have effects on metabolism of fat although they appear to be opposite in nature. While the mechanism for increasing adiposity by Zn appears to be its ability to increase glucose uptake, the mechanism for decreasing adiposity by Cu is not clear.

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CHAPTER III

EFFECTS OF COPPER LEVEL AND ZINC LEVEL AND SOURCE ON FINISHING CATTLE PERFORMANCE AND CARCASS TRAITS

L. J. McBeth, C. R. Krehbiel, D. R. Gill and C. K. Larson

Abstract

One hundred sixty heifers (BW = 317 ± 22 kg; Exp. 1) and 160 steers (BW = 341 ± 18 kg; Exp. 2) were fed for an average of 140 and 141 d, respectively, and used to evaluate the effects of Zn and Cu source and level in finishing cattle diets. Experimental treatments were arranged in a 2 x 2 x 2 factorial with two levels (DM basis) of Cu (12 vs. 24 mg/kg DM; CuL), two levels of Zn (80 vs. 360 mg/kg DM; ZnL), and two sources of Zn ($ZnSO_4$ vs. Availa®Zn; ZnS). Interim weights were obtained every 28 d, and upon completion of the feeding period cattle were harvested and carcass measurements obtained. In Exp. 1, ADG and GF were decreased from d 85 to 112 when Availa Zn vs. $ZnSO_4$ was fed at 24 mg Cu/kg DM, whereas ADG and GF were similar when Availa Zn and $ZnSO_4$ were fed at 12 mg Cu/kg DM (CuL x ZnS interaction, $P = 0.04$). Heifers consuming 24 mg Cu/kg DM experienced decreased ADG ($P = 0.02$) and GF ($P = 0.02$) and tended to have decreased DMI ($P = 0.08$) from d 0 to 27, but this effect was reversed in subsequent periods for ADG ($P = 0.05$) and GF ($P = 0.05$). Over the entire feeding

period, heifers consuming 12 mg Cu/kg DM were more efficient ($P = 0.04$) than heifers fed 24 mg Cu/kg DM. A significant interaction (CuL x ZnS; $P = 0.02$) resulted in heifers consuming Availa Zn at 12 mg Cu/kg DM, and $ZnSO_4$ and Availa Zn at 24 mg Cu/kg DM having higher yield grades (YG) compared with $ZnSO_4$ at 12 mg Cu/kg DM. Heifers fed 360 mg Zn/kg DM had greater ($P = 0.04$) 12th-rib fat depth (BF and tended to have higher YG ($P = 0.08$) than heifers fed 80 mg Zn/kg DM. Similarly, heifers consuming Availa Zn tended ($P = 0.06$) to have higher YG than those consuming $ZnSO_4$. In Exp. 2, steers consuming $ZnSO_4$ and Availa Zn at 12 mg Cu/kg DM and $ZnSO_4$ at 24 mg Cu/kg DM had greater ADG than steers that consumed Availa Zn at 24 mg Cu/kg DM from d 0 to 27 (CuL x ZnS interaction, $P = 0.01$). Steers consuming Availa Zn and 12 mg Cu/kg DM had greater (CuL x ZnS interaction, $P = 0.02$) ADG than those consuming Availa Zn and 24 mg Cu/kg DM from d 85 to 112. From d 113 to the end of the feeding period steers consuming $ZnSO_4$ and 12 mg Cu/kg DM, and Availa Zn and 24 mg Cu/kg DM had greater (CuL x ZnS interaction, $P = 0.03$) ADG than those consuming Availa Zn and 12 mg Cu/kg DM. From d 84 to 112 steers consuming Availa Zn with 12 mg Cu/kg DM had greater (CuL x ZnS interaction, $P = 0.02$) GF than those consuming Availa Zn with 24 mg Cu/kg DM. This effect was reversed in the subsequent period so that over the entire experiment, GF was not influenced by CuL x ZnS ($P = 0.54$). Steers consuming 360 mg Zn/kg DM had greater BF ($P = 0.03$) and YG ($P = 0.01$) and tended to have greater HCW ($P = 0.06$) and dressing percent ($P = 0.08$) than steers consuming 80 mg Zn/kg DM. Steers consuming 80 mg Zn/kg DM had greater ($P = 0.01$) REA vs. 360 mg Zn/kg DM. Carcass characteristics were not affected ($P > 0.10$) by Zn source. Feeding combinations of Zn and Cu from different sources elicits differences that are

inconsistent, while Zn level and Cu level can effect both performance and carcass characteristics.

Key Words: Copper Level, Finishing Cattle, Zinc Level, Zinc Source

Introduction

Zinc and Cu have been shown to play a major role in disease resistance and immune responsiveness in stressed feeder cattle. For example, Chirase et al. (1994) observed that an organic source of Zn reduced the recovery time for cattle challenged with an infectious bovine rhinotracheitis virus (**IBRV**), and Stabel et al. (1993) showed that Cu concentrations were decreased in immune regulatory organs such as the liver, spleen, thymus and lung in cattle challenged with an IBRV. In addition, several studies have shown improved performance in response to supplemental Zn (Galyean et al., 1995; Malcolm-Callis et al., 2000; Spears and Kegley, 2002). Generally, increased performance was observed when supplemental Zn was compared against controls, and fewer studies have evaluated combinations of organic and inorganic sources of Zn. Supplemental Zn has also been observed to increase external fat deposition, marbling and/or percent of carcasses grading choice (Rust et al., 1985; Greene et al., 1988; Spears and Kegley, 2002).

Less information is available which has evaluated the effects of Cu on finishing cattle performance and carcass traits. Ward and Spears (1997) investigated the long-term effects of dietary Cu and Mo on performance of cattle during receiving, growing, and finishing phases and on carcass characteristics at slaughter. During the finishing phase, Cu-supplemented (5 mg/kg of DM) steers had greater ADG and GF. In addition, Cu

supplementation increased carcass leanness and muscling without altering quality. These data suggest that similar to Zn, Cu can improve efficiency of feed utilization and meat quality by feedlot cattle. However, data evaluating the interaction between Zn and Cu are limited. In a survey of feedlot consulting nutritionists, Galyean and Gleghorn (2002) reported mean dietary Zn levels of 74 mg/kg of DM, and mean dietary Cu levels of 14.75 mg/kg of DM. Accordingly, our diets were formulated at a level near (80 mg Zn/kg DM and 12 mg Cu/kg DM) or four (360 mg Zn/kg DM) and two (24 mg Cu/kg DM) times the amount currently fed by the feedlot industry. We hypothesized that increasing Zn and Cu levels would interact to increase intramuscular fat deposition with minimal effects on performance. Therefore, these experiments were designed to evaluate the effects of Cu level and Zn source and level on finishing cattle performance and carcass merit.

Materials and Methods

Experiment 1

One hundred sixty crossbred heifers (initial BW = 317 ± 22 kg) were delivered to the Willard Sparks Beef Research Center near Stillwater, OK on November 21, 2000. At processing, heifers were individually weighed, ear tagged, implanted with Component E-H (Vet Life, LLC, Overland Park, KS), horn tipped as needed, vaccinated with IBR-PI_3-BVD-BRSV (BRSV Vac-4, Bayer Animal Health, Shawnee Mission, KS), and treated for control of external and internal parasites (Ivomec Plus, Merial Animal Health, Duluth, GA). Heifers were re-implanted on day 85 with both Component E-H and Component T-H. After weighing and processing, heifers were blocked by weight into two blocks, and randomly assigned to 32 pens (5 head/pen; 16 pens/block). Pens (4.6 x 12.2 m) were

partially covered and contained 4.6 m of bunk space with water basins positioned to supply water to two adjacent pens. Heifers were fed for 140 d and harvested at Tyson Fresh Meats, Emporia, KS.

Experiment 2

One hundred sixty crossbred steers (initial BW = 341 ± 18 kg) were delivered to the Willard Sparks Beef Research Center near Stillwater, OK on July 12, 2001. At processing, steers were individually weighed, ear tagged, implanted with Revalor-S (Intervet, Inc., Millsboro, DE), horn tipped as needed, vaccinated with IBR-PI_3-BVD-BRSV (F3Lp, Bayer Animal Health, Shawnee Mission, KS), and treated for control of external and internal parasites (Ivomec Plus, Merial Animal Health, Duluth, GA). After weighing and processing, steers were blocked by weight into two blocks, and assigned randomly to pens (5 head/pen; 16 pens/block). Pens (4.6 x 12.2 m) were partially covered and contained 4.6 m of bunk space with water basins positioned to supply water to two adjacent pens. Steers were harvested by respective weight block with the heavy block being fed for 131 days and the light block being fed for 148 days. All steers were harvested by Excel Corp., Dodge City, KS.

Experiments 1 and 2

For both experiments treatments included (DM basis): 1) 80 ppm $ZnSO_4$, 12 ppm Availa®Cu (ZinPro Corp., Eden Prairie, MN); 2) 80 ppm $ZnSO_4$, 12 ppm Availa Cu and 12 ppm $CuSO_4$; 3) 40 ppm $ZnSO_4$, 40 ppm Availa®Zn (ZinPro Corp., Eden Prairie, MN) and 12 ppm Availa Cu; 4) 40 ppm $ZnSO_4$, 40 ppm Availa Zn, 12 ppm Availa Cu and 12

ppm $CuSO_4$; 5) 360 ppm $ZnSO_4$ and 12 ppm Availa Cu; 6) 360 ppm $ZnSO_4$, 12 ppm Availa Cu and 12 ppm $CuSO_4$; 7) 160 ppm $ZnSO_4$, 160 ppm Availa Zn and 12 ppm Availa Cu; and 8) 160 ppm $ZnSO_4$, 160 ppm Availa Zn, 12 ppm Availa Cu and 12 ppm $CuSO_4$. Basal diets were formulated to meet or exceed NRC (1996) nutrient requirements (Table 1). Basal ingredients were identical with the exception of supplements that were formulated for each dietary treatment. Supplement formulation was identical with the exception of Cu and Zn source and level that were added at the expense of wheat midds in the supplement (Table 2). Monensin (33 mg/kg of the diet; Elanco Animal Health, Greenfield, IN) and tylosin (11 mg/kg of the diet; Elanco Animal Health, Greenfield, IN) were fed. Cattle were gradually adapted to the final diet by offering approximately 60, 70 and 80% concentrate diets for 7, 7 and 7 d, respectively. All diets were fed ad libitum. Heifers were fed once daily at 0800 and steers were fed twice daily at 0800 and 1400. Feed refused was weighed every 28 days. In addition, diet samples were collected and DM content of the diets and dietary ingredients were determined. Diet and ingredient samples were composited by 28-d periods, allowed to air dry, and ground in a Wiley mill to pass a 1-mm screen. Diet and ingredient samples were analyzed for N, ash (AOAC, 1990) and ADF (Goering and Van Soest, 1970).

Cattle were weighed individually before feeding once every 28 d throughout the experiments. Initial weight was analyzed as taken, whereas all interim weights were analyzed with a 4% pencil shrink. Final live weight was calculated by dividing hot carcass weight by a common dressing percentage (Exp. 1 = 64%; Experiment 2 = 63%). Feed intake was measured and gain efficiency (GF) was calculated every 28 d. Hot carcass weight (**HCW**) was determined following harvest, and carcasses were evaluated

by trained personnel after a 24-h chill for subcutaneous fat depth at the twelfth rib, longissimus muscle area (**REA**), percentage kidney, pelvic, and heart fat, yield grade (**YG**), marbling score, and quality grade (**QG**) (USDA, 1997).

Liver biopsies were obtained via an incision between the 11^{th} and 12^{th} rib similar to procedures used by Swanson et al. (2000). Liver biopsies were obtained prior to consumption of treatment diets at initiation of the experiments and samples of liver were obtained after evisceration postmortem. Liver samples were collected into scintillation vials and analyzed for Zn and Cu concentrations (Michigan State University Animal Health Diagnostic Laboratory, East Lansing, MI). All procedures were approved by the Oklahoma State University Animal Care and Use Committee.

Statistics

Because sex of animal and experiment were confounded, Exp. 1 and 2 were analyzed separately. Cattle performance, carcass merit and liver mineral concentration data were analyzed using PROC MIXED (SAS Inst,. Inc., Cary, NC). Class variables included in the model as fixed effects were pen and treatment, and weight replicate was included as a random effect. The model included Cu level (12 vs. 24 mg Cu/kg DM), Zn level (80 vs. 360 mg Zn/kg DM), and Zn source ($ZnSO_4$ vs. Availa Zn) and the appropriate interactions were conducted. Pen was considered the experimental unit for all cattle performance and carcass data. There were four replicates for each treatment. Treatment least squares means were calculated, and means were compared using the least significant difference method when protected by a F value ($P \leq 0.05$). Carcass quality and yield grades as assigned by USDA (nonparametric variables) were examined on an

individual animal basis using the Chi-square analysis technique (SAS, 2004). Results are discussed as significant if $P \leq 0.05$, and as tendencies if $P \leq 0.06$ to $P \leq 0.10$.

Results

No differences ($P > 0.10$) were observed in initial or final liver Cu or Zn concentrations for Exp. 1 or 2. Initial Cu and Zn averaged 202.5 and 117.6 mg/kg of liver tissue, respectively, and final Cu and Zn averaged 267.5 and 160.2 mg/kg of liver tissue respectively for Trial 1. Initial Cu and Zn averaged 180.2 and 127.2 mg/kg of liver tissue respectively and final Cu and Zn averaged 203.8 and 158.0 mg/kg of liver tissue respectively for Trial 2.

Experiment 1

No significant ($P \geq 0.12$) Cu level x Zn level x Zn source interactions were detected for initial or final weights, ADG, DMI, or GF (Appendix A – Table 1). Similarly, no differences ($P \geq 0.17$) were detected for performance variables for interactions of Cu level x Zn level (Appendix Table A-2) or for Zn level x Zn source (Appendix Table A-3). Although ADG and GF were decreased (Cu level x Zn source interaction, $P = 0.04$) from d 85 to 112 when Availa Zn vs. $ZnSO_4$ was fed with 24 mg Cu/kg DM, no differences ($P \geq 0.22$) were detected over the entire feeding period (Table 3). Heifers consuming 24 mg Cu/kg DM had lower ADG ($P = 0.02$) and GF ($P = 0.02$) and tended ($P = 0.08$) to have lower DMI from d 0 to 27 (Table 4); however, this response was reversed for ADG ($P = 0.05$) and GF ($P = 0.05$) from d 28 through 56. Over the entire feeding period, heifers consuming 12 mg Cu/kg DM were more ($P =$

0.04) efficient than heifers consuming 24 mg Cu/kg DM. Heifers consuming 360 mg Zn/kg DM had greater DMI from d 0 to 27 ($P = 0.01$) and d 28 to 56 ($P = 0.05$); however, over the entire feeding period DMI was not affected ($P = 0.73$) by dietary Zn level (Table 5). No differences ($P \geq 0.12$) were observed for ADG, DMI, or GF when heifers were supplemented with $ZnSO_4$ vs. Availa Zn (Appendix Table A-4).

Copper level x Zn level x Zn source (Appendix Table A-5) or Cu level x Zn level (Appendix Table A-6) interactions were not observed ($P \geq 0.22$) for carcass characteristics in Exp. 1. However, there was a Cu level x Zn source interaction ($P = 0.02$) resulting in heifers fed Availa Zn with 12 mg Cu/kg DM, and $ZnSO_4$ and Availa Zn with 24 mg Cu/kg DM having a greater YG compared with heifers fed $ZnSO_4$ with 12 mg Cu/kg DM (Table 6). There was also a Zn level x Zn source interaction ($P = 0.03$) for dressing percent (Table 7). Carcasses from heifers fed $ZnSO_4$ or Availa Zn at 80 mg Zn/kg DM and $ZnSO_4$ at 360 mg/kg DM had a higher dressing percent than heifers fed Availa Zn at 360 mg Zn/kg DM. In addition, heifers fed 12 mg Cu/kg DM had a greater ($P = 0.03$) dressing percent than those fed 24 mg Cu/kg DM (Table 8). Heifers fed 360 mg Zn/kg DM had greater subcutaneous fat ($P = 0.04$) and tended ($P = 0.08$) to have higher YG than heifers fed 12 mg Cu/kg DM (Table 9). Heifers consuming Availa Zn had a higher ($P = 0.02$) YG than heifers consuming $ZnSO_4$ (Table 10).

Experiment 2

No significant ($P \geq 0.22$) Cu level x Zn level x Zn source (Appendix Table A-8) or Cu level x Zn level (Appendix Table A-9) interactions were detected for initial or final BW, ADG, DMI or GF. Steers that consumed $ZnSO_4$ and Availa Zn with 12 mg Cu/kg

DM and $ZnSO_4$ with 24 mg Cu/kg DM had greater (Cu level x Zn source interaction, P = 0.01) ADG from d 0 to 27 than steers that consumed Availa Zn with 24 mg Cu/kg DM (Table 11). Similarly, steers consuming Availa Zn with 12 mg Cu/kg DM had greater (Cu level x Zn source interaction, P = 0.02) ADG than those consuming Availa Zn with 24 mg Cu/kg DM from d 85 to 112. In contrast, from d 113 to the end of the feeding period steers consuming $ZnSO_4$ with 12 mg Cu/kg DM and Availa Zn with 24 mg Cu/kg DM had greater (Cu level x Zn source interaction, P = 0.03) ADG than steers consuming Availa Zn with 12 mg Cu/kg DM. Over the entire feeding period, ADG was not affected (P = 0.52) by Cu level x Zn source. Similar results were obtained for GF, and the Cu level x Zn source interaction was not significant (P = 0.54) over the entire feeding period (Table 11). From d 0 to 27, steers that were fed $ZnSO_4$ at 80 mg Zn/kg DM had greater (Zn level x Zn source, P = 0.03) ADG than steers fed Availa Zn (Table 12). A similar response was observed for GF from d 0 to 27; steers that consumed $ZnSO_4$ at 80 mg Zn/kg DM and Availa Zn at 360 mg Zn/kg DM had greater (Zn level x Zn source, P = 0.01) GF than steers consuming Availa Zn at 80 mg Zn/kg DM. Steers fed $ZnSO_4$ at 360 mg Zn/kg DM were intermediate. No differences ($P \geq 0.12$) due to Cu level, Zn level, or Zn source were observed for BW, ADG, DMI, or GF (Appendix Tables A-10, A-11 and A-12, respectively).

There were no significant ($P \geq 0.59$) Cu level x Zn level x Zn source interactions observed for carcass characteristics (Appendix Table A-13). Dressing percent tended (Cu level x Zn level, P = 0.09) to be greater for steers consuming 360 mg Zn/kg DM with 12 mg Cu/kg DM vs. steers consuming 80 mg Zn/kg DM with 12 mg Cu/kg DM and 80 or 360 mg Zn/kg DM with 24 mg Cu/kg DM (Table 13). Dressing percent was greater (Cu

level x Zn source, $P = 0.03$) for steers consuming $ZnSO_4$ with 12 mg Cu/kg DM than steers consuming Availa Zn with 12 mg Cu/kg DM or $ZnSO_4$ with 24 mg Cu/kg DM (Table 14). Longissimus muscle area was greater (Cu level x Zn source, $P < 0.01$) for steers consuming $ZnSO_4$ with 24 mg Cu/kg DM than for steers consuming Availa Zn with 24 mg Cu/kg DM; steers consuming $ZnSO_4$ or Availa Zn with 12 mg Cu/kg DM were intermediate. Dressing percent tended (Zn level x Zn source; $P = 0.10$) to be greater for steers fed 360 mg Zn/kg DM from $ZnSO_4$ vs. those consuming 80 mg Zn/kg DM from $ZnSO_4$ (Appendix Table 14). Dressing percent was also greater ($P = 0.05$) for steers consuming 12 mg Cu/kg DM vs. 24 mg Cu/kg DM (Appendix Table A-15). Steers consuming 360 mg Zn/kg DM had greater 12th-rib fat depth ($P = 0.03$) and YG ($P = 0.01$) and tended to have greater HCW ($P = 0.06$) and dressing percent ($P = 0.08$) than steers consuming 80 mg Zn/kg DM (Table 15). In contrast, steers consuming 80 mg Zn/kg DM had greater ($P = 0.01$) REA compared with steers fed 360 mg Zn/kg DM. Similar to Exp. 1, carcass characteristics were not affected ($P \geq 0.20$) by Zn source (Appendix Table A-16).

Discussion

The effects of Cu and Zn on performance have met with varying results and have generally been evaluated at levels below those investigated in the present experiments. In the present experiments, DMI was not affected by Cu level, Zn level or Zn source when measured across the entire feeding period. However, increasing Cu level from 12 to 24 mg Cu/kg DM decreased DMI in heifers from d 0 to 27 and d 28 to 56. Similar to the present Exp. 1, Engle and Spears (2000b) reported lower DMI over an 80-d feeding

period for steers supplemented with 20 or 40 mg Cu/kg DM vs. non-supplemented controls, and postulated that this might be caused by inhibition of ruminal fermentation from high dietary Cu. Similarly, Essig et al. (1972) reported decreases in ruminal acetate, propionate, and total volatile fatty acid concentrations for steers fed 4.4 g Cu/100 kg BW vs. control steers. In contrast, several authors have reported no change in DMI with Cu supplementation from 10 to 40 mg Cu/kg DM from both organic and inorganic sources (Engle and Spears 2000a; Engle and spears 2001; Lee et al., 2002). In addition to DMI, decreased performance in response to the higher Cu level occurred during the adaptation period (d 0 to 27) when heifers were transitioning to the final high-concentrate diet, suggesting that higher levels of Cu may have inhibited ruminal function early in the finishing period in the present Exp. 1.

The increase in DMI with increasing Zn from d 0 to 27 and d 28 to 56 in the present Exp. 1 might be due to the ability of Zn to enhance DMI during periods of stress or immune challenge. Chirase et al. (1994) reported greater DMI for steers supplemented with Zn methionine vs. controls or steers supplemented with ZnO during an immune challenge with infectious bovine rhinotracheitis virus. The increase in DMI early in the feeding period of the present Exp. 1 was countered by a decrease in DMI from d 113 to the end of the feeding period, and Zn level did not affect DMI across the entire feeding period. In contrast, other authors have reported increased DMI with increasing Zn level in finishing diets. Malcolm-Callis (2000) reported a linear increase in DMI with 20, 100, or 200 mg Zn/kg DM, and Galyean et al. (1995) reported greater DMI for steers supplemented with 70 or 105 mg Zn/kg DM vs. controls (35 mg Zn/kg DM). Reasons for discrepancies among experiments are not clear.

A common result in the present experiments was decreased ADG with supplementation of an organic Zn source at the higher Cu level early in the finishing period (Exp. 2) and from d 85 to 112 (Exp. 1 and 2). Decreased performance in both experiments was compensated for in previous or subsequent periods, and no Cu level x Zn level interactions were observed for the entire feeding period in either experiment. Galyean et al. (1995) reported that steers previously supplemented with Cu lysine responded favorably to Zn supplementation during transition to a high-concentrate diet vs. those not previously supplemented with Cu. The mechanisms that affect the interactions of Cu and Zn are not readily apparent, and their effects on performance are inconsistent. Zinc has been reported to decrease Cu uptake in the intestinal mucosa, but it is not clear if Zn competes directly with Cu for receptors (Cousins, 1985). Competition for receptor sites might explain the decreased performance with 24 mg/kg DM Cu and the organic source of Zn.

The interaction between Cu level and Zn level for dressing percent appears to be consistent with numerical differences in external fat and REA. In the present experiments, dressing percent was generally greater when 360 mg Zn from $ZnSO_4$ was fed, although interactions with Cu level were observed. In Exp. 1 and 2, dressing percent was greater for cattle supplemented with the lower level of Cu. This is inconsistent with several studies (Engle et al., 2000; Engle and Spears, 2000a; Engle and Spears, 2001) which have reported no difference in dressing percent when steers were fed Cu levels ranging from 10 to 40 mg Cu/kg DM. In the present experiments there was no effect of Cu level on 12th-rib fat depth, which is also in contrast to previous reports. Ward and Spears (1997) reported a decrease in 12th-rib fat depth with added dietary Cu. Similarly,

Engle and Spears (2000a) reported a decrease in external fat depth when steers were fed 10 or 20 mg Cu/kg DM vs. controls, and Engle and Spears (2001) and Engle et al. (2000) reported decreased 12th-rib fat depth for steers supplemented with 10 or 40 mg Cu/kg DM from $CuSO_4$ compared with non-supplemented controls.

In both the present Exp. 1 and 2, Zn level increased 12th-rib fat depth and YG was higher for steers and tended to be higher for heifers consuming 360 compared with 80 mg Zn/kg DM. Malcolm-Callis et al. (2000) reported quadratic increases in 12th-rib fat depth in response to 20, 100 or 200 mg Zn/kg DM. Similarly, Greene et al. (1998) reported increased 12th-rib fat depth for steers supplemented with 360 mg Zn methionine/kg DM vs. controls. These studies suggest that Zn supplementation at levels up to 360 mg Zn/kg DM will increase external fat deposition and potentially carcass weight. In addition to increased 12th-rib fat depth, Greene et al. (1998) reported increased marbling and percent choice carcasses when steers were supplemented with 360 mg Zn/kg DM from Zn methionine vs. ZnO. Kegley and Spears (2002) reported increased marbling and quality grade for steers supplemented with either ZnO or Zn proteinate at 51 mg Zn/kg DM vs. controls (26 mg Zn/kg DM). No differences in carcass quality were observed due to Zn source in the present experiments.

Supplementation of Cu and Zn separately have been shown to have similar affects in enhancing immune response and growth performance in diets that are marginal in these elements or have vast differences in bioavailability. However, there appears to be competition between Cu and Zn when both are supplemented at high levels from various sources, and further research is needed to clarify the importance of these interactions.

Implications

Zinc and copper appear to alter carcass fat deposition independently of each other. While the present study suggests that supplementation of zinc at 360 vs. 80 mg zinc/kg dry matter increases deposition of external fat, there appeared to be no affect on intramuscular deposition due to copper level, zinc level or zinc source in the present experiment. Performance seems to be enhanced by supplemental Zn in the initial portion of the feeding period, however consistent results were not observed throughout the entire feeding period.

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Table 3-1. Dry matter and nutrient composition of basal finishing diets.

	% of diet DM
Rolled Corn	76.50
Cotton seed hulls	10.00
Yellow grease	3.00
Supplement[a]	10.50
Nutrients[a]	
DM, % as fed	87.65
CP, % of DM	13.50
ADF,% of DM	6.90
Calcium, % of DM	0.52
Phosphorus, % of DM	0.39
Potassium, % of DM	0.57
Magnesium, % of DM	0.15
Sulfur, % of DM	0.16
Manganese, mg/kg	43.3
Cobalt, mg/kg	0.07
Iron, mg/kg	121.5
Selenium, mg/kg	0.16

[a]Contained (% DM basis): soybean meal 47.7 (50.48), wheat midds (11.73), cottonseed meal (9.52), limestone 38% (8.57), urea (8.10), di-calcium phosphate (4.76), cane molasses (3.81), salt (2.38), Rumensin 80 (0.18), Tylan 40 (0.12), vitamin A-30,000 (0.11), manganous oxide (0.03), and $CuSO_4$, Availa®Cu, $ZnSO_4$, and/or Availa® were included to meet total dietary treatment levels.

[a]All values are estimates based on NRC (1996) values for feedstuffs.

Table 3-2. Dry matter composition of supplements.

Ingredient[b]	Diets[a]							
	1	2	3	4	5	6	7	8
Soybean Meal	50.46	50.48	50.48	50.48	50.48	50.48	50.48	50.47
Wheat Midds	11.73	11.69	11.52	11.48	11.10	11.05	10.06	10.02
Cottonseed Meal	9.52	9.52	9.52	9.52	9.52	9.52	9.52	9.52
Limestone 38%	8.57	8.57	8.57	8.57	8.57	8.57	8.57	8.57
Urea	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10
Cane Molasses	3.81	3.81	3.81	3.81	3.81	3.81	3.81	3.81
Dical	4.76	4.76	4.76	4.76	4.76	4.76	4.76	4.76
Salt	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38
Rumensin 80	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Tylan 40	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Vitamin A 30	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Manganous Oxide	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
$CuSO_4$		0.04		0.04		0.04		0.04
Availa Cu	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
$ZnSO_4$	0.16	0.16	0.08	0.08	0.79	0.79	0.40	0.40
Availa Zn			0.29	0.29			1.43	1.43

[a]1 = 80 mg/kg $ZnSO^4$ and 12 mg/kg Availa® Cu; 2 = 80 mg/kg $ZnSO_4$, 12 mg/kg Availa Cu and 12 mg/kg $CuSO_4$; 3 = 40 mg/kg $ZnSO_4$, 40 mg/kg Availa®Zn and 12 mg/kg Availa Cu; 4 = 40 mg/kg $ZnSO_4$, 40 mg/kg Availa Zn, 12 mg/kg Availa Cu and 12 mg/kg $CuSO_4$; 5 = 360 mg/kg $ZnSO_4$ and 12 mg/kg Availa Cu; 6 = 360 mg/kg $ZnSO_4$, 12 mg/kg Availa Cu and 12 mg/kg $CuSO_4$; 7 = 160 mg/kg $ZnSO_4$, 160 mg/kg Availa® Zn and 12 mg/kg $CuSO_4$; and 8 = 160 mg/kg $ZnSO_4$, 160 mg/kg Availa Zn, 12 mg/kg Availa Cu and 12 mg/kg $CuSO_4$.

[b]Percent of DM.

Table 3-3. Effects of copper level and zinc source on cumulative feedlot performance by heifers (Exp. 1).

Item	12 mg Cu/kg DM		24 mg Cu/kg DM		SEM	CuL x ZnS[a]
	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn		
Initial wt., kg	308	309	306	307	3	0.37
Final wt., kg	511	515	518	505	6	0.18
Daily gain, kg						
d 0 - 27	1.49	1.40	1.19	1.32	0.13	0.15
d 28 - 56	1.40	1.42	1.69	1.48	0.09	0.22
d 56 - 84	1.24	1.33	1.32	1.37	0.11	0.87
d 85 - 112	1.44[bc]	1.49[bc]	1.56[b]	1.31[c]	0.07	0.04
d 113 - end	1.18	1.13	1.22	1.03	0.09	0.45
d 0 - end	1.35	1.35	1.39	1.30	0.06	0.22
DM intake, kg/d						
d 0 - 27	7.64	7.70	7.46	7.50	0.10	0.96
d 28 - 56	8.13	8.23	8.43	8.14	0.20	0.32
d 57 - 84	8.19	8.37	8.60	8.26	0.20	0.21
d 85 - 112	7.80	7.92	8.35	8.20	0.29	0.65
d 113 - end	7.14	7.20	7.64	7.28	0.20	0.31
d 0 - end	7.78	7.88	8.25	8.32	0.22	0.93
Gain:feed						
d 0 - 27	0.196	0.181	0.159	0.175	0.015	0.10
d 28 - 56	0.172	0.172	0.201	0.182	0.009	0.32
d 57 - 84	0.151	0.157	0.153	0.166	0.0112	0.76
d 85 - 112	0.184[b]	0.189[b]	0.188[b]	0.160[c]	0.008	0.04
d 113 - end	0.165	0.158	0.157	0.141	0.011	0.69
d 0 - end	0.173	0.171	0.169	0.157	0.007	0.25

[a]Probability of an interaction between Cu level and Zn source.
[bc]Means in row with different superscripts differ, $P < 0.10$.

Table 3-4. Effect of copper level on cumulative performance by heifers (Exp. 1).

Item	12 mg Cu/kg DM	24 mg Cu/kg DM	SEM	Cu level[a]
Initial wt., kg	309	306	2	0.45
Final wt., kg	513	511	4	0.82
Daily gain, kg				
d 0 - 27	1.45	1.25	0.11	0.02
d 28 - 56	1.41	1.59	0.06	0.05
d 56 - 84	1.28	1.34	0.86	0.53
d 85 - 112	1.46	1.43	0.05	0.64
d 113 - end	1.15	1.12	0.07	0.74
d 0 - end	1.35	1.35	0.05	0.96
DM intake, kg/d				
d 0 - 27	7.67	7.48	0.07	0.08
d 28 - 56	8.18	8.28	0.14	0.59
d 57 - 84	8.28	8.43	0.14	0.46
d 85 - 112	7.86	8.27	0.21	0.18
d 113 - end	7.17	7.46	0.14	0.17
d 0 - end	7.83	8.28	0.16	0.05
Gain:feed				
d 0 - 27	0.189	0.167	0.014	0.02
d 28 - 56	0.172	0.191	0.006	0.05
d 57 - 84	0.154	0.159	0.001	0.58
d 85 - 112	0.186	0.174	0.005	0.11
d 113 - end	0.161	0.149	0.008	0.29
d 0 - end	0.172	0.163	0.006	0.04

[a]Probablity of an effect of Cu level.

Table 3-5. Effect of zinc level on cumulative performance by heifers (Exp. 1).

Item	80 mg Zn/kg DM	360 mg Zn/kg DM	SEM	Zn level[a]
Initial wt., kg	307	308	2	0.62
Final wt., kg	509	515	4	0.33
Daily gain, kg				
d 0 - 27	1.30	1.40	0.11	0.21
d 28 - 56	1.48	1.52	0.06	0.68
d 56 - 84	1.32	1.30	0.09	0.84
d 85 - 112	1.41	1.48	0.05	0.29
d 113 - end	1.17	1.11	0.07	0.55
d 0 - end	1.33	1.36	0.05	0.52
DM intake, kg/d				
d 0 - 27	7.43	7.72	0.07	0.01
d 28 - 56	8.03	8.43	0.14	0.05
d 57 - 84	8.33	8.38	0.14	0.84
d 85 - 112	8.06	8.08	0.21	0.96
d 113 - end	7.49	7.14	0.14	0.10
d 0 - end	8.10	8.02	0.16	0.73
Gain:feed				
d 0 - 27	0.175	0.181	0.014	0.48
d 28 - 56	0.184	0.179	0.006	0.59
d 57 - 84	0.158	0.155	0.010	0.76
d 85 - 112	0.176	0.184	0.005	0.27
d 113 - end	0.156	0.155	0.008	0.92
d 0 - end	0.166	0.170	0.006	0.36

[a]Probablity of an effect of Zn level.
[bc]Means within a row with different superscripts differ, $P < 0.05$.

Table 3- 6. Effects of copper level and zinc source on carcass traits in heifers (Exp.1).

	12 mg Cu/kg DM		24 mg Cu/kg DM			
Item	$ZnSO_4$	Availa Zn	$ZnSO_4$	Availa Zn	SEM	CuL x ZnS[a]
HCW, kg	329	331	333	325	4	0.19
Dressing %	64.68	64.55	64.47	63.65	0.24	0.16
Ribeye area, cm^2	94.28	88.10	89.77	90.86	2.23	0.19
12th-rib fat, cm	1.45	1.67	1.65	1.66	0.09	0.17
KPH	2.47	2.34	2.60	2.52	0.12	0.87
Marbling[b]	430	435	455	443	18	0.61
Yield grade	2.46[d]	3.01[c]	2.79[c]	2.79[c]	0.11	0.02

[a]Probability of an interaction between Cu level and Zn source.

[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

[cd]Means within a row with different superscripts differ, $P < 0.05$.

Table 3-7. Effects of zinc level and zinc source on carcass traits in heifers (Exp. 1).

	80 mg Zn/kg DM		360 mg Zn/kg DM			
Item	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	SEM	ZnL x ZnS[a]
HCW, kg	326	329	336	328	4	0.20
Dressing %	64.17[d]	64.24[d]	64.98[c]	63.95[d]	0.24	0.03
Ribeye area, cm^2	89.87	90.38	94.18	88.58	2.23	0.12
12th-rib fat, cm	1.52	1.53	1.58	1.80	0.09	0.20
KPH	2.52	2.53	2.55	2.33	0.12	0.34
Marbling[b]	456	448	428	429	18	0.79
Yield grade	2.60	2.73	2.64	3.08	0.11	0.15

[a]Probability of an interaction between Zn level and Zn source.

[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

[cd]Means within a row with different superscripts differ, $P < 0.05$.

Table 3-8. Effect of copper level on carcass traits in heifers (Exp. 1).

Item	12 mg Cu/kg DM	24 mg Cu/kg DM	SEM	Copper L[a]
HCW, kg	330	329	3	0.82
Dressing %	64.62	64.06	0.20	0.03
Ribeye area, cm^2	91.18	90.32	1.58	0.70
12th-rib fat, cm	1.56	1.66	0.07	0.22
KPH	2.41	2.56	0.8	0.21
Marbling[b]	432	449	12	0.35
Yield grade	2.73	2.79	0.08	0.59

[a]Probability of an effect of copper level.

[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

Table 3-9. Effect of zinc level on carcass traits in heifers (Exp. 1).

Item	80 mg Zn/kg DM	360 mg Zn/kg DM	SEM	Zinc L[a]
HCW, kg	327	332	3	0.31
Dressing %	64.21	64.47	0.17	0.29
Ribeye area, cm^2	90.13	91.38	1.58	0.58
12th-rib fat, cm	1.52	1.69	0.07	0.04
KPH	2.52	2.44	0.09	0.50
Marbling[b]	452	429	12	0.19
Yield grade	2.67	2.86	0.07	0.08

[a]Probability of an effect of zinc level.

[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

Table 3-10. Effect of zinc source on carcass traits in heifers (Exp. 1).

Item	$ZnSO_4$	Availa Zn	SEM	Zinc Source[a]
HCW, kg	331	328	3	0.51
Dressing %	64.58	64.10	0.17	0.06
Ribeye area, cm^2	92.02	89.48	1.58	0.27
12th-rib fat, cm	1.55	1.66	0.07	0.15
KPH	2.53	2.43	0.08	0.40
Marbling[b]	442	439	12	0.84
Yield grade	2.62	2.90	0.09	0.02

[a]Probability of an effect of zinc source.

[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

Table 3-11. Effects of copper level and zinc source on cumulative feedlot performance by steers (Exp. 2).

	12 mg Cu/kg DM		24 mg Cu/kg DM			
Item	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	SEM	CuL x ZnS[a]
Initial wt., kg	342	342	342	340	14	0.72
Final wt., kg	600	588	592	591	8	0.50
Daily gain, kg						
d 0 - 27	1.74[b]	1.93[b]	1.86[b]	1.65[c]	0.07	0.01
d 28 - 56	2.00	1.74	1.94	2.02	0.14	0.24
d 57 - 84	1.93	1.81	1.74	1.97	0.18	0.34
d 85 - 112	1.92[bc]	2.15[b]	2.08[bc]	1.78[c]	0.11	0.02
d 113 - end	1.60[b]	1.13[c]	1.36[bc]	1.62[b]	0.16	0.03
d 0 - end	1.84	1.76	1.80	1.79	0.06	0.52
DM intake, kg/d						
d 0 - 27	8.2	8.7	8.6	8.3	0.4	0.06
d 28 - 56	10.1	9.7	9.4	10.2	0.2	0.06
d 57 - 84	10.7	10.0	10.2	10.5	0.4	0.27
d 85 - 112	11.8	11.4	11.5	11.7	0.3	0.44
d 113 - end	11.2	10.7	11.1	10.6	0.5	0.95
d 0 - end	11.0	11.0	10.8	11.0	0.6	0.83
Gain:feed						
d 0 - 27	0.211[bc]	0.222[b]	0.217[b]	0.198[c]	0.010	0.02
d 28 - 56	0.198	0.177	0.207	0.198	0.012	0.61
d 57 - 84	0.179	0.181	0.170	0.188	0.018	0.60
d 85 - 112	0.163[bc]	0.190[b]	0.181[bc]	0.155[c]	0.010	0.02
d 113 - end	0.144[bc]	0.106[c]	0.120[bc]	0.151[b]	0.014	0.02
d 0 - end	0.168	0.160	0.166	0.163	0.011	0.54

[a]Probability of an interaction between Cu level and Zn source.

[bc]Means within a row with different superscripts differ $P < 0.05$.

[de]Means within a row with different superscripts differ $P < 0.10$.

Table 3-12. Effects of zinc level and zinc source on cumulative feedlot performance by steers (Exp. 2).

	80 mg Zn/kg DM		360 mg Zn/kg DM			
Item	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	SEM	ZnL x ZnS[a]
Initial wt., kg	342	342	342	340	14	0.64
Final wt., kg	594	580	597	599	8	0.31
Daily gain, kg						
d 0 - 27	1.88[b]	1.71[c]	1.72[bc]	1.87[bc]	0.07	0.03
d 28 - 56	1.93	1.81	2.01	1.95	0.14	0.81
d 57 - 84	1.88	1.74	1.79	2.04	0.18	0.29
d 85 - 112	1.95	1.86	2.04	2.07	0.11	0.58
d 113 - end	1.42	1.39	1.54	1.36	0.16	0.65
d 0 - end	1.81	1.70	1.83	1.85	0.06	0.24
DM intake, kg/d						
d 0 - 27	8.5	8.6	8.4	8.4	0.4	0.96
d 28 - 56	9.6	9.8	9.9	10.1	0.3	0.88
d 57 - 84	10.5	9.7	10.3	10.7	0.4	0.19
d 85 - 112	11.7	11.1	11.6	11.8	0.3	0.10
d 113 - end	11.2	10.5	11.1	10.8	0.5	0.46
d 0 - end	10.8	10.7	10.9	11.4	0.6	0.40
Gain:feed						
d 0 - 27	0.221[b]	0.199[c]	0.207[bc]	0.221[b]	0.010	0.01
d 28 - 56	0.202	0.183	0.202	0.192	0.012	0.67
d 57 - 84	0.176	0.180	0.173	0.190	0.018	0.66
d 85 - 112	0.167	0.168	0.177	0.177	0.010	0.97
d 113 - end	0.124	0.133	0.139	0.124	0.014	0.39
d 0 - end	0.167	0.159	0.167	0.164	0.011	0.49

[a]Probability of an interaction between Zn level and Zn source.

[bc]Means within a row with different superscripts differ $P \leq 0.05$.

[de]Means within a row with different superscripts differ $P \leq 0.10$.

Table 3-13. Effects of copper and zinc level on carcass traits in steers (Exp. 2).

	12 mg Cu/kg DM		24 mg Cu/kg DM			
Item	80 mg Zn/kg DM	360 mg Zn/kg DM	80 mg Zn/kg DM	360 mg Zn/kg DM	SEM	CuL x ZnL[a]
HCW, kg	369	378	368	374	6	0.75
Dressing %	62.6	63.6[c]	62.5	62.6	0.3	0.09
Ribeye area, cm^2	81.3	80.2	82.1	79.5	1.9	0.25
12th-rib fat, cm	1.56	1.65	1.42	1.72	0.09	0.26
KPH	2.26	2.27	2.29	2.36	0.10	0.79
Marbling[b]	429	449	440	446	24	0.65
Yield grade	3.47	3.74	3.33	3.84	0.13	0.37

[a]Probability of an interaction between Cu level and Zn level.

[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

[cd]Means in a row with different superscripts differ $P < 0.10$.

Table 3-14. Effects of copper level and zinc source on carcass traits in steers (Exp. 2).

	12 mg Cu/kg DM		24 mg Cu/kg DM			
Item	$ZnSO_4$	Availa Zn	$ZnSO_4$	Availa Zn	SEM	CuL x ZnS[a]
HCW, kg	379	369	371	370	6	0.28
Dressing %	63.5[c]	62.7[d]	62.3[d]	62.8[cd]	0.3	0.03
Ribeye area, cm^2	80.0[de]	81.5[cd]	82.2[c]	79.4[e]	1.9	< 0.01
12th-rib fat, cm	1.67	1.54	1.60	1.55	0.09	0.66
KPH	2.25	2.28	2.31	2.34	0.10	0.99
Marbling[b]	441	438	447	439	24	0.84
Yield grade	3.74	3.47	3.59	3.58	0.13	0.32

[a]Probability of an interaction between Cu level and Zn source.

[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

[cde]Means within a row with different superscripts differ $P < 0.05$.

Table 3-15. Effect of zinc level on carcass traits in steers (Exp. 2).

Item	80 mg Zn/kg DM	360 mg Zn/kg DM	SEM	Zinc L[a]
HCW, kg	368	376	5	0.06
Dressing %	62.6	63.1	0.2	0.08
Ribeye area, cm^2	81.7	79.9	1.9	0.01
12th-rib fat, cm	1.49	1.69	0.06	0.03
KPH	2.28	2.31	0.07	0.72
Marbling[b]	435	447	22	0.37
Yield grade	3.40	3.79	0.09	0.01

[a]Probability of an effect of zinc level.

[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

CHAPTER IV

EFFECT OF ZINC LEVEL AND SOURCE ON FINISHING CATTLE PERFORMANCE AND CARCASS TRAITS

L. J. McBeth[*], C. R. Krehbiel[*], M. S. Brown[†], J. J. Martin[‡], C. S. Strasia[*], C. K. Larson, and D. R. Gill[*]

[*]Oklahoma State University, Department of Animal Sciences, Stillwater, 74074

[†]Division of Agriculture, West Texas A&M University, Canyon, TX 79016 and Texas Agricultural Experiment Station, Amarillo, TX 79106

[‡]Panhandle State University, Division of Agriculture, Goodwell, Oklahoma, 73939

Abstract

Dietary Zn formulations for feedlot cattle are commonly between 50 and 80 mg of supplemental Zn/kg of diet, and often may not consider Zn provided in basal ingredients. Three trials were conducted to determine the effects of Zn source and level on performance and carcass characteristics of finishing steers. In Trial 1, 336 steers (avg initial BW = 349 ± 22 kg) were blocked by weight and fed for 130 d. Treatments included (DM basis): 1) 60 mg of Zn from $ZnSO_4$/kg of diet (control); 2) control plus 30 mg of Zn from $ZnSO_4$/kg of diet; 3) control plus 30 mg of Zn from ZINPRO®100 Zn methionine/kg of diet; 4) control plus 30 mg of Zn from

Availa®Zn/kg diet; 5) control plus 60 mg of Zn from $ZnSO_4$/kg of diet; and 6) control plus 60 mg of Zn from Availa Zn/kg of diet. In Trial 2, 277 steers (avg initial BW = 349 ± 22 kg) were blocked by weight and fed for either 151 or 166 d. Treatments for Trial 2 were the same as for Trial 1 with the exception of Treatment 5, which contained control (60 mg of Zn from $ZnSO_4$/kg) plus 60 mg of Zn from Zn methionine/kg of diet. In Trial 3, 160 crossbred steers (avg initial BW = 320 kg ± 40) were blocked by weight and fed for 139 d. Treatments were the same as Treatments 1 through 4 of Trials 1 and 2. In Trial 1, a trend for a linear increase ($P = 0.07$) in ADG was observed with increasing Zn level from d 0 to the end of the feeding period. Dry matter intake increased ($P = 0.03$) linearly with increasing Zn level from d 0 to the end of the feeding period. Steers consuming Availa Zn had greater ($P = 0.02$) GF than those consuming Zn methionine. Steers consuming organic sources of Zn had greater ($P = 0.02$) marbling than steers consuming Zn from $ZnSO_4$, and steers consuming Zn methionine had greater ($P = 0.04$) marbling than steers consuming Availa Zn. Steers consuming Availa Zn had greater ($P = 0.04$) longissimus muscle area than steers consuming Zn methionine. There was a linear increase ($P = 0.04$) in kidney, pelvic and heart fat (KPH) with increasing Zn level. In Trial 2, 12th-rib fat tended ($P = 0.09$) to increase quadratically with increasing Zn level and tended ($P = 0.08$) to be greater for steers consuming Zn methionine vs. Availa Zn. In Trial 3, feed efficiency was increased ($P = 0.04$) from d 0 to 56 for steers consuming Availa Zn vs. those consuming Zn methionine. Our data suggest that increasing Zn level up to 120 mg Zn/kg of DM and inclusion of an organic Zn source can enhance carcass quality, ADG and DMI in finishing cattle.

Key Words: Zinc Level, Zinc Source, Finishing Cattle

Introduction

A review of 22 trials summarizing finishing performance and carcass merit of feedlot cattle (Anonymous, 2001) fed basal diets containing from 24 to 122 mg of Zn/kg of DM reported greater ADG (3.2%), greater gain efficiency (4.0%), and a tendency for more carcasses grading at least low Choice when cattle were supplemented with approximately 40 mg of additional Zn/kg of DM from a metal-amino acid complex, zinc methionine (Zinpro 100®; Zinpro Corp., Inc., Eden Prairie, MN). However, few data are available quantifying growth performance by feedlot cattle supplemented with a more recently developed Zn-amino acid complex, Availa Zn® (Zinpro Corp., Inc.). Malcolm-Callis et al. (2000) reported that performance by finishing steers was similar when $ZnSO_4$, Availa Zn, or a Zn-polysaccharide complex was fed. In contrast, Green et al. (1988) reported increased marbling, quality grade and kidney, pelvic and heart fat percent when Zn methione was supplemented vs. ZnO at 360 mg Zn/kg DM. While it is common practice to utilize organic sources of Zn in feedlot diets (Galyean and Gleghorn, 2002) there is little literature addressing this practice. A survey of feedlot nutritional consultants (Glayean and Gleghorn, 2001) indicates that practical dietary Zn formulations for feedlot cattle are commonly between 50 and 80 mg/kg of diet DM. Data further suggest that formulation targets for Zn and other trace minerals often reflect desired supplemental mineral addition, likely because Zn and other trace minerals in basal ingredients can be variable in content and availability. The objective of the present experiments was to evaluate the influence of

Zn source ($ZnSO_4$, Zinpro 100®, and Availa-Zn®) and level on growth performance and carcass characteristics.

Materials and Methods

Experiment 1

Approximately 550 crossbred yearling steers were delivered to CRI Feedlot near Goodwell, OK, on July 25, 2001. Steers were owned by Harold Wooderson of Blackwell, OK. On the morning of July 26, 336 steers (avg initial BW = 349 ± 22 kg) were sorted and processed. At processing, steers were ear tagged, horn tipped as needed, implanted with Ralgro (Schering-Plough Animal Health, Union, NJ), vaccinated with IBR-PI_3-BVD-BRSV (Titanium 5, Agri Laboratories, Ltd, St. Joseph, MO), vaccinated with a seven-way clostridial preparation (Vision 7, Intervet, Millsboro, DE), and treated for control of external and internal parasites (Ivomec-Plus injectable, Merial, Duluth, GA). Steers received a second implant (Revalor-S, Intervet, Millsboro, DE) on day 56 of the finishing period. After processing, 336 steers were trucked to the Oklahoma Panhandle State University (**OPSU**) Research Center, Goodwell, OK. On arrival, steers were weighed individually, blocked by weight into five weight blocks, and assigned randomly to 30 pens (24 pens of 12 steers each and six pens of eight steers each).

Treatments included (DM basis): 1) 60 mg of Zn from $ZnSO_4$/kg of diet (control); 2) control plus 30 mg of Zn from $ZnSO_4$/kg of diet; 3) control plus 30 mg of Zn from ZINPRO®100 (Zinpro Corp., Inc., Eden Prairie, MN) Zn methionine/kg of diet; 4) control plus 30 mg of Zn from Availa®Zn (Zinpro Corp., Inc., Eden Prairie,

MN)/kg diet; 5) control plus 60 mg of Zn from $ZnSO_4$/kg of diet; and 6) control plus 60 mg of Zn from Availa Zn/kg of diet. Diets were formulated to meet or exceed NRC (1996) nutrient requirements (Table 1). Monensin (33 mg/kg of diet; Elanco Animal Health, Greenfield, IN) and tylosin (11 mg/kg of diet; Elanco Animal Health, Greenfield, IN) were fed. Steers were gradually adapted to the final diet by offering approximately 65, 75, and 85% concentrate diets for 7, 7 and 7 d, respectively. The basal diet was purchased from Texas County Feed Yard, Guymon, OK by Mr. Wooderson. Steers were fed twice daily at 0700 and 1300. A premix containing ground corn and the appropriate treatment was top-dressed at a rate of 0.23 $kg \cdot hd^{-1} \cdot d^{-1}$ at the evening feeding. Feed refused was weighed every 28 d. In addition, diet samples were collected, and DM content of the diets and dietary ingredients were determined. Diet and ingredient samples were composited by 28-d periods, allowed to air dry, and ground in a Wiley mill to pass a 1-mm screen. Diet samples and ingredients were returned to the Oklahoma State University campus and analyzed for N, ash (AOAC, 1990) and ADF (Goering and Van Soest, 1970). Steers were weighed individually before feeding once every 28 d throughout the trial. Initial weight was analyzed as taken, whereas all interim weights were analyzed with a 4% pencil shrink. Final live weight was calculated by dividing hot carcass weight by a common dressing percentage (65%). Feed intake was measured and gain efficiency was calculated every 28 d. Steers were slaughtered at National Beef, Liberal, KS on December 4, 2001. Hot carcass weight was determined following harvest, and carcasses were evaluated after a 24-h chill for subcutaneous fat depth at the 12th rib

(**BF**), longissimus muscle area (**LMA**), percentage kidney, pelvic, and heart fat (**KPH**), yield grade (**YG**), marbling score, and quality grade (USDA, 1997).

Data for BW, DMI, ADG, GF and normally distributed carcass characteristics were analyzed as a randomized complete block design using the Proc Mixed procedure of SAS Release 8.02 (SAS Institute Inc., Cary, NC). The model included treatment, and block was included as a random variable. Pen served as the experimental unit. There were 5 replicates for each treatment available for the analyses. Pre-planned comparisons were: 1) linear Zn level; 2) quadratic Zn level; 3) inorganic vs organic Zn; and 4) Zn methionine vs Availa Zn. Results are discussed as significant if $P \leq 0.05$, and as tendencies if $P \leq 0.06$ to $P \leq 0.10$.

Experiment 2

Two hundred seventy crossbred steers (avg initial BW = 349 ± 22 kg) were purchased from an order buyer and delivered to the WTAMU Research Feedlot on 15 August 2001. All procedures were reviewed and approved by the Amarillo-Area Cooperative Research, Education, and Extension Triangle Animal Care and Use Committee (protocol number 2001 – 08). Animals were processed on arrival, and processing included: individual identification; individual BW determination; vaccination against viral antigens (IBR, PI_3, BRSV, BVD; Titanium 5, Agri Laboratories, St. Joseph, MO) and Clostridial organisms (Vision 7 with Spur; Intervet, Inc., Millsboro, DE); treatment for external and internal parasites (Cydectin; Fort Dodge Animal Health, Fort Dodge, IA); excision of previous implant(s); and administering an initial implant (Ralgro, Schering-Plough Animal Health, Union, NJ).

All animals were fed a basal 55% concentrate diet at a common percentage of BW for 8 d before initial BW was determined on 23 August 2001. Six light steers were excluded from the study; therefore, 180 steers were blocked by BW and randomly assigned to treatments (5 pens/treatment, 9 steers/pen) on 24 August 2001.

Treatments included: 1) 60 mg of supplemental Zn from $ZnSO_4$/kg DM (control); 2) 90 mg of Zn from $ZnSO_4$/kg DM; 3) control plus 30 mg of Zn from Availa Zn/kg DM; 4) control plus 30 mg of Zn from Zinpro 100/kg DM; 5) control plus 60 mg of Zn from Availa Zn/kg DM; and 6) control plus 60 mg of Zn from Zinpro 100/kg DM. Zinc concentration in the positive control diet was selected to be representative of current industry formulations. Reimplant date was adjusted across blocks to allow an average of 56 d of exposure to the initial implant and a similar number of days of exposure to the terminal implant. Steers in the heaviest block (block 5) were weighed and reimplanted with Revalor-S (Hoechst Roussel Vet, Clinton, NJ) after 42 d and fed for 126 d. Steers in blocks 3 and 4 were weighed and reimplanted with Revalor-S after 56 d and fed for 151 d, whereas steers in blocks 1 and 2 were weighed and reimplanted with Revalor-S after 70 d and fed for 166 d. All BW measurements were acquired using a single animal scale. The scale was validated before each use using certified weights and calibrated as needed.

Steers were adapted to 92% concentrate diets (Table 1) by feeding 70 and 81% concentrate diets for 6 and 7 d, respectively. Meal-form supplements were manufactured for each treatment using a stationary ribbon mixer (Model No. S-3; H. C. Davis Sons Manufacturing Co., Inc., Bonner Springs, KS). The ribbon mixer was cleaned between each batch using compressed air. Samples of each Zn source were

assayed (described subsequently) for Zn before premixes were prepared, and laboratory results were used for formulation. Diets were prepared once daily in a stationary paddle mixer (Model No. 84-8; Roto-Mix, Inc., Dodge City, KS), and flushed with whole corn between each batch. Samples of diets and dietary ingredients were collected weekly, DM determined, and samples composited to 28-d intervals. As-fed diet composition was updated weekly. Composited diet samples were dried (55°C for 48 h), ground to pass a 2-mm screen, and assayed for N by micro-Kjeldahl, EE (AOAC, 1990), ash (500°C for 16 h), ADF (Goering and Van Soest, 1970) and minerals by ICP (AOAC, 1990).

Cattle were slaughtered at a commercial facility (IBP, Amarillo, TX). Hot carcass weight was determined after slaughter. Carcasses were evaluated after chilling for approximately 48 h for: LMA; BF; KPH; YG; marbling score; quality grade (USDA, 1997); and presence and severity of liver abscesses (Brink et al., 1990) by the Beef Carcass Research Center of West Texas A&M University. Carcass-adjusted final BW was determined by dividing hot carcass weight by the overall average dressing percentage. Although carcass fatness seemed to differ numerically, final live BW of cattle in blocks 1 and 2 was likely influenced by the muddy pen conditions evident at that time. Thus, carcass-adjusted performance is presented.

Data for BW, DMI, ADG, GF and normally distributed carcass characteristics were analyzed as a randomized complete block design using the Proc Mixed procedure of SAS Release 8.02 (SAS Institute Inc., Cary, NC). The model included treatment, and block was included as a random variable. Pen served as the experimental unit. There were 5 replicates for each treatment available for the

analyses. Pre-planned comparisons included: 1) linear Zn level; 2) quadratic Zn level; 3) inorganic vs organic Zn; and 4) Zn methionine vs Availa Zn. Results are discussed as significant if $P \leq 0.05$, and as tendencies if $P \leq 0.06$ to $P \leq 0.10$.

Experiment 3

One hundred sixty crossbred steers (avg initial BW = 320 kg ± 40) were delivered to the Willard Sparks Beef Research Center near Stillwater, OK on March 14, 2003. On arrival, steers were individually weighed and ear tagged. On the following day, steers were horn tipped as needed, implanted with Revalor-S (Intervet, Millsboro, DE), vaccinated with IBR-PI_3-BVD-BRSV (Titanium 5, Agri Laboratories, St. Joseph, MO), vaccinated with a seven-way clostridial preparation (Vision 7, Intervet, Millsboro, DE), and treated for control of external and internal parasites (Ivomec-Plus injectable, Merial, Duluth, GA). Steers were blocked by initial BW into eight weight blocks. Body weight (unshrunk) taken on the day of arrival (day 0) was considered initial weight. Within block steers were assigned randomly to 4 pens (5 steers/pen; 8 pens/treatment).

Treatments included: 1) 60 mg of supplemental Zn from $ZnSO_4$/kg DM (control); 2) 90 mg of Zn from $ZnSO_4$/kg DM; 3) control plus 30 mg of Zn from Availa Zn/kg DM; 4) control plus 30 mg of Zn from Zinpro 100/kg DM. The basal diet is shown in Table 3, and was formulated to meet or exceed NRC (1996) nutrient requirements. Monensin (33 mg/kg of diet) and tylosin (11 mg/kg of diet) were fed. Steers were gradually adapted to the final 90% concentrate diet by offering 65, 75, and 85% concentrate diets each for seven days. Feed refused was weighed at 28-d

intervals and as needed (e.g., following inclement weather). In addition, diet and ingredient samples were collected, and DM samples were composited by 28-d periods, allowed to air dry, and ground in a Wiley mill to pass a 1-mm screen. Diet samples were analyzed for N, starch, ash (AOAC, 1990), ADF (Goering and Van Soest, 1970) and Zn by ICP (AOAC, 1990). Interim unshrunk BW was determined at 28-d intervals. Steers were slaughtered at a commercial facility (Monfort, Cactus, TX). Hot carcass weight, BF, KPH, LMA, marbling score, YG and quality grade were determined by the Beef Carcass Research Center of West Texas A&M University.

Data for BW, DMI, ADG, GF and normally distributed carcass characteristics were analyzed as a randomized complete block design using the Proc Mixed procedure of SAS Release 8.02 (SAS Institute Inc., Cary, NC). The model included treatment, and block was included as a random variable. Pen served as the experimental unit. Pre-planned comparisons were: 1) linear Zn level (60 vs 90 ppm); 2) inorganic vs organic Zn; and 3) Zn Methionine vs Availa Zn. Carcass data for 73 carcasses were lost at harvest. Therefore, data were analyzed for pens that had carcass information for no less than two animals per pen. If this criterion was not met the pen was eliminated from the analyses. Results are discussed as significant if $P \leq 0.05$, and as tendencies if $P \leq 0.06$ to $P \leq 0.10$.

Results

Experiment 1

Increasing Zn level tended ($P = 0.08$) to result in a linear increase in calculated final BW. There was no difference in ADG from d 0 to 56 (Table 4). However, a trend ($P = 0.07$) for a linear increase in ADG was observed with increasing Zn level from d 0 to the end of the feeding period. Dry matter intake tended ($P = 0.06$) to increase linearly with increasing Zn level from d 0 to 56, and increased ($P = 0.03$) linearly with increasing Zn level from d 0 to the end of the feeding period. Steers consuming $ZnSO_4$ tended ($P = 0.10$) to have greater GF compared with steers consuming organic sources of Zn from d 0 to 56. During the same period steers consuming Availa Zn had greater ($P = 0.02$) GF than steers consuming Zn methionine. In addition, there was a tendency ($P = 0.09$) for a similar effect from d 0 to the end of the feeding period.

Hot carcass weight, KPH and YG were not affected by Zn level or source. Marbling scores tended (Linear effect, $P = 0.10$) to increase with increasing Zn level. In addition, steers consuming organic sources of Zn had higher ($P = 0.02$) marbling scores than steers consuming Zn from $ZnSO_4$, and steers consuming Zn methionine had higher ($P = 0.04$) marbling scores than steers consuming Availa Zn with dietary Zn at 90 mg Zn/kg DM. In contrast, steers consuming Availa Zn had greater ($P = 0.04$) LMA than steers consuming Zn methionine. There was a tendency ($P = 0.08$) for a linear increase in KPH with increasing level of Zn.

Experiment 2

No differences ($P > 0.10$) were observed for BW, DMI or GF. Average daily gain tended (P = 0.10) to be greater for steers consuming Availa Zn vs. Zn methionine. Dressing percent increased (P = 0.02) linearly with increasing Zn levels (Table 5). Steers consuming Zn methionine tended ($P = 0.08$) to have greater BF than steers consuming Availa Zn. Similarly, BF tended ($P = 0.09$) to increase quadratically with increasing Zn level.

Experiment 3

No differences ($P > 0.10$) were observed for BW, ADG, DMI (Table 6) or carcass characteristics (Table 7). Gain efficiency was increased ($P = 0.04$) from d 0 to 56 for steers consuming Availa Zn vs. steers consuming Zn methionine (Table 6).

Discussion

Spears (1989) reported that apparent absorption of ZnO and Zn methionine appeared to be similar; however, urinary excretion of Zn was greater for ZnO suggesting that these two Zn sources may be metabolized differently. Formation of insoluble, nonabsorbable complexes as well as antagonists of Zn absorption might influence Zn availability. Regardless of differences in source, McCusker (1998) demonstrated that Zn plays an important role in animal growth by promoting cellular delivery of IGF from IGFBP 3 and 5. Difference in utilization between organic and inorganic sources needs to be defined.

In Exp. 1 both ADG and DMI increased linearly with increasing Zn level; however, no differences in overall performance were observed for Exp. 2 and 3. Similar to Exp.1, Malcolm-Callis (2000) reported a linear increase in DMI with Zn levels of 20, 100, and 200 mg Zn/kg DM from $ZnSO_4$ for a 112-d finishing period. The Zn levels utilized in their experiment were similar to those utilized in the present experiments; however, $ZnSO_4$ was the only source used. Galyean et al. (1995) reported increased ADG for a 161-d finishing trial for steers fed diets containing a basal diet plus 35 mg supplemental Zn/kg DM from Zn methionine, 70 mg supplemental Zn/kg DM from $ZnSO_4$, and 70 mg supplemental Zn/kg DM from Zn methionine vs. steers fed the basal diet containing 30 mg supplemental Zn from $ZnSO_4$. However, no differences were reported for DMI across the entire feeding period (Galyean et al., 1995). Spears and Kegley (2002) reported increased DMI for steers fed two Zn proteinate sources vs. those fed ZnO. Although results are inconsistent, these data generally suggest that increasing Zn above 30 mg/kg DM might increase DMI. However, reasons for discrepancies among experiments remain unclear.

Gain efficiency was greater for steers consuming Availa Zn than those consuming Zn methionine from d 0 to 56 in Exp. 1 and Exp. 3. Malcolm-Callis et al. (2000) reported a tendency for greater GF for steers consuming organic Zn sources vs. $ZnSO_4$ from d 84 to 112 of the finishing period, but no difference for the entire feeding period. Similar to the present experiments, Spears and Kegley (2002) reported increased GF for steers consuming Zn proteinate vs. steers consuming ZnO. Other authors (Greene et al., 1998; Galyean et al., 1995) have reported no difference

in GF when steers were fed Zn levels well above the NRC (1996) recommended levels from both organic and inorganic Zn sources.

Longissimus muscle area was increased for steers consuming Availa Zn vs. Zn methionine in Exp. 1. Similarly, Spears and Kegley (2002) reported increased LMA for steers fed Zn proteinate vs. those fed ZnO. However, other authors (Galyean et al., 1995; Greene et al., 1988; Malcolm-Callis et al., 2000) have reported no difference in LMA over similar ranges of Zn levels and Zn sources. In Exp. 2, 12th-rib fat tended to increase quadratically with increasing Zn level. These results are similar to those reported by Malcolm-Callis et al. (2000) who reported a quadratic increase in 12th-rib fat when Zn was fed at 20, 100, or 200 mg Zn/kg DM from $ZnSO_4$. There was also a tendency for a linear increase in marbling with increasing Zn level in the present Exp. 1. This is consistent with results of Spears and Kegley (2002) who reported increased marbling when steers were supplemented with 51 mg Zn/kg DM from Zn proteinate or ZnO vs. control diets that contained 26 mg Zn/kg DM. In contrast, Galyean et al. (1995) reported no differences in marbling with treatments (DM basis) including a basal diet with 30 mg Zn from $ZnSO_4$, basal plus 35 mg Zn from Zn methionine, basal plus 70 mg Zn from $ZnSO_4$, or basal plus 70 mg Zn from Zn methionine. Several authors have reported no differences in KPH when various levels and sources of Zn were supplemented (Galyean et al., 1995; Malcolm-Callis et al., 2000; Spears and Kegley, 2002). In contrast, Greene et al. (1998) reported that KPH was greater for steers fed Zn methionine vs. those fed ZnO or unsupplemented control diets. Similarly, KPH tended to increase with increasing Zn level in the present Exp. 1.

In general, data suggest increased external and/or internal carcass fat is a more consistent response to supplemental Zn-amino acid complexes than altered growth performance at dietary concentrations between 80 and 280 mg of total Zn/kg of DM. The lower portion of this range coincides with dietary Zn concentrations fed to steers from which adipocytes demonstrated a dose-dependent increase in lipid synthesis from acetate when incubated with insulin (Archibeque et al., 2001). While the effects of Zn level and Zn source have met with inconsistent results, there has been evidence linking Zn to fat deposition. Recent Japanese work has suggested that serum Zn concentration was positively related to serum adipogenic activity (Tanaka et al., 2001). The same authors reported that the specific activity of glycerol phosphate dehydrogenase was increased by addition of Zn to the media of cultured 3T3-L1 cells without insulin and in the presence of insulin. Shisheva et al. (1992) reported increases in glucose uptake by rat adipocytes both in the presence of Zn and insulin but the greatest response was in the presence of both Zn and insulin. This enhanced substrate uptake by adipocytes in response to enhanced Zn status should be of particular importance in the later portion of the feeding period, because glucose metabolism of steers becomes less responsive to insulin as steers become older and fatter (Eismann et al., 1997). Conversely, Greene et al. (1998) postulated that changes in quality and marbling score could be due to methionine provided with the chelated supplemental Zn. In the present experiments, the added induction of marbling by Availa Zn (Zn bound to a non-specific amino acid) might suggest that other amino acids in addition to methionine might play a role in the increase in adiposity in the longissimus muscle.

Implications

Although results are inconsistent, zinc level and supplementation of organic zinc sources might enhance performance and carcass quality of finishing steers. While the relationship between zinc sources and levels is not clear, there appears to be an effect of zinc on carcass fatness at dietary concentrations between 80 and 280 mg of total zinc/kg of dry matter. The potential for improved carcass merit with increasing levels and organic sources of zinc warrants further research.

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Table 4-1. Dry matter and nutrient composition of the finishing diet (Exp.1).

Ingredients	% of diet DM
Steam flaked corn	81.0
Corn silage	4.5
Alfalfa hay	4.5
Yellow grease	3.0
Supplement[a]	7.0
Nutrients[b]	
Dry matter, % as fed	77.1
CP, % of DM	12.99
ADF, % of DM	4.77
Calcium, % of DM	0.49
Phosphorus, % of DM	0.31
Potassium, % of DM	0.56
Magnesium, % of DM	0.16
Sulfur, % of DM	0.15
Manganese, mg/kg of DM	39.8
Cobalt, mg/kg of DM	0.09
Iron, mg/kg of DM	49.9
Selenium, mg/kg of DM	0.15
Copper, mg/kg of DM	8.1
Zinc, mg/kg of DM	59.8

[a]Contained (% DM basis): cottonseed meal (40.94), soybean meal 47.7 (28.57), limestone 38% (14.00), urea (10.00), salt (4.29), tallow (1.43), Rumensin 80 (0.29), Tylan 40 (0.14), zinc sulfate (0.17), vitamin A (0.10), manganous oxide (0.06), and copper sulfate (0.01).

[b]All values are estimate based on NRC (1996) values for feedstuffs.

Table 4-2. Ingredient and chemical composition of the finishing diet (Exp.2).

Ingredient composition, % of DM	% of diet DM
Whole shelled corn	79.25
Cottonseed meal, solvent 41%	2.25
Supplement[b]	3.0
Cane molasses	5.0
Choice white grease	2.5
Alfalfa hay	8.0
Chemical composition[c]	
CP, % of DM	13.2
EE, % of DM	5.94
ADF, % of DM	6.70
Ash, % of DM	5.38
K, % of DM	0.84
Ca, % of DM	0.65
P, % of DM	0.30
Mg, % of DM	0.28
S, % of DM	0.28
Na, % of DM	0.15
Fe, mg/kg of DM	158
Zn, mg/kg of DM	89
Mn, mg/kg of DM	54
Cu, mg/kg of DM	18

[b]Provided the following nutrients beyond basal ingredients: 0.2 mg of Co, 10 mg of Cu, 10 mg of Fe, 0.5 mg of I, 40 mg of Mn, 0.05 mg of Se, 2,300 IU of vitamin A, 15 IU of vitamin E, 30.9 g of monensin, and 11 mg of tylosin/kg of diet DM; and 0.4% Ca, 0.06% K, 0.09% Mg, 0.06% S, 2.32% CP from urea, 0.25% NaCl, and 0.0075% mineral oil in the final diet.

[c]Determined analytically from weekly samples composited over the course of the study.

Table 4-3. Dry matter and nutrient composition of the basal finishing diet (Exp.3).

Ingredients	% of diet DM
Rolled corn	76.50
Ground alfalfa	10.00
Cane molasses	4.00
Yellow grease	2.00
Supplement[a]	7.50
Nutrients[b]	
Dry matter, % as fed	87.91
CP, % of DM	13.19
ADF, % of DM	6.27
NDF, % of DM	12.25
Calcium, % of DM	0.68
Phosphorus, % of DM	0.40
Potassium, % of DM	0.77
Magnesium, % of DM	0.18
Sulfur, % of DM	0.18
Manganese, mg/kg	36.2
Cobalt, mg/kg	0.13
Iron, mg/kg	126.5
Copper, mg/kg	8.6
Selenium, mg/kg	0.14
Zinc, mg/kg	80.3

[a]Contained (% DM basis): cottonseed meal (14.00), soybean meal 47.7 (42.00), limestone 38% (12.00), urea (8.00), salt (3.33),Wheat midds (13.16), Rumensin 80 (0.25), Tylan 40 (0.13), zinc sulfate (0.17), vitamin A (0.15), manganous oxide (0.003), dicalcium phosphate (6.67).

[b]All values are estimate based on NRC (1996) values for feedstuffs.

Table 4-4. Effects of zinc level and zinc source on feedlot performance and carcass characteristics in steers (Exp.1).

		60 mg/kg $ZnSO_4$			60 mg/kg $ZnSO_4$			Contrasts			
$ZnSO_4$ Availa Zn Zn Methionine	60 mg/kg $ZnSO_4$	30 mg/kg $ZnSO_4$	30 mg/kg Availa Zn	30 mg/kg Zn Met	60 mg/kg $ZnSO_4$	60 mg/kg Availa Zn	SEM[a]	Linear Zn[b]	Quadratic Zn[c]	Inorganic vs Organic[d]	Zn Met vs Availa Zn[e]
BW, kg											
Initial	346	347	347	347	346	347	11	1.00	0.37	0.25	0.82
d 56	454	464	461	456	462	458	11	0.14	0.37	0.49	0.33
Final	572	589	584	577	584	589	14	0.08	0.71	0.76	0.45
Daily gain, kg											
d 0 - 56	1.96	2.13	2.07	1.98	2.11	2.03	0.06	0.13	0.53	0.34	0.28
d 0 – end[f]	1.74	1.87	1.82	1.77	1.83	1.86	0.05	0.07	0.77	0.88	0.44
DM intake, kg/d											
d 0 - 56	9.60	10.12	9.98	10.55	10.39	10.14	0.34	0.06	0.45	0.41	0.16
d 0 - end	9.66	10.24	10.28	10.49	10.47	10.19	0.29	0.03	0.27	0.34	0.54
ADG:DMI											
d 0 - 56	0.204	0.211	0.208	0.189	0.204	0.200	0.006	0.68	0.96	0.10	0.02
d 0 - end	0.180	0.182	0.178	0.169	0.175	0.183	0.004	0.87	0.32	0.39	0.09
Dressing %	65.0	65.2	65.7	65.8	64.9	66.3	0.5	0.31	0.73	0.03	0.78
Hot carcass wt., kg	374	386	382	378	382	385	9	0.06	0.64	0.76	0.44
Marbling[g]	382	399	391	424	388	422	11	0.10	0.40	0.02	0.04
External fat, cm	1.15	1.23	1.18	1.15	1.26	1.19	0.06	0.37	0.75	0.45	0.68
Ribeye area, cm^2	93.1	96.2	96.1	92.5	95.0	95.8	1.3	0.12	0.74	0.97	0.04
KPH, %	1.31	1.41	1.38	1.44	1.43	1.48	0.07	0.08	0.97	0.37	0.52
Yield grade	2.41	2.45	2.38	2.49	2.52	2.44	0.11	0.61	0.81	0.78	0.46

[a]Standard error of the least squares means.
[b]Significance level of linear contrast of Zn level.
[c] Significance level of quadratic contrast of Zn level.
[d]Significance level of contrast of the average of 60 mg $ZnSO_4$/ kg DM + 30 mg Availa® Zn/kg DM, 60 mg $ZnSO_4$/kg DM + 30 mg Zn methionine/kg DM, and 60 mg $ZnSO_4$/kg DM + 60 mg Availa® Zn/kg DM vs. the average of 60 mg $ZnSO_4$/kg DM, 90 mg $ZnSO_4$/kg DM and 120 mg $ZnSO_4$/kg DM.
[e]Significance level of contrast of the 60 mg $ZnSO_4$/kg DM + 30 mg Availa® Zn/kg DM vs. 60 mg $ZnSO_4$/ kg DM + 30 mg Zn methionine/kg, DM.
[f]Days on feed per block.
[g]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

Table 4-5. Effects of zinc level and zinc source on feedlot performance and carcass characteristics in steers (Exp.2).

		60 mg/kg $ZnSO_4$			60 mg/kg $ZnSO_4$			Contrasts			
Item	60 mg/kg $ZnSO_4$	30 mg/kg $ZnSO_4$	30 mg/kg Zn Met	30 mg/kg Availa Zn	60 mg/kg Zn Met	60 mg/kg Availa Zn	SEM[a]	Linear Zn[b]	Quadratic Zn[c]	Inorganic vs Organic[d]	Zn Met vs Availa Zn[e]
BW, kg											
Initial	325	325	325	325	325	326	12	0.73	0.49	0.47	0.40
d 56	437	435	435	439	436	435	6	0.80	0.91	0.71	0.71
Final	580	575	577	586	578	591	8	0.50	0.49	0.86	0.09
Daily gain, kg											
d 0 - 56	1.90	1.87	1.86	1.92	1.87	1.87	0.06	0.72	0.88	0.74	0.59
d 0 - end	1.68	1.65	1.66	1.72	1.67	1.75	0.04	0.49	0.53	0.79	0.10
DM intake, kg/d											
d 0 - 56	8.92	8.95	8.99	9.10	9.00	8.87	0.13	0.93	0.34	0.23	0.87
d 0 - end	9.95	9.82	9.74	9.95	9.79	1.01	0.22	0.78	0.47	0.71	0.12
ADG:DMI											
d 0 - 56	0.212	0.208	0.208	0.212	0.210	0.210	0.006	0.78	0.78	1.00	0.73
d 0 - end	0.170	0.168	0.170	0.174	0.170	0.172	0.004	0.83	1.00	0.54	0.43
Dressing %	60.9	61.7	61.7	62.0	61.7	61.7	0.3	0.02	0.10	0.15	0.68
Hot carcass wt., kg	357	354	356	361	356	364	5	0.52	0.55	0.79	0.08
Marbling[f]	413	398	414	397	403	402	12	0.58	0.83	0.91	0.56
External fat, cm	1.12	1.12	1.01	1.18	1.23	1.25	0.09	0.13	0.09	0.15	0.16
Ribeye area, cm^2	83.1	84.1	83.0	84.3	84.9	84.2	2.6	0.42	0.82	0.72	0.82
KPH, %	2.00	2.00	2.08	2.04	2.08	2.03	0.06	0.37	0.96	0.45	0.36
Yield grade	2.86	2.80	2.77	2.91	2.89	3.00	0.19	0.50	0.25	0.54	0.22

[a]Standard error of the least squares means.
[b]Significance level of linear contrast of Zn level.
[c] Significance level of quadratic contrast of Zn level.
[d]Significance level of contrast of the average of 60 mg $ZnSO_4$/ kg DM + 30 mg Availa® Zn/kg DM, 60 mg $ZnSO_4$/kg DM + 30 mg Zn methionine/kg DM, and 60 mg $ZnSO_4$/kg DM + 60 mg Availa® Zn/kg DM vs. the average of 60 mg $ZnSO_4$/kg DM, 90 mg $ZnSO_4$/kg DM and 120 mg $ZnSO_4$/kg DM.
[e]Significance level of contrast of the average of 60 mg $ZnSO_4$/kg DM + 30 mg Availa® Zn/kg DM,and 60 mg $ZnSO_4$/kg DM + 60 mg Availa® Zn/kg DM vs. 60 mg $ZnSO_4$/ kg DM + 30 mg Zn methionine/kg, DM, and 60 mg $ZnSO_4$/ kg DM + 60 mg Zn methionine/kg, DM.
[f]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

Table 4-6. Effects of zinc level and source on feedlot cattle performance (Exp.3).

		60 mg/kg $ZnSO_4$				Contrasts		
Item	60 mg/kg $ZnSO_4$	30 mg/kg $ZnSO_4$	30 mg/kg Availa Zn	30 mg/kg Zn Met	SEM[a]	60 vs. 90 mg/kg[b]	Inorganic vs Organic[c]	Availa Zn vs Zn methionine[c]
BW, kg								
Initial	357	356	356	356	7	0.40	0.22	0.10
d 56	464	462	464	461	9	0.58	0.78	0.48
Final	596	589	589	598	10	0.47	0.84	0.19
Daily gain, kg								
d 0 - 56	1.92	1.90	1.93	1.87	0.07	0.81	0.93	0.49
d 0 - end	1.72	1.68	1.68	1.74	0.04	0.58	0.74	0.17
DM intake, kg/d								
d 0 - 56	10.08	9.99	9.83	9.90	0.29	0.46	0.41	0.83
d 0 - end	10.61	10.48	10.31	10.53	0.22	0.35	0.41	0.33
ADG:DMI								
d 0 -56	0.190	0.191	0.197	0.189	0.004	0.56	0.42	0.04
d 0 - end	0.162	0.160	0.163	0.165	0.002	0.76	0.16	0.43

[a]Standard error of the least squares means.

[b]Significance level of 60 mg Zn SO_4/ kg DM vs the average of 90 mg $ZnSO_4$/kg DM, 60 mg $ZnSO_4$/kg DM + 30 mg Availa® Zn/kg DM, and 60 mg $ZnSO_4$/kg DM + 30 mg Zn methionine/kg DM.

[c]Significance level of contrast of the average of 60 mg $ZnSO_4$/ kg DM + 30 mg Availa® Zn/kg DM and 60 mg $ZnSO_4$/kg DM + 30 mg Zn methionine/kg DM, vs. the average of 60 mg $ZnSO_4$/kg DM and 90 mg $ZnSO_4$/kg DM.

[d]Significance level of contrast of the 60 mg $ZnSO_4$/kg DM + 30 mg Availa® Zn/kg DM vs. 60 mg $ZnSO_4$/ kg DM + 30 mg Zn methionine/kg, DM.

Table 4-7. Effects of zinc level and source on feedlot carcass characteristics (Exp.3).

		60 mg/kg $ZnSO_4$				Contrasts		
Item	60 mg/kg $ZnSO_4$	30 mg/kg $ZnSO_4$	30 mg/kg Availa Zn	30 mg/kg Zn Met	SEM[a]	60 vs. 90 mg/kg[b]	Inorganic vs Organic[c]	Availa Zn vs Zn Methionine[d]
Pens	6	6	5	5				
Animals	22	24	20	21				
Dressing %	66.8	61.0	60.0	58.0	1.61	0.46	0.18	0.34
Hot carcass wt., kg	378	378	380	383	6	0.51	0.34	0.59
Marbling[e]	395	374	382	396	25	0.72	0.87	0.71
External fat, cm	1.43	1.69	1.38	1.39	0.12	0.65	0.16	0.95
Ribeye area, cm^2	90.3	87.6	92.2	90.0	2.6	0.88	0.38	0.55
KPH, %	1.93	1.97	2.00	1.94	0.07	0.62	0.79	0.54
Yield grade	2.98	3.40	2.87	2.98	0.20	0.62	0.20	0.70

[a]Standard error of the least squares means.
[b]Significance level of 60 mg Zn SO_4/ kg DM vs the average of 90 mg $ZnSO_4$/kg DM, 60 mg $ZnSO_4$/kg DM + 30 mg Availa® Zn/kg DM, and 60 mg $ZnSO_4$/kg DM + 30 mg Zn methionine/kg DM.
[c]Significance level of contrast of the average of 60 mg $ZnSO_4$/ kg DM + 30 mg Availa® Zn/kg DM and 60 mg $ZnSO_4$/kg DM + 30 mg Zn methionine/kg DM, vs. the average of 60 mg $ZnSO_4$/kg DM and 90 mg $ZnSO_4$/kg DM.
[d]Significance level of contrast of the 60 mg $ZnSO_4$/kg DM + 30 mg Availa® Zn/kg DM vs. 60 mg $ZnSO_4$/ kg DM + 30 mg Zn methionine/kg, DM.
[e]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

APPENDIX A

ADDITIONAL RESULTS FOR CHAPTER III

Appendix Table A-1. Effects of copper and zinc level and zinc source on cumulative feedlot performance by heifers (Exp. 1).

	12 mg Cu/kg DM				24 mg Cu/kg DM					
	80 mg Zn/kg DM		320 mg Zn/kg DM		80 mg Zn/kg DM		320 mg Zn/kg DM			
Item	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	SEM	Pr > F[a]
Initial wt., kg	306	311	309	307	304	306	309	308	4	0.72
Final wt., kg	499	519	523	512	515	504	521	506	9	0.28
Daily gain, kg										
d 0 - 27	1.42	1.37	1.57	1.43	1.20	1.22	1.18	1.42	0.14	0.32
d 28 - 56	1.39	1.42	1.41	1.41	1.67	1.43	1.71	1.53	0.12	0.80
d 57 - 84	1.16	1.39	1.31	1.26	1.37	1.36	1.26	1.38	0.15	0.32
d 85 - 112	1.36	1.55	1.52	1.43	1.53	1.21	1.58	1.41	0.09	0.14
d 113 - end	1.14	1.09	1.21	1.18	1.18	1.26	1.26	0.80	0.13	0.14
d 0 - end	1.29	1.36	1.40	1.34	1.39	1.30	1.40	1.30	0.07	0.43
DM intake, kg/d										
d 0 - 27	7.46	7.57	7.81	7.83	7.44	7.25	7.47	7.76	0.15	0.18
d 28 - 56	7.89	8.29	8.37	8.16	8.19	7.76	8.67	8.52	0.28	0.26
d 57 - 84	7.96	8.34	8.42	8.40	8.73	8.31	8.47	8.21	0.28	0.50
d 85 - 112	7.56	8.05	8.05	7.79	8.69	7.95	8.01	8.45	0.42	0.12
d 113 - end	7.23	7.18	7.05	7.22	7.34	7.80	7.54	6.76	0.29	0.20
d 0 - end	7.62	7.88	7.94	7.88	8.48	8.41	80.3	8.23	0.31	0.52
Gain:feed										
d 0 - 27	0.190	0.181	0.200	0.183	0.159	0.168	0.158	0.182	0.018	0.50
d 28 - 56	0.176	0.171	0.168	0.173	0.205	0.185	0.197	0.179	0.013	0.84
d 57 - 84	0.146	0.165	0.155	0.149	0.157	0.164	0.149	0.168	0.015	0.36
d 85 - 112	0.180	0.192	0.187	0.185	0.177	0.153	0.198	0.167	0.011	0.78
d 113 - end	0.158	0.152	0.172	0.163	0.151	0.163	0.164	0.120	0.016	0.24
d 0 - end	0.170	0.173	0.177	0.170	0.165	0.155	0.173	0.159	0.008	0.80

[a]Probability of an interaction between Cu level, Zn level, and Zn source.

Appendix Table A-2. Effects of copper and zinc level on cumulative feedlot performance by heifers (Exp. 1).

	12 mg Cu/kg DM		24 mg Cu/kg DM			
Item	80 mg Zn/kg DM	320 mg Zn/kg DM	80 mg Zn/kg DM	320 mg Zn/kg DM	SEM	CuL x ZnL[a]
Initial wt., kg	309	308	305	308	3	0.50
Final wt., kg	509	517	509	513	6	0.71
Daily gain, kg						
d 0 - 27	1.40	1.50	1.21	1.30	0.12	0.95
d 28 - 56	1.41	1.41	1.55	1.62	0.08	0.73
d 56 - 84	1.28	1.29	1.27	1.32	0.11	0.79
d 85 - 112	1..45	1.48	1.37	1.49	0.07	0.46
d 113 - end	1.12	1.19	1.22	1.03	0.09	0.17
d 0 - end	1.32	1.37	1.34	1.35	0.06	0.64
DM intake, kg/d						
d 0 - 27	7.52	7.82	7.34	7.62	0.10	0.87
d 28 - 56	8.09	8.26	7.97	8.59	0.20	0.27
d 57 - 84	8.15	8.41	8.52	8.34	0.20	0.29
d 85 - 112	7.80	7.92	8.32	8.23	0.29	0.74
d 113 - end	7.21	7.14	7.77	7.15	0.20	0.19
d 0 - end	7.75	7.91	8.44	8.13	0.22	0.30
Gain:feed						
d 0 - 27	0.186	0.192	0.164	0.170	0.015	0.98
d 28 - 56	0.174	0.171	0.195	0.179	0.009	0.83
d 57 - 84	0.156	0.151	0.160	0.158	0.012	0.93
d 85 - 112	0.186	0.186	0.165	0.182	0.008	0.27
d 113 - end	0.155	0.168	0.157	0.142	0.011	0.21
d 0 - end	0.171	0.173	0.160	0.166	0.007	0.69

[a]Probability of an interaction between Cu level and Zn level.

Appendix Table A-3. Effects of zinc level and zinc source on cumulative feedlot performance by heifers (Exp. 1).

Item	80 mg Zn/kg DM		320 mg Zn/kg DM		SEM	ZnL x ZnS[a]
	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn		
Initial wt., kg	305	309	309	307	3	0.37
Final wt., kg	507	511	522	509	6	0.18
Daily gain, kg						
d 0 - 27	1.31	1.30	1.37	1.42	0.12	0.69
d 28 - 56	1.53	1.43	1.56	1.47	0.09	0.94
d 56 - 84	1.27	1.37	1.28	1.32	0.11	0.73
d 85 - 112	1.45	1.38	1.55	1.42	0.07	0.64
d 113 - end	1.16	1.18	1.23	0.99	0.09	0.18
d 0 - end	1.34	1.33	1.40	1.32	0.06	0.41
DM intake, kg/d						
d 0 - 27	7.45	7.41	7.64	7.79	0.10	0.35
d 28 - 56	8.04	8.03	8.52	8.34	0.20	0.67
d 57 - 84	8.34	8.33	8.45	8.31	0.20	0.77
d 85 - 112	8.12	8.00	8.03	8.12	0.30	0.72
d 113 - end	7.48	7.49	7.30	6.99	0.20	0.44
d 0 - end	8.05	8.14	7.98	8.05	0.22	0.95
Gain:feed						
d 0 - 27	0.175	0.175	0.179	0.183	0.154	0.86
d 28 - 56	0.190	0.178	0.182	0.176	0.009	0.77
d 57 - 84	0.152	0.164	0.152	0.159	0.012	0.77
d 85 - 112	0.179	0.172	0.193	0.176	0.008	0.51
d 113 - end	0.154	0.157	0.168	0.142	0.011	0.20
d 0 - end	0.167	0.164	0.175	0.165	0.007	0.42

[a]Probability of an interaction between Zn level and Zn source.

Appendix Table A-4. Effect of zinc source on cumulative performance by heifers (Exp. 1).

Item	$ZnSO_4$	AvailaZn	SEM	Zn source[a]
Initial wt., kg	307	308	2	0.72
Final wt., kg	514	510	4	0.51
Daily gain, kg				
d 0 - 27	1.34	1.36	0.11	0.82
d 28 - 56	1.55	1.45	0.06	0.28
d 56 - 84	1.28	1.35	0.09	0.47
d 85 - 112	1.50	1.40	0.05	0.15
d 113 - end	1.20	1.08	0.07	0.24
d 0 - end	1.37	1.33	0.05	0.27
DM intake, kg/d				
d 0 - 27	7.54	7.60	0.07	0.60
d 28 - 56	8.28	8.18	0.14	0.63
d 57 - 84	8.39	8.32	0.14	0.70
d 85 - 112	8.08	8.06	0.21	0.96
d 113 - end	7.39	7.24	0.14	0.46
d 0 - end	8.02	8.10	0.16	0.71
Gain:feed				
d 0 - 27	0.177	0.179	0.014	0.87
d 28 - 56	0.186	0.177	0.006	0.33
d 57 - 84	0.152	0.161	0.010	0.33
d 85 - 112	0.186	0.174	0.005	0.15
d 113 - end	0.161	0.149	0.008	0.30
d 0 - end	0.171	0.164	0.006	0.12

[a]Probablity of an effect of Zn source.

Appendix Table A-5. Effects of copper and zinc level and zinc source on carcass traits in heifers (Exp.1)

Item	12 mg Cu/kg DM				24 mg Cu/kg DM				SEM	Cu x ZnL x ZnS[a]
	80 mg Zn/kg DM		320 mg Zn/kg DM		80 mg Zn/kg DM		320 mg Zn/kg DM			
	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn		
HCW, kg	321	333	336	329	331	324	335	326	6	0.31
Dressing %	64.04	64.63	65.32	64.46	64.30	63.85	64.64	63.44	0.34	0.47
Ribeye area, cm^2	93.07	88.52	95.48	87.68	86.68	92.23	92.87	89.49	3.16	0.53
12th-rib fat, cm	1.44	1.56	1.46	1.78	1.59	1.50	1.71	1.82	0.10	0.22
KPH	2.48	2.49	2.45	2.20	2.55	2.58	2.65	2.46	0.17	0.93
Marbling[b]	432	448	427	423	481	449	430	436	25	0.42
Yield grade	2.44	2.89	2.47	3.14	2.77	2.56	2.82	3.03	0.15	0.64

[a]Probability of an interaction between Cu level, Zn level, and Zn source.

[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

Appendix Table A-6. Effects of copper and zinc level on carcass traits in heifers (Exp.1).

	12 mg Cu/kg DM		24 mg Cu/kg DM			
Item	80 mg Zn/kg DM	320 mg Zn/kg DM	80 mg Zn/kg DM	320 mg Zn/kg DM	SEM	CuL x ZnL[a]
HCW, kg	327	333	327	330	4	0.70
Dressing %	64.34	64.89	64.07	64.04	0.24	0.24
Ribeye area, cm^2	90.80	91.58	89.46	91.18	2.23	0.84
12th-rib fat, cm	1.50	1.62	1.55	1.77	0.09	0.51
KPH	2.49	2.33	2.56	2.56	0.12	0.53
Marbling[b]	440	425	465	433	18	0.62
Yield grade	2.67	2.80	2.66	2.92	0.11	0.56

[a]Probability of an interaction between Cu level and Zn level.

[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

Appendix Table A-7. Frequency distribution for various individual carcass measurements in heifers (Exp. 1)

	12 mg Cu/kg DM				24 mg Cu/kg DM			
	80 mg Zn/kg DM		320 mg Zn/kg DM		80 mg Zn/kg DM		320 mg Zn/kg DM	
	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn
n	21	18	19	18	20	20	20	19
USDA Quality Grade[a]								
Prime	0	1	0	1	0	0	0	0
Choice	13	12	11	7	13	13	10	11
Select	8	5	8	10	7	7	10	8
Standard	0	0	0	0	0	0	0	0
USDA Yield Grade[b]								
One	2	2	0	1	3	2	2	1
Two	7	4	7	8	4	2	1	3
Three	12	11	8	7	12	12	12	9
Four	0	2	4	2	1	4	3	6
Five	0	0	0	0	0	0	2	0

[a]Chi square value = 11.10; Probability = 0.68.

[b]Chi square value = 39.46; Probability = 0.07.

Appendix Table A-8. Effects of copper and zinc level and zinc source on cumulative feedlot performance by steers (Exp. 2).

	12 mg Cu/kg DM				24 mg Cu/kg DM					
	80 mg Zn/kg DM		320 mg Zn/kg DM		80 mg Zn/kg DM		320 mg Zn/kg DM			
Item	$ZnSO_4$	Availa Zn	$ZnSO_4$	Availa Zn	$ZnSO_4$	Availa Zn	$ZnSO_4$	Availa Zn	SEM	Pr > F[a]
Initial wt., kg	342	343	342	341	342	342	341	339	14	0.95
Final wt., kg	599	577	600	599	589	583	595	599	11	0.72
Daily gain, kg										
d 0 - 27	1.84	1.85	1.63	2.00	1.92	1.57	1.81	1.73	0.10	0.69
d 28 - 56	1.95	1.69	2.04	1.80	1.91	1.93	1.98	2.11	0.20	0.86
d 57 - 84	1.91	1.64	1.95	1.98	1.85	1.83	1.64	2.10	0.26	0.80
d 85 - 112	1.94	2.00	1.89	2.30	1.97	1.72	2.19	1.84	0.15	0.32
d 113 - end	1.52	1.16	1.68	1.09	1.33	1.61	1.40	1.63	0.22	0.78
d 0 - end	1.85	1.68	1.84	1.84	1.78	1.72	1.82	1.86	0.08	0.74
DM intake, kg/d										
d 0 - 27	8.4	8.8	8.0	8.6	8.5	8.3	8.7	8.3	0.4	0.54
d 28 - 56	9.7	9.6	10.4	9.8	9.4	10.0	9.5	10.4	0.4	0.49
d 57 - 84	10.8	9.6	10.6	10.4	10.3	9.9	10.1	11.0	0.6	0.84
d 85 - 112	11.8	11.2	11.7	11.5	11.6	10.9	11.4	12.1	0.4	0.34
d 113 - end	11.3	10.7	11.0	10.7	11.1	10.3	11.2	11.0	0.6	0.85
d 0 - end	11.0	10.5	10.9	11.6	10.7	11.0	11.0	11.1	0.6	0.29
Gain:feed										
d 0 - 27	0.217	0.211	0.205	0.233	0.225	0.187	0.209	0.209	0.011	0.90
d 28 - 56	0.200	0.172	0.195	0.182	0.205	0.194	0.209	0.202	0.017	0.79
d 57 - 84	0.175	0.174	0.183	0.187	0.177	0.185	0.163	0.192	0.023	0.77
d 85 - 112	0.164	0.178	0.161	0.201	0.170	0.158	0.192	0.153	0.015	0.22
d 113 - end	0.134	0.111	0.153	0.102	0.114	0.156	0.126	0.147	0.019	0.88
d 0 - end	0.168	0.160	0.168	0.161	0.166	0.158	0.166	0.168	0.012	0.58

[a]Probability of an interaction between Cu level, Zn level, and Zn source.

Appendix Table A-9. Effects of copper and zinc level on cumulative feedlot performance by steers (Exp. 2).

	12 mg Cu/kg DM		24 mg Cu/kg DM			
Item	80 mg Zn/kg DM	320 mg Zn/kg DM	80 mg Zn/kg DM	320 mg Zn/kg DM	SEM	CuL x ZnL[a]
Initial wt., kg	342	342	342	340	14	0.68
Final wt., kg	588	599	586	597	8	0.99
Daily gain, kg						
d 0 - 27	1.85	1.82	1.74	1.77	0.07	0.69
d 28 - 56	1.82	1.92	1.92	2.04	0.14	0.93
d 57 - 84	1.77	1.96	1.84	1.87	0.18	0.66
d 85 - 112	1.97	2.10	1.84	2.01	0.11	0.86
d 113 - end	1.34	1.38	1.47	1.51	0.16	0.99
d 0 - end	1.76	1.84	1.75	1.84	0.06	0.91
DM intake, kg/d						
d 0 - 27	8.6	8.3	8.4	8.5	0.4	0.33
d 28 - 56	9.7	10.1	9.7	9.9	0.3	0.80
d 57 - 84	10.3	10.3	1.01	10.5	0.3	0.82
d 85 - 112	11.5	11.6	11.3	11.7	0.3	0.53
d 113 - end	11.0	10.9	10.7	11.1	0.5	0.41
d 0 - end	10.7	11.3	10.8	11.0	0.6	0.61
Gain:feed						
d 0 - 27	0.214	0.219	0.206	0.209	0.010	0.87
d 28 - 56	0.186	0.188	0.199	0.205	0.012	0.86
d 57 - 84	0.175	0.185	0.181	0.177	0.018	0.67
d 85 - 112	0.171	0.181	0.164	0.173	0.010	0.94
d 113 - end	0.123	0.127	0.135	0.137	0.014	0.92
d 0 - end	0.164	0.164	0.162	0.167	0.011	0.56

[a]Probability of an interaction between Cu level and Zn level.

Appendix Table A-10. Effect of copper level on cumulative performance by steers (Exp. 2).

Item	12 mg Cu/kg DM	24 mg Cu/kg DM	SEM	Cu level[a]
Initial wt., kg	342	341	14	0.72
Final wt., kg	594	591	6	0.77
Daily gain, kg				
d 0 - 27	1.83	1.76	0.05	0.29
d 28 - 56	1.87	1.98	0.10	0.42
d 57 - 84	1.87	1.86	0.13	0.96
d 85 - 112	2.03	1.93	0.08	0.34
d 113 - end	1.36	1.49	0.11	0.42
d 0 - end	1.80	1.79	0.05	0.90
DM intake, kg/d				
d 0 - 27	8.5	8.5	0.4	0.95
d 28 - 56	9.9	9.8	0.2	0.76
d 57 - 84	10.3	10.3	0.3	0.96
d 85 - 112	11.56	11.52	0.2	0.86
d 113 - end	10.9	10.9	0.4	0.80
d 0 - end	11.0	10.9	0.5	0.85
Gain:feed				
d 0 - 27	0.217	0.207	0.009	0.14
d 28 - 56	0.187	0.202	0.010	0.19
d 57 - 84	0.180	0.179	0.014	0.95
d 85 - 112	0.176	0.168	0.007	0.44
d 113 - end	0.125	0.136	0.010	0.43
d 0 - end	0.164	0.164	0.011	0.94

[a]Probablity of an effect of Cu level.

Appendix Table A-11. Effect of zinc level on cumulative performance by steers (Exp. 2).

Item	80 mg Zn/kg DM	320 mg Zn/kg DM	SEM	Zn level[a]
Initial wt., kg	342	341	14	0.56
Final wt., kg	587	598	6	0.16
Daily gain, kg				
d 0 - 27	1.80	1.79	0.05	0.98
d 28 - 56	1.87	1.98	0.10	0.41
d 57 - 84	1.81	1.92	0.13	0.54
d 85 - 112	1.91	2.05	0.08	0.19
d 113 - end	1.41	1.45	0.11	0.79
d 0 - end	1.75	1.84	0.05	0.15
DM intake, kg/d				
d 0 - 27	8.5	8.4	0.4	0.51
d 28 - 56	9.7	10.0	0.2	0.23
d 57 - 84	10.1	10.5	0.3	0.38
d 85 - 112	11.4	11.7	0.2	0.26
d 113 - end	10.8	11.0	0.4	0.63
d 0 - end	10.8	11.2	0.5	0.23
Gain:feed				
d 0 - 27	0.210	0.214	0.009	0.58
d 28 - 56	0.193	0.197	0.010	0.70
d 57 - 84	0.178	0.181	0.014	0.85
d 85 - 112	0.167	0.177	0.007	0.37
d 113 - end	0.129	0.132	0.010	0.82
d 0 - end	0.163	0.165	0.011	0.58

[a]Probablity of an effect of Zn level.

Appendix Table A-12. Effect of zinc source on cumulative performance by steers (Exp. 2).

Item	$ZnSO_4$	Availa Zn	SEM	Zn source[a]
Initial wt., kg	342	341	14	0.77
Final wt., kg	596	589	6	0.38
Daily gain, kg				
d 0 - 27	1.80	1.79	0.05	0.88
d 28 - 56	1.97	1.88	0.10	0.52
d 57 - 84	1.84	1.89	0.13	0.78
d 85 - 112	2.00	1.96	0.08	0.76
d 113 - end	1.48	1.37	0.11	0.50
d 0 - end	1.82	1.77	0.05	0.44
DM intake, kg/d				
d 0 - 27	8.4	8.5	0.4	0.68
d 28 - 56	9.7	10.0	0.2	0.46
d 57 - 84	10.4	10.2	0.3	0.62
d 85 - 112	11.6	11.4	0.2	0.40
d 113 - end	11.1	10.7	0.4	0.12
d 0 - end	10.9	11.0	0.5	0.64
Gain:feed				
d 0 - 27	0.214	0.210	0.009	0.53
d 28 - 56	0.202	0.187	0.010	0.19
d 57 - 84	0.175	0.185	0.014	0.50
d 85 - 112	0.172	0.173	0.007	0.94
d 113 - end	0.132	0.129	0.010	0.83
d 0 - end	0.167	0.162	0.011	0.19

[a]Probablity of and effect of Zn Source.

Appendix Table A-13. Effects of copper and zinc level and zinc source on carcass traits in steers (Exp.2)

Item	12 mg Cu/kg DM				24 mg Cu/kg DM				SEM	Cu x ZnL x ZnS[a]
	80 mg Zn/kg DM		320 mg Zn/kg DM		80 mg Zn/kg DM		320 mg Zn/kg DM			
	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn		
HCW, kg	376	362	381	375	370	366	373	375	7	0.89
Dressing %	62.8	62.4	64.3	63.0	62.0	63.1	62.6	62.6	0.4	0.88
Ribeye area, cm^2	80.7	81.9	79.4	81.1	83.6	81.6	80.8	78.2	2.0	0.98
12th-rib fat, cm	1.70	1.42	1.65	1.66	1.49	1.36	1.72	1.73	0.12	0.65
KPH	2.21	2.32	2.30	2.25	2.26	2.33	2.36	2.36	0.14	0.83
Marbling[b]	434	425	448	450	442	438	453	439	28	0.71
Yield grade	3.67	3.27	3.81	3.67	3.33	3.33	3.85	3.83	0.18	0.59

[a]Probability of an interaction between Cu level, Zn level, and Zn source.

[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

Appendix Table A-14. Effects of zinc level and zinc source on carcass traits in steers (Exp. 2).

	80 mg Zn/kg DM		320 mg Zn/kg DM			
Item	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	SEM	ZnL x ZnS[a]
HCW, kg	373	364	377	375	6	0.38
Dressing %	62.4[d]	62.7[cd]	63.4[c]	62.8[cd]	0.3	0.10
Ribeye area, cm^2	82.2	81.3	80.1	79.6	1.9	0.75
12th-rib fat, cm	1.59	1.39	1.68	1.70	0.09	0.23
KPH	2.24	2.32	2.33	2.30	0.10	0.58
Marbling[b]	438	432	450	444	24	0.99
Yield grade	3.50	3.30	3.83	3.75	0.13	0.65

[a]Probability of an interaction between Zn level and Zn source.
[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.
[cd]Means within a row with different superscripts differ $P < 0.10$.

Appendix Table A-15. Effect of copper level on carcass traits in steers (Exp. 2).

Item	12 mg Cu/kg DM	24 mg Cu/kg DM	SEM	Copper L[a]
HCW, kg	374	371	5	0.52
Dressing %	63.1	62.6	0.2	0.05
Ribeye area, cm^2	80.8	80.8	1.9	0.94
12th-rib fat, cm	1.61	1.57	0.06	0.72
KPH	2.27	2.32	0.07	0.58
Marbling[b]	439	443	22	0.78
Yield grade	3.61	3.59	0.09	0.88

[a]Probability of an effect of copper level.
[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.
[cd]Means within row with different superscripts differ $P < 0.05$.

Appendix Table A-16. Effect of zinc source on carcass traits in steers (Exp. 2).

Item	$ZnSO_4$	AvailaZn	SEM	Zinc Source[a]
HCW, kg	375	369	5	0.20
Dressing %	62.9	62.8	0.2	0.61
Ribeye area, cm^2	81.1	80.5	1.9	0.30
12th-rib fat, cm	1.64	1.54	0.06	0.30
KPH	2.28	2.31	0.07	0.77
Marbling[b]	444	438	22	0.67
Yield grade	3.67	3.53	0.09	0.29

[a]Probability of an effect of zinc source.
[b]Practically devoid = 100; traces = 200; slight = 300; small = 400; modest = 500; moderate = 600; slightly abundant = 700.

Appendix Table A-17. Frequency distribution for various individual carcass measurements in steers (Exp. 2)

	12 mg Cu/kg DM				24 mg Cu/kg DM			
	80 mg Zn/kg DM		320 mg Zn/kg DM		80 mg Zn/kg DM		320 mg Zn/kg DM	
	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn	$ZnSO_4$	AvailaZn
n	20	20	19	18	20	19	18	20
USDA Quality Grade[a]								
Choice	12	12	11	9	12	15	14	14
Select	8	8	8	9	7	4	4	6
Standard	0	0	0	0	1	0	0	0
USDA Yield Grade[b]								
Two	1	2	0	1	0	0	0	0
Three	6	10	14	11	7	8	6	6
Four	11	7	4	7	9	7	10	11
Five	2	1	1	0	3	4	2	3

[a]Chi square value = 12.56; Probability = 0.56.
[b]Chi square value = 25.82; Probability = 0.21.

APPENDIX B

ADDITIONAL RESULTS FOR CHAPTER IV

Table B-1. Effects of treatment and day on performance of feedlot performance in steers fed for 130 days (Exp.1).

		60 ppm $ZnSO_4$			60 ppm $ZnSO_4$					
Period	60 ppm $ZnSO_4$	30 ppm $ZnSO_4$	30 ppm AvailaZn	30.ppm ZnMet	60 ppm $ZnSO_4$	60 ppm AvailaZn	SEM[a]	Trt	Per	Trt*Per
BW, kg										
d 0	346	347	347	347	346	347	12	<0.001	<0.001	0.93
d 29	398	404	404	397	403	401				
d 55	454[a]	464[b]	461[b]	456[ab]	462[b]	458[ab]				
d 83	509[a]	527[b]	525[b]	516[ab]	524[ab]	521[ab]				
d 112	556[a]	574[b]	571[b]	562[ab]	565[ab]	566[ab]				
d 130	572[a]	590[b]	584[ab]	577[ab]	584[ab]	589[b]				
Daily gain, kg										
d 0 - 29	1.80	1.98	1.96	1.74	1.96	1.86	0.10	0.16	<0.001	0.06
d 29 - 55	2.15	2.30	2.19	2.26	2.28	2.21				
d 56 - 83	1.94	2.23	2.28	2.14	2.21	2.23				
d 84 - 112	1.63	1.63	1.61	1.59	1.43	1.55				
d 113 - 130	0.89	0.86	0.71	0.83	1.06	1.28				
DM intake, kg/d										
d 0 - 29	9.23	9.66	9.34	9.76	9.89	9.35	0.33	<0.001	<0.001	0.99
d 29 - 55	10.00[a]	10.64[ab]	10.70[ab]	11.23[b]	10.96[b]	10.74[ab]				
d 56 - 83	9.77[a]	10.44[ab]	10.74[b]	10.71[b]	10.69[b]	10.48[ab]				
d 84 - 112	9.92	10.47	10.58	10.42	10.67	10.46				
d 113 - 130	9.28	9.95	9.97	9.79	10.03	9.79				
Feed:Gain										
d 0 - 29	5.23	4.90	4.78	5.68	5.09	5.05	1.64	0.32	<0.001	0.14
d 29 - 55	4.66	4.68	4.89	4.97	4.83	4.88				
d 56 - 83	5.08	4.70	4.71	5.02	4.87	4.70				
d 84 - 112	6.08	6.42	6.58	6.61	7.59	6.74				
d 113 - 130	10.67	14.60	19.86	13.07	10.03	7.97				

[a]Standard error of the least squares means.

[a,b]Means within a row with common superscripts do not differ.

Table B-2. Effects of zinc level and zinc source on cumulative feedlot performance in steers fed for 130 days (Exp.1).

		60 ppm $ZnSO_4$			60 ppm $ZnSO_4$			Contrasts			
Item	60 ppm $ZnSO_4$	30 ppm $ZnSO_4$	30 ppm AvailaZn	30 ppm Zn Met	60 ppm $ZnSO_4$	60 ppm AvailaZn	SEM[a]	Zn Level Linear	Zn Level Quadratic	Inorganic vs Organic	ZnMet vs Availa Zn
Initial wt., kg	346	346	347	347	346	347	0.55	NS	NS	NS	NS
Final wt., kg	572	590	584	577	584	589					
Daily gain, kg											
d 0 - 29	1.80	1.98	1.96	1.74	1.96	1.86	0.09	NS	NS	NS	NS
d 0 - 55	1.96	2.13	2.07	1.99	2.11	2.03	0.05	NS	NS	NS	NS
d 0 - 83	1.95	2.17	2.14	2.04	2.14	2.10	0.06	NS	NS	NS	NS
d 0 - 112	1.87	2.03	2.00	1.92	1.96	1.96	0.05	NS	NS	NS	NS
d 0 - 130	1.74	1.87	1.82	1.77	1.83	1.86	0.05	NS	NS	NS	NS
DM intake, kg/d											
d 0 - 29	9.24	9.66	9.34	9.76	9.88	9.34	0.25	NS	NS	NS	NS
d 0 - 55	9.60	10.12	9.98	10.55	10.39	10.13	0.27	NS	NS	NS	NS
d 0 - 83	9.65	10.23	10.24	10.60	10.49	10.26	0.25	NS	NS	NS	NS
d 0 - 112	9.72	10.29	10.33	10.60	10.54	10.26	0.25	NS	NS	NS	NS
d 0 - 130	9.66	10.24	10.28	10.49	10.47	10.19	0.25	NS	NS	NS	NS
Feed:Gain											
d 0 - 29	5.23	4.90	4.78	5.69	5.09	5.05	0.22	NS	NS	NS	NS
d 0 - 55	4.91	4.75	4.82	5.30	4.92	5.02	0.12	0.64	0.93	0.07	0.01
d 0 - 83	4.96	4.73	4.78	5.20	4.90	4.90	0.10	0.66	0.84	0.23	0.01
d 0 - 112	5.21	5.07	5.15	5.51	5.39	5.26	0.09	0.30	0.60	0.25	0.01
d 0 - 130	5.57	5.49	5.63	5.92	5.72	5.49	0.02	0.81	0.33	0.33	0.07

[a]Standard error of the least squares means.

Table B-3. Effects of zinc level and source on feedlot cattle performance (Exp.3).

		60 ppm $ZnSO_4$				Contrasts		
Item	60 ppm $ZnSO_4$	30 ppm $ZnSO_4$	30 ppm Availa Zn	30 ppm Zn Met	SEM	60 vs. 90 ppm	Inorganic vs Organic	Availa Zn vs Zn Methionine
BW								
Initial	786	783	783	783	14.7	--	--	--
d 28	900	894	897	892	18.0	0.37	0.66	0.54
d 56	1022	1018	1022	1014	19.2	0.62	0.81	0.50
d 86	1134	1127	1126	1129	21.2	0.50	0.73	0.83
d 112	1243	1220	1228	1227	22.9	0.16	0.71	0.95
d 139	1312	1297	1297	1317	22.5	0.47	0.84	0.19
Daily gain, kg								
d 0 – 28	4.10	3.96	4.08	3.90	0.23	0.61	0.85	0.56
d 29 – 56	4.35	4.41	4.44	4.36	0.22	0.83	0.91	0.78
d 57 – 84	3.98	3.91	3.74	4.08	0.22	0.79	0.88	0.28
d 85 – 112	3.90	3.34	3.64	3.52	0.18	0.07	0.82	0.65
d 113 – 139	2.49	2.74	2.46	3.20	0.17	0.14	0.23	0.005
d 0 – 139	3.79	3.70	3.70	3.84	0.08	0.58	0.74	0.17
DM intake, lb/d								
d 0 – 28	22.3	21.8	21.6	21.7	0.70	0.30	0.44	0.84
d 29 – 56	22.1	22.2	21.8	21.9	0.74	0.85	0.59	0.90
d 57 – 84	23.9	23.0	22.8	23.2	0.56	0.11	0.39	0.54
d 85 – 112	24.2	23.8	22.9	23.8	0.57	0.29	0.24	0.20
d 113 – 139	24.5	24.7	24.5	25.4	0.52	0.47	0.44	0.22
d 0 – 139	23.4	23.1	22.7	23.2	0.49	0.34	0.41	0.32
Feed:Gain								
d 0 – 28	5.53	5.63	5.31	5.63	0.22	0.96	0.60	0.30
d 29 – 56	5.14	5.14	4.94	5.05	0.21	0.70	0.50	0.71
d 57 – 84	6.21	5.92	6.25	5.73	0.32	0.51	0.82	0.25
d 85 – 112	6.24	7.18	6.44	6.82	0.24	0.30	0.25	0.01
d 113 – 139	10.63	9.21	10.57	7.97	0.89	0.19	0.47	0.05
d 0 – 139	6.17	6.26	6.14	6.05	0.09	0.84	0.16	0.40

VITA

Levi Joel McBeth

Candidate for the Degree of

Doctor of Philosophy

Thesis: EFFECT OF COPPER LEVEL AND ZINC LEVEL AND SOURCE ON FINISHING CATTLE PERFORMANCE AND CARCASS TRAITS

Major Field: Animal Nutrition

Biographical:

Personal Data: Born in Wichita, Kansas, February 21, 1975, the son of Mr. and Mrs. Thomas H. McBeth and Married Loree Burum, August 15, 1998.

Education: Graduated from Bluestem High School, Leon, Kansas, May, 1993; received Bachelor of Science degree from Kansas State University in Manhattan, Kansas, December, 1998 with major in Animal Science. Received a Master of Science from The University of Arkansas, January, 2002. Completed the requirements for the Doctor of Philosophy in Animal Nutrition at Oklahoma State University, May, 2007.

Professional Experience: Graduate Assistant at the University of Arkansas, August, 1998 – September, 2000. Graduate Assistant at Oklahoma State University October, 2000 – February, 2005.

Professional Organizations: Member of American Society of Animal Science, American Registry of Professional Animal Scientists.

Name: Levi J. McBeth Date of Degree: May, 2007

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: EFFECT OF COPPER LEVEL AND ZINC LEVEL AND SOURCE ON FINISHING CATTLE PERFORMANCE AND CARCASS TRAITS

Pages in Study: 96 Candidate for the Degree of Doctor of Animal Science

Major Field: Animal Nutrition

Scope and Method of Study: The purpose was to evaluate the effects of Cu level and Zn level and source (organic vs. inorganic) on performance and carcass merit of cattle fed high-concentrate diets. In Study 1, the effects of two levels (DM basis) of Cu (12 vs. 24 mg/kg DM), two levels of Zn (80 vs. 360 mg/kg DM), and two sources of Zn ($ZnSO_4$ vs. Availa®Zn) on feedlot cattle performance and carcass merit were determined. In Study 2, the effects of feeding 60 mg of Zn from $ZnSO_4$/kg of DM (control); control plus 30 mg of Zn from $ZnSO_4$/kg DM; control plus 30 mg of Zn from ZINPRO®100 Zn methionine/kg of DM; control plus 30 mg of Zn from Availa®Zn/kg of DM; control plus 60 mg of Zn from $ZnSO_4$/kg of DM; control plus 60 mg of Zn from Availa®Zn/kg of DM, and control plus 60 mg of Zn from ZINPRO®100 Zn methionine/kg of DM on feedlot cattle performance and carcass merit were determined.

Findings and Conclusions: Zinc and copper appear to alter carcass fat deposition independently of each other. While the present study suggests that supplementation of Zn at 360 vs. 80 mg Zn/kg DM increases deposition of external fat, there appeared to be no affect on intramuscular deposition due to Cu level, Zn level or Zn source in the present experiment. Performance seems to be enhanced by supplemental Zn in the initial portion of the feeding period; however, consistent results were not observed throughout the entire feeding period. Although results were inconsistent, Zn level and supplementation of organic Zn sources might enhance performance and carcass quality of finishing steers. While the relationship between Zn sources and levels is not clear, there appears to be an effect of Zn on carcass fatness at dietary concentrations between 80 and 280 mg of total Zn/kg of DM. The potential for improved carcass merit with increasing levels and organic sources of Zn warrants further research.

ADVISER'S APPROVAL: Dr. Clint Krehbiel