Comparison of inorganic and organic trace mineral supplementation on the growth, performance and fecal mineral excretion in phase-fed, grow-finish swine

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Comparison of inorganic and organic trace mineral supplementation on 
the growth, performance and fecal mineral excretion in phase-fed, grow-
finish swine

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Signatures have been redacted for privacy
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CHAPTER 1. INTRODUCTION

Modern lean genetic lines of pigs require nutritionally dense diets to meet their requirements for lean tissue deposition (Schinckel and deLange, 1996; Thompson et al., 1996). Additionally, pigs have been fed concentrated diets that are typically formulated to provide an excess margin of nutrients to maximize performance. Until recently, livestock producers have not been concerned with the concentration and/or the mass of nutrients excreted. In recent years, large commercial swine production systems have been developed in order to maximize efficient use of capital, facilities, and labor, and they have frequently been sited on relatively limited acreage. If an operation is diversified, having land which is used for crop production, then excreted nutrients from livestock production can be desirable and economically advantageous to meet crop nutrient requirements (Kornegay and Harper, 1997).

Concentration of livestock operations, including pork facilities, has given rise to environmental concerns, and moreover, the environmental impact these operations have in densely populated livestock areas is not well known. Large-scale intensive swine production systems have concentrated the volume of manure produced in a geographical area. These manure stores could possibly lead to nutrient accumulations, often exceeding crop nutrient requirements. Chelated trace minerals (e.g. Bioplex™ Products, Alltech Inc., Nicholasville, KY) can be utilized at a lower concentration in the diet because of improved bioavailability when compared to inorganic minerals, without affecting economically important performance traits. Feeding organic minerals could reduce nutrient excretion, and hence, the rate of nutrient buildup in the soil where manure is applied. Leeson (2003) has indicated that chelated trace minerals (Bioplex™ Products, Alltech, Inc. Nicholasville, KY) are at least
30% more bioavailable when compared to inorganic trace mineral salts when fed to broilers. Hence, current environmental concerns facing intensive pork production may be further investigated by determining the effect of enhanced bioavailability of trace minerals utilized in typical swine diets, and any potential concern of buildup of Cu, Fe, and Zn could be alleviated.

The objectives of this study were three-fold. The primary objective was to quantify the growth and carcass response to traditional inorganic trace mineral supplementation (Cu, Fe, Zn) compared to organic forms (Bioplex™ Products, Alltech, Inc. Nicholasville, KY) of the same minerals. The second objective was to determine fecal excretion differences between pigs fed traditional inorganic trace mineral supplements and the organic chelated trace minerals. The final goal of the study was to determine the effect of trace mineral supplementation, both inorganic and organic forms, on the nutrient and mineral digestibility of grow-finish swine.

**THESIS ORGANIZATION**

This thesis is organized as a general literature review followed by two papers which are in the style of the Journal of Animal Science, followed by a general summary of the complete thesis. The review of literature examines the impact of trace mineral supplementation on pig growth and performance. The review also focuses on the supplementation of trace minerals and excretion concentrations in pigs, and possible environmental impact associated with over feeding of heavy metals. The research reported in the papers was conducted by Jeremy L. Burkett under the direction of Dr. Kenneth Stalder, Dr. Thomas J. Baas, Dr. Wendy Powers, and Dr. James Pierce with the financial support of Alltech Inc., Nicholasville, Kentucky.
CHAPTER 2. LITERATURE REVIEW

Copper

Function

Copper is a unique trace mineral in that it has growth promoting properties in growing finishing pigs when included at relatively high (>200 ppm) dietary concentrations. The performance improvement resulting from Cu supplementation is thought to be due to the antibacterial properties of the mineral in high concentrations (>200 ppm) (Wallace, 1967; Cromwell et al., 1989; Coffey et al., 1994; Apgar et al., 1995; Cromwell, 1997). It was originally proposed that elevated dietary Cu concentrations stimulated growth through an antibacterial action in the gastrointestinal tract (Fuller et al., 1960). More recent evidence suggests that Cu may act systemically as well (Zhou et al., 1994).

A correlation was shown by Cromwell et al. (1989) between growth stimulation and Cu source bioavailability. Although the direct mechanism of action is unknown, it is thought the growth enhancing properties of Cu is attributable to the antimicrobial properties of the metal (Fuller et al., 1960). The initial reports on improved pig performance resulting from high dietary Cu (125 to 250 ppm) stemmed from research conducted by Evvard et al. (1928) at Iowa State University and by Braude (1945) in the United Kingdom. The improvement in growth rate from feeding 250 ppm of Cu (as CuSO₄) to weanling pigs is well documented (Hawbaker et al., 1961; Bunch et al., 1961, 1965). Copper supplementation of swine diets has been utilized for many years to increase rate of gain and feed efficiency (Braude, 1967; Burnell et al., 1988; Cromwell et al., 1989).

Braude (1948) observed that pigs who licked Cu pipes grew faster than those without access to the pipes. Additionally, Braude (1945) is responsible for the first reports outlining
the effects of pharmacological or growth promoting concentrations (125 to 250 ppm) of Cu on growth enhancement characteristics (Barber et al., 1957). The supplementation of high dietary concentrations of Cu to weanling (Bunch et al., 1961) and growing (Hawbaker et al., 1961) pigs altered the microflora patterns in the feces of these animals. If the microbial population of the intestine can be affected by Cu, then microbial fermentation and subsequent malodor of waste may be altered (Armstrong et al., 2000).

The pig requires Cu for normal metabolism to occur. Copper is necessary for the synthesis of hemoglobin and for the synthesis and activation of several oxidative enzymes (Miller et al., 1979). The requirements for neonatal pigs (Okonkwo et al., 1979; Hill et al., 1983) and late grow-finish pigs (NRC, 1998) are no more than 5 to 6 ppm per day. However, there is no definitive research which establishes the requirements for lactating and gestating sows. Kirchgessner et al. (1981) estimated that pregnant sows had a 6 ppm per day requirement for normal body functions that occur during gestation.

Absorption and Transport

Copper appears to be absorbed by two mechanisms, active transport system (saturable), and passive diffusion (nonsaturable) (Turnland, 1999). Like other transport systems, low concentrations of dietary Cu are primarily transported via the active carrier-mediated pathway, whereas the diffusion process usually occurs at much higher concentrations.

Gut absorption of metals, like Cu, occurs mainly in the duodenum (Shils et al., 1999). It is thought to be largely an active, carrier-mediated process at low concentrations, however, Rucker et al. (1994) suggests that passive diffusion occurs when pharmacological concentrations are present. Upon entering the intestinal absorptive cells known as
enterocytes, metals are released to intracellular proteins to be transferred to the serosal side of the intestine and into blood circulation (Shils et al., 1999).

Groff and Gropper (1999) reported that the enterocytes of the gastrointestinal tract absorb, typically, between 30 and 50% of ingested Cu. However, the percentage of Cu absorbed, is most certainly affected by the Cu status of the animal, and the relative bioavailability of the copper source (Turnland, 1999). There are many factors that both positively and negatively influence Cu absorption. Copper transport across the brush border membrane of the intestine may be influenced or facilitated by amino acids, especially histidine, which may bind to Cu and allow absorption through an amino acid transport system, as well as sulfur containing amino acids such as methionine and cysteine. Copper also forms ligands with amino acid sulfhydryl groups, in compounds such as glutathione. DiSilvestro and Cousins (1983) showed that citric, gluconic, lactic, acetic, and malic acids act as binding ligands to improve solubilization and more importantly absorption of Cu.

Several substances have been reported to decrease or inhibit Cu absorption. Zinc-copper antagonism is mediated primarily through the absorption process as shown by ligated intestinal segments (van Campen and Scaife, 1967) and the vascularly perfused intestine (Oestreicher and Cousins, 1985). Accordingly, Zn induces high concentrations of metallothionein in the intestinal mucosa and this protein binds Cu more strongly than Zn. Most of the ingested Cu replaced Zn in the metallothionein molecule due to it’s higher affinity for the metal. The Cu bound to metallothionein was not absorbed but sloughed off with mucosal cells (Hall et al., 1979; Fischer et al., 1983). Whether or not there is an impairment of Cu absorption or utilization in pigs fed excess Zn is unknown, but it is clear
that the activities of Cu metalloenzymes are depressed (Ammerman et al., 1995a; Ammerman et al., 1995b).

Metallothionein is found in most tissues of the body, including the liver, pancreas, kidney, intestine, and red blood cells. This compound primarily exists in two forms, designated metallothionein MT-1 and MT-2. The compound metallothionein has a chemical nature that is comprised of a high proportion of cysteine residues (20 of 61 amino acids), each of which binds metals. Due to the high concentration of cysteine residues, metallothionein has a high affinity for binding metals such as Cu, cadmium, mercury, and Zn (Hamer, 1986).

Although many factors have been shown to affect the absorption of Cu both positively and negatively, the body’s Cu status appears to play the most significant role. The efficiency of absorption of Cu by the body appears to be directly related to the whole-body Cu status. Changes in fecal excretion have also been shown to mediate this process. In general, as the Cu dietary intake increases, less Cu is absorbed. The reverse also appears to hold true, with moderately low Cu intakes, increased absorption and decreased excretion usually holds true.

Storage

In comparison with other trace minerals, relatively little Cu (<110 mg) is found in the human body (Groff and Gropper, 1999). Additionally, Groff and Gropper (1999) stated what little Cu is located in the body is found within a variety of cells and tissues in the body. While Cu is rapidly extracted from the blood by both the liver and kidney, other tissues that store Cu include, brain, heart, bone, muscle, skin, intestine, spleen, hair, and nails, among others. Copper present in these tissues is bound to amino acids or proteins. The main
storage point for available Cu is thought to be the liver, where Cu is bound to metallothionein. This bound form Cu is said to protect cells by scavenging damaging superoxide and hydroxyl radicals.

Deficiency

The concentrations of Cu needed to prevent physiological deficiencies are very low (Mateos et al., 2005). Although cereal grains and milk products are poor sources of Cu (2 to 10 ppm), oilseed meals are good sources (15 to 30 ppm) (Mateos et al., 2005). In the current intensive production system a Cu deficiency is unlikely when supplemented with 5 to 10 ppm Cu in the diet (Mateos et al., 2005).

Copper deficiency has detrimental effects on numerous organs and tissues, including the hematopoietic system, cardiovascular system, central nervous system, and the integument. A deficiency of Cu leads to poor Fe mobilization; abnormal hemopoiesis; and poor keratinization (tyrosinase) (Hill and Spears, 2001), and synthesis of collagen, elastin, and myelin (NRC, 1998). Anemia occurring as a result of Cu deficiency results from impairment of Fe metabolism and is particularly manifested when available dietary Fe is present at approximately the metabolic requirement; however, the specific copper-dependent enzyme or protein involved with Fe metabolism is not clearly understood (Baker and Ammerman, 1995).

Copper deficiency is a serious problem in grazing animals in many countries of the world. This is due to a two-fold problem: the interactions of molybdenum and sulfur, which interfere with Cu utilization and the low concentrations of the element in the grazed or stored forages. Most practical swine and poultry diets contain adequate amounts of Cu; however, the element is still commonly supplemented to complete diets for these species. This
supplementation ensures appropriate concentrations of the metal are reached to gain the additive performance benefit that are obtained with high concentrations of Cu (200-250 ppm) supplementation (Wallace, 1967; Cromwell et. al., 1989; Coffey et. al., 1994; Apgar et al., 1995; Cromwell, 1997). The NRC (1988) reported that Cu may be limiting in certain human diets and particularly at risk are the premature infant and the exclusively breast-fed infant. The metabolic functions of Cu, which have been described by O’Dell (1976), serve as indices of Cu status and bioavailability.

The severity of a Cu deficiency can be influenced by the extent of the reduction of Cu status and dietary Cu content as well as the length of time the deficient diet was fed or was consumed. Because the complexity of Cu mechanisms is not fully understood in monogastric organisms, symptoms of Cu deficiency are sometimes difficult to diagnose.

**Performance**

Bunch (1965) reported 250 ppm supplemented Cu as the optimum for nursery pig performance in a trial where diets were supplemented with differing concentrations of Cu from 0 to 375 ppm. However, Bradley (1983) showed no effect on performance with the inclusion of 8 to 240 ppm of Cu was added. Furthermore, in studies conducted by Lillie et al. (1977), 125 ppm had no effect on performance of nursery pigs while 250 ppm actually caused a performance reduction. This reduction in performance could be due to the interaction of Fe and Cu, when low concentrations of Fe (<100 ppm) and 50 ppm of Fe supplementation came from Fe carbonate, a poor dietary source of the element.
In studies conducted by Armstrong et al. (2004) over a 45-day nursery period ADG, ADFI, and G:F were improved when pigs were supplemented with 250 ppm Cu fed as CuSO\(_4\) when compared to pigs fed the control diets (10 ppm as CuSO\(_4\)) in two experiments.

**Bioavailability**

Conflicting results concerning the bioavailability of Cu in animal feeding experiments have been documented (Baker and Ammerman, 1995). Relative bioavailability range from 88 to 147% of the response relative to cupric SO\(_4\) in poultry, swine, sheep, and cattle, (Guo et al., 2001). Few studies have compared bioavailability differences among organic products. Organic Cu sources were found to differ in regard to chemical indicators of chelation effectiveness and solubility in pH 5.0 buffer (Gou et al., 2001).

Copper salts (inorganic forms) which include sulfates, carbonates, and chlorides, all have high biological availabilities (Miller, 1980; Cromwell et al., 1998). Organic complexes of Cu appear to have been shown to have equal bioavailability to CuSO\(_4\) in several trials (Bunch et al. 1965; Zoubek et al., 1975; Stansbury et al., 1990; Coffey et al., 1994; Apgar et al., 1995). Although studies have shown equal bioavailability of these Cu supplements, Coffey et al. (1994) and Zhou et al. (1994), reported improved ADG in pigs fed growth-promoting concentrations of Cu from copper lysine complex when compared to pigs fed CuSO\(_4\) when fed at the same concentrations.

Stansbury et al. (1990) reported no performance differences from pigs fed organic chelates (polysaccharides of Pacific Coast kelp at 10% provided 125 ppm Cu) and inorganic Cu sources (chelated with EDTA). The highest concentration of Cu supplemented in all diets provided 125 ppm. Conflicting studies do not support the utilization of varying concentrations of Cu. Bunch et al. (1961) showed increased response of pigs with 250 ppm
versus 125 ppm, however, Stahly et al. (1980) and Roof and Mahan, (1982) showed equal performance, and lastly, Young and Jamieson (1970) showed greater response from 125 ppm than 250 ppm Cu supplementation. These conflicting studies, however, may be the result of genetic changes in the pig that has occurred over the time period, health status of the pigs utilized in each of the studies and basal Cu concentration found in the corn and soybean meal used in the experimental diets.

**Environmental**

Miller (1973) investigated different Cu feeding regimes, in response to environmental concerns, in an attempt to reduce the amount of Cu in swine manure. He reported that the lack of Cu in finishing diets did not affect performance when Cu was fed at 250 ppm during the grower phase. Pharmacological concentrations of dietary Cu present an environmental concern because excess Cu is excreted in feces and could potentially cause soil buildup (Kornegay and Harper, 1997). Metals accumulate in the environment when fed in excess to pigs and cattle. These minerals pose problems, as they can adversely affect the growth of aquatic organisms (Davis, 1974). This possible accumulation of heavy metals can also pose problems for metal sensitive species such as sheep (Besser, 2001).

Excess Cu causes undesirable effects on plant growth and will impair lagoon bacteria activity that is responsible for waste degradation (Matoes et al., 2005). Demonstration of a reduction of Cu content from 175 to 6 ppm in piglet feeds and from 100 to 4 ppm in finishing diets was conducted by Jondreville et al. (2002). Results from this study revealed a Cu slurry concentration reduction from 911 to 31 mg Cu/kg DM.

Armstrong et al. (2000) reported that the supplementation of swine diets with high concentrations of Cu improved the odor characteristics of swine waste. In a nursery trial
consisting of 96 barrows and 96 gilts, weaned at approximately 18 to 22 d of age, at weight of 6.4 kg, the effects of Cu on animal waste odor was evaluated. In addition, odor characteristics of waste were compared from pigs receiving an inorganic, sulfur-containing Cu source (CuSO₄) or an organic, non-sulfate source Cu source (cupric citrate). Results from this trial demonstrated that the odor and irritation intensity of the feces were decreased \( (P < 0.05) \) in animals consuming diets containing 225 ppm Cu from the inorganic source (CuSO₄) and 66 to 100 ppm Cu from the organic (cupric citrate) when compared to the control diets (10 ppm as CuSO₄). Previous work indicates an effect of dietary Cu on the odor characteristics of swine waste. Although odor quality was significantly improved by the addition of supplemental Cu in the form of 225 ppm from CuSO₄, the odor was still classified as unpleasant. These data are evidence that Cu can change odor characteristics of swine waste; however, it does not change its odor sufficiently enough to move it from the unpleasant category. Armstrong et al. (2000) suggested that the mechanism of action is attributable to the antibiotic-like functions of Cu in the intestinal tract of pigs, much like the mechanism associated with the growth stimulating action of high dietary Cu (Cromwell et al., 1989). This antibiotic-like function of Cu helps to maintain healthy gut morphology and allows for a proper absorption to occur in the intestinal environment. This work suggests that there are dietary modifications that may be included in odor management planning.

In research conducted by Armstrong et al. (2004) fecal concentrations did not differ for pigs fed diets containing 62 ppm from either CuSO₄ or CuCit sources of Cu. However, fecal Cu concentrations were increased when pigs fed diets containing 250 ppm Cu as CuSO₄ compared with the pigs fed the control diets and pigs receiving diets containing 125 ppm Cu as CuCit. Additionally, pigs consuming diets containing 15, 31, or 62 ppm as CuCit excreted
less Cu than that of pigs fed supplemental diets of Cu as CuCit at a concentration of 125 ppm. No odor characteristics of the feces were affected by dietary Cu supplementation or source.

When pharmacological concentrations of CuSO₄ are fed for growth promotion, fecal Cu excretions have been reported to increase approximately 14-fold with the addition of 250 ppm Cu as CuSO₄ compared with the basal diet (Roof and Mahan, 1982). Smits and Henman (2000) reported, from field-research, Cu proteinate (Bioplex™) fed at 40 ppm greatly decreased fecal Cu concentration without sacrificing growth performance when compared to inorganic Cu fed as CuSO₄ at 150 ppm. Those pigs fed the diets containing organic Cu at 40 ppm achieved similar performance to those fed inorganic CuSO₄ at 150 ppm. However the quantity of Cu excreted in the feces was three to four times less in pigs fed organic Cu. Similar studies were conducted by Pierce et al. (2001) who also measured the fecal Cu content of growing pigs when fed either a control diet, or diets containing CuSO₄ or Bioplex Cu. Once again those pigs fed the organic Cu had similar performance to those fed the inorganic source of Cu, but had a 46% decrease in fecal Cu concentration. Veum et al. (2004) also demonstrated no significant difference in growth rate in nursery pigs fed Bioplex organic Cu and inorganic CuSO₄, however, fecal output of Cu was reduced by a factor of four. Thus, organic Cu can be utilized to gain the benefits of growth while greatly reducing the mass of Cu in excreta and reducing the environmental impact.

Chelation

Chelating agents are widely distributed in all living systems. Besides water, and among others, carbohydrates, lipids, amino acids, peptides, nucleotides, plant alkaloids and phenolics, as well as vitamins may form metal complexes and chelates. These ligands are
involved in all steps of the mechanisms for channeling the proper amounts of metals to the correct physiological location, in order to carry out a specific function(s). These types of molecules play a central role in digestion, absorption, transport, intracellular metabolism, as well as uptake and efflux of metals by cells (DiSilvestro and Cousins 1983).

Chelation is the ability of a chemical agent to form a ring with a metal ion (Stansbury et al. 1990). Fouad (1976) illustrated that inorganic forms of metals were less efficient and retained in the body at lower concentrations when compared to similar minerals in their chelated organic form. Chelating agents can be organic (amino acids or polysaccharides) or inorganic (e.g., EDTA). Numerous studies have shown little effect on pig performance when chelated Cu has been added to swine diets (Bunch et al., 1965; Zoubeck et al., 1975) or in which the chelating agent was added separately (Hawbaker et al., 1961).

Research has concluded (Apgar and Kornegay, 1996; Lou and Dove, 1996; Veum et al., 2004) that organic sources of trace minerals have superior bioavailability when compared to inorganic sources due to their ability to maintain structural integrity in the digestive tract. This allows the organic mineral to arrive at the binding or absorptive site of enterocyte in the small intestine as the original intact molecule (Guo et al., 2001). Additionally Gou et al. (2001) reported that numerous well designed experiments have indicated relative responses in various tissue deposition and performance traits of the organic trace elements ranging from 90% to 120% compared with SO₄, a highly available inorganic source.

Chelation chemistry is a very complex and sophisticated science (Kratzer and Vohra, 1986). The degree of chelation of an organic mineral source has been a means of determining the value of products used as supplements in animal nutrition, this according to Gou et. al. (2001).
Trace metals in the gastrointestinal tract lumen exist mostly bound to organic compounds from dietary or endogenous origin. Gut absorption of these metals mainly occurs in the duodenum. It is thought to be largely an active carrier-mediated process when low concentrations are fed. Upon entering the gastrointestinal cell, metals are released to intracellular proteins and then utilized in the same or similar manner as other sources of the same metal.

**Zinc**

*Function*

Zinc is commonly added to all formulated animal diets by the means of ZnO (zinc oxide, 72% Zn) or ZnSO₄·H₂O (zinc sulfate, 35% Zn), the two most predominant forms in the animal industry (Wedekind and Baker, 1990).

Zinc is a trace element essential for animals, plants and microorganisms (Baker and Ammerman, 1995). Animals obtain Zn from the dietary ingredients such as cereal grains, and other seeds, forages or from extrinsically supplied inorganic sources (Underwood and Suttle, 1999). Solomons and Cousins (1984) noted that the need for Zn is related to the size of the animal and its energy consumption. Zinc is a component of many metalloenzymes, including DNA and RNA synthetases and transferases, many digestive enzymes, and plays an important role in protein, carbohydrate, and lipid metabolism (NRC, 1998). Its role may be one of structural integrity, host defense, cytostructural, and regulatory processes, which are non-enzymatic in nature (Hill and Spears, 2001). Zinc plays a central role in the immune system, and it is well documented that Zn deficiency in animals and humans results in increased susceptibility to a variety of pathogens, including parasitic nematodes in intestinal and systemic sites (Shankar and Prasad, 1998; Scott and Koski, 2000). Multiple aspects of
the immune system are affected by Zn status, from the skin barrier to gene regulation of T and B lymphocyte function; Zn is crucial for development and function of cell mediated immunity, including neutrophil and macrophage activity (Scott and Koski, 2000).

While being present in many valence states within the body, most commonly Zn\(^{2+}\), Zn is found in the highest concentrations in organs such as bone, liver, and the kidneys (Groff and Gropper, 1999). A good indicator of Zn status is not yet known due to the complexity of the homeostatic regulation that protects the activity of many Zn enzymes during times of dietary deficiency. However, elemental Zn in blood plasma is widely used as an indicator of Zn status due to lack of more specific indicators. Activity of alkaline phosphatase is dependent on Zn status (Larsen and Sandstrom, 1993). Elemental Zn in liver tissue is an indicator of internal Zn deposition or stores.

**Absorption and Transport**

Zinc plays a role in many metabolic functions including the normal absorption and function of vitamins. Biochemically, zinc functions by maintaining spatial and configurational relationships by the utilization of zinc fingers. In this role it helps to bind enzymes to substrates and may modify the molecular shape of enzymes by binding to amino acids at different places on the protein, affecting the overall protein structure. Zinc also plays a role in the cell division and in the synthesis of DNA. This binding of zinc to the amino acids and nucleic acids of certain proteins requires zinc to be hydrolyzed from these amino acids and nucleic acids prior to absorption. Zinc is believed to be liberated from food during the digestive process, most likely by proteases and nucleases in the stomach and small intestine (King and Keen, 1999). Hydrochloric acid also appears to play an important role in Zn digestion and/or absorption (Groff and Gropper, 1999). The role of gastric acid in Zn
digestion and/or absorption has not been elucidated but may relate to impaired hydrolysis of Zn from nucleic or amino acids, changes in Zn ionic state, or alterations in the enterocyte membrane to affect permeability and thus, Zn absorption (Groff and Gropper, 1999).

The main site of Zn absorption in the gastrointestinal tract is the proximal small intestine, and more specifically the jejunum (Groff and Gropper, 1999). However, overall Zn absorption in the relative segments of the small intestine (duodenum, jejunum, and ileum) has not been demonstrated.

Zinc is absorbed into the enterocyte by a carrier-mediated process, which occurs more efficiently in low Zn intakes than in higher Zn intakes. Due to the fact that absorption of Zn is a carrier-mediated process or mechanism is enhanced with low Zn status; this suggests that the total amount of Zn absorbed is homeostatically regulated, even though the process is not fully understood. The body’s Zn status plays a major role in the absorption of Zn, however the mode of action is unclear. The energy need of this carrier mediated process is also not thoroughly known. Passive diffusion (nonsaturable) and/or paracellular Zn absorption are thought to occur with high Zn intakes (Groff and Gropper, 1999; King and Keen, 1999).

The body’s Zn status, as well as, several endogenous substances is thought to facilitate or enhance Zn absorption. Possible endogenous ligands include citric acid, picolinic acid, and prostaglandins. Picolinic acid is a metabolite of the tryptophan to niacin pathway. Amino acids ligands (lysine and glycine), glutathione (tripeptide consisting of cysteine, glutamate, and glycine) also serve as Zn absorption enhancers, particularly in the presence of an inhibitor (phytate, oxalate, etc.) (Groff and Gropper, 1999). Specifically these ligands contain sulfur which allows the Zn to bind and form an absorptive Zn molecule in the villus epithelial cells within the intestine.
While the bodies Zn status remains in homeostasis in normal or ideal conditions, several factors negatively influence Zn absorption when properly balanced diets are not consumed. Factors that negatively influence Zn absorption include phytate, oxalate, polyphenols, fibers, and nutrients including divalent cations and certain vitamins (Groff and Gropper, 1999).

Phytate, also known as inositol hexaphosphate or polyphosphate, is found in plant derived food sources, particularly cereals such as corn or bran, and legumes. Phytate has the potential to form insoluble salts with Ca, Fe, Zn, Mn, and Cu (Vohra et al., 1965), which may decrease the availability of these minerals. Several studies have reported that Zn bioavailability and retention were improved with the addition of phytase in the diet for weanling pigs (Lei et al., 1993; Adeola et al., 1995). Additionally, research conducted by Spears et al. (2001) reported that pigs fed phytase with no supplemental Zn performed as well as those fed supplemental Zn only. Therefore, phytase addition to pig diets could prove beneficial to allow for increased Zn bioavailability, thus less need for excess mineral supplementation.

Storage

There is no specific Zn storage area located in the body (King and Keen, 1999). In all species, a marked reduction in dietary Zn intake is quickly followed by signs of Zn deficiency, namely hyperkeratinization. In research conducted by Emmert and Baker (1995) chicks fed a high-Zn diet prior to depletion took longer to develop a deficiency than chicks fed a low-Zn diet previously. High Zn intakes have been shown in many research studies to increase bone, liver, and intestinal Zn (Ott et al., 1966; Rojas et al., 1995). Release of Zn
from those tissues during depletion may slow the rate of onset of Zn deficiency symptoms, but it is hard to speculate (Rojas et al., 1995).

**Deficiency**

The classic sign of a Zn deficiency in growing pigs is hyperkeratinization of the skin, a condition called parakeratosis (Kernkamp and Ferrin, 1953; Tucker and Salmon, 1955). Failure to eat, grow, and reproduce, accompanied by alopecia, gross skin lesions, poor wound healing, and impaired brain development are the primary characteristics of Zn deficiency (Hill and Spears, 2001). Deficiency of Zn can be induced when the concentration of one or more nutrients is increased beyond the necessary requirements. For example the overfeeding of Ca with adequate Zn in the diet, would decrease the Zn available for bodily functions (Morris and Ellis, 1980). The lack of research relative to Zn absorption in swine may be because corn-soybean meal diets, typical of the U. S. swine industry, provide approximately 40 ppm Zn, which prevents parakeratosis (Smith, 1960).

Reduced appetite is one of the first major signs for a Zn deficiency observed in animals. O'Dell and Reeves (1989) showed that changes in appetite are associated with changes in the concentrations of amino acid derived neurotransmitters in the brain. Berger (2001) hypothesized that the reduction in enzyme activity leads to the accumulation of one or more metabolites causing a marked change in eating behavior. This sensitivity of appetite to nutrient supply is unique to Zn, expressed in all species, and reflects the key role of Zn in nutrient metabolism (Berger, 2001).

**Performance**

Researchers have shown that high concentrations of inorganic Zn as ZnO improved growth performance of nursery pigs (Hahn and Baker, 1993; Carlson et al., 1999; Hill et al.,
The Zn requirement as reported (NRC, 1998) is set at 100 ppm Zn; however, the addition of 2,000 to 3,000 ppm of Zn as ZnO is commonly supplemented commercially at the present time by the U. S. swine industry.

Carlson et al. (1999) conducted experiments to determine the effect of 3,000 ppm Zn as ZnO on the growth response of early-weaned nursery pigs. Two experiments of Yorkshire x Landrace x Hampshire pigs were utilized to determine the growth responses of pharmacological supplementation of Zn in the nursery phase. Pigs fed the high concentrations of Zn for weeks 1 and 2 of the entire 28-day nursery experiment had the greatest \( P < 0.05 \) ADG. Additionally, both early- and traditionally-weaned pigs need to be fed pharmacological concentrations of Zn provided as ZnO for a minimum of two weeks immediately after weaning to enhance growth (Carlson et al., 1999).

Recent studies with swine suggest that replacing inorganic trace minerals with the more bioavailable chelated forms of the minerals could improve overall performance. Nursery pigs that were supplemented with 36% of the total mineral supplementation in the form of chelated metal proteinates of Zn, Fe, and Cu experienced increased \( P < 0.05 \) gain and gain:feed (Veum et al., 1995). Spears et al. (2000) furthered this research by feeding 192 weanling pigs for the 35 d nursery phase. Results from this study demonstrated that 50 ppm of supplemental Zn is adequate for growth and immunity in nursery pigs. Additionally, replacing 25 or 50% of the supplemental inorganic Zn with Zn proteinate tended to improve gain and feed intake of pigs receiving 50 ppm of added Zn.

Hahn and Baker (1993) evaluated the growth of young pigs fed pharmacological concentrations of Zn from different sources and concentrations, either ZnO or ZnSO\(_4\) at a supplemented rate of 3000 and 5000 ppm. Results indicated that ADG and ADFI were
increased \((P < 0.05)\) by \(\text{ZnO}\) addition, regardless of concentration, whereas \(\text{ZnSO}_4\) addition increased these performance indices only at the 3000 ppm concentration of supplementation. Feeding high concentrations of supplemental \(\text{Zn}\) from \(\text{ZnO}\) stimulated voluntary feed intake and weight gain of young pigs that were between 28 and 49 d of age. Feed intake was improved by 14\% which is consistent with the 17\% improvement reported by Case and Carlson (2002) in a similar study. Increased weight gain was primarily due to the increase in voluntary feed intake experienced by the pigs fed the \(\text{Zn}\) supplementation.

Further speculation into the reason for improved performance was detailed by Carlson et al. (1998) who reported deeper crypts and greater total thickness in the duodenum. Additionally, increased metallothionein concentrations were documented, which indicates that high concentrations of \(\text{Zn}\) have an enteric effect on the nursery pig. This increase in voluntary feed intake and enteric activity can explain both the increase in growth and performance for the young nursery pig.

**Bioavailability and Chelation**

In early research by Roberson and Schaible (1960), Pensack et al. (1958) and Edwards (1959) suggested the bioavailability of \(\text{Zn}\) sulfates, oxides and carbonates did not differ in chicks. Consistent data was reported in pigs (Hill et al., 1986; Swinkels et al., 1991) which also failed to show differences in \(\text{Zn}\) bioavailability between organic (chelates and complexes) and inorganic \(\text{Zn}\) sources. In a study conducted by Cao et al. (2000) the organic sources of \(\text{Zn}\) were found to differ in regard to chemical indicators of chelation effectiveness and \(\text{Zn}\) solubility in pH 2.0 or 5.0 buffers. High dietary concentrations of \(\text{Zn}\) sources were supplemented to chick and lamb diets in order to assess their overall bioavailability. Estimates of \(\text{Zn}\) bioavailability in animals from the different organic sources were not related
to laboratory estimates of degree of chelation but were inversely related to Zn solubility in pH 5.0 buffer in chicks and pH 2.0 buffer in lambs (Cao et al., 2000).

Standard sources of Zn used in supplementation to livestock have included sulfate, carbonate, chloride, oxide and acetate forms of the element with zinc sulfate (ZnSO₄) being the most common. Zinc from animal products is generally more available than plant products due to the lack of phytate. The relative bioavailability of Zn in meat, milk, and milk products shown by Baker and Ammerman (1995) in chickens and rats approached 100%. Also reported were values, determined with rats, of Zn utilization in grains and legume seeds, or in products produced by grains or legume seeds, which averaged about 60-70%, depending on the Zn source. Baker and Ammerman (1995) also reported that average bioavailability of Zn from corn was approximately 45%. Supplemental sources of Zn were generally well utilized and their relative bioavailabilities were about 100%, regardless of source (Baker and Ammerman, 1995).

Zinc uptake in the liver and metallothioneine synthesis has been used to estimate bioavailability, especially when high dietary concentrations are being fed (Sandoval et al., 1997). Zinc intake has been shown to induce intestinal metallothioneine synthesis when chicks were fed high dietary concentrations of the mineral according to research by Sandoval et al., 1997). This protein will influence the regulation of Zn absorption and possibly the bioavailability of Zn, regardless of source.

**Environmental**

Heavy metals are of great concern with regard to environmental pollution. These metals are dangerous because they tend to accumulate in the environment. Bioaccumulation means an increase in the concentration of an element of chemical in biological organism over
Heavy metals pose problems as they can enter a water supply by industrial or consumer waste, or even from acidic rain breaking down soils and releasing heavy metals into streams, lakes, rivers and groundwater. An excess concentration of Zn can be toxic to plants, and when soil accumulation exceeds 200-300 ppm, microflora activity is reduced (Mateos et al., 2005). Revy et al., (2003) reported pigs fed diets containing 100-250 ppm Zn would produce slurry that contained between 850 and 1300 mg Zn per kg DM. Dietary reduction in Zn supplementation from 150 ppm to 90 ppm can reduce Zn in feces by 40% (Paboeuf et al., 2001). Additionally, Revy et al. (2003) indicated a reduction in finishing diets from 100 to 60 ppm, and a reduction of piglet diets from 3000 to 150 ppm, will reduce the Zn slurry concentration from 1860 to 450 mg Zn per kg DM.

Hernandez et al. (unpublished, from Mullan et al., 2005) revealed no significant differences in performance from grow-finish (25-117 kg BW) pigs fed diets containing either organic (Bioplex) or inorganic Cu and Zn, however, an 83% reduction in Cu and 65% in Zn excretion was achieved when the low Bioplex concentration was fed as compared to the high concentrations of the inorganic forms of Cu and Zn as sulfates (Mullan et al., 2005). Diets consisted of low Bioplex concentrations (25 ppm Cu, 40 ppm Zn), medium Bioplex (80 ppm Cu, 80 ppm Zn) or high Bioplex (160 ppm Cu, 160 ppm Zn) concentrations of Cu and Zn compared with those of the high Bioplex concentrations in the diet supplemented in the inorganic sulphate form (160 ppm CuSO₄, 160 ppm ZnSO₄).

These studies clearly demonstrate the ability to reduce trace mineral content in diets in order to decrease environmental contamination.
**Iron**

**Function**

Essential Fe is important for its role in physiological function in: 1. hemoglobin, in which the heme portion functions to carry oxygen from the lungs to tissues, 2. mitochondrial Fe enzymes that are essential for oxidative production of cellular energy through the Krebs cycle, and 3. the transport of oxygen by myoglobin to the cells and tissue of muscle. Stored Fe is said to help maintain and regulate Fe homeostasis and provide a reserve for the body's deficient tissues (Beard, 2000).

Iron is a crucial piece of a heme molecule, which is the active site of electron transport in cytochromes and cytochrome oxidase. Most importantly, heme is the site of oxygen uptake by myoglobin and hemoglobin, both of which are responsible for transporting oxygen to tissues and within muscle cells.

Iron plays a role in oxygen transport, immune function, and metabolism. The role of Fe in the electron transport chain is found in chytochrome a-a3 (the last enzyme in the transport chain), which has one coordinate bound with Fe and protein. Additionally, cytochromes b and c, also involved in the electron transport chain, pass electrons onto oxygen by changing the valance state of the Fe atom. Iron also plays a role in lipid metabolism with its inclusion in Cytochrome b5, and drug metabolism with P-450, an Fe containing enzyme (Hill and Spears, 2001).

**Absorption and Transport**

In healthy animals, Fe loss is very limited and is often regulated absorption (Fairbanks, 1999). Ingested organic Fe is solubulized and ionized by acid gastric juice, reduced to the ferrous (Fe^{2+}) form, and chelated. The mucin of normal gastric juice chelates
and stabilizes Fe, thereby reducing its precipitation at the alkaline pH of the small intestine. Impaired Fe absorption in achlorhydric or gastrectomized persons reflects decreased solubilization and chelation of the ferric (Fe$^{3+}$) form in food (Fairbanks, 1999).

Absorption can and may occur in any portion of the small intestine, but Fe is most efficiently absorbed in the duodenum and jejunum. The common theory in Fe absorption, known as the mucosal block theory, is that only enough Fe to meet the animals needs are absorbed (Hahn et al., 1943). This theory has been modified in more recent research, however, it is still believed that only a small amount of the Fe a pig consumes is actually absorbed. In order for mucosal cell brush border uptake to occur, the Fe atom must first traverse the mucous layer. Passage of the Fe through this layer is facilitated by organic acids (Simpson et al., 1988; Simpson et al., 1989), or taurocholic acid (Sanyal et al., 1990) in normal bile or by polypeptides containing cysteine (Slatkavitz and Clydesdale, 1988; Taylor et al., 1986). The divalent, or Fe(II), form of Fe is more readily soluble than the trivalent, or Fe(III), form because of the low solubility of ferric hydroxides and phosphates at the alkaline pH of intestinal fluid (Fairbanks, 1999). From mucin, Fe is taken up by one or more proteins on the luminal surface of the mucosal epithelium of the duodenum (Conrad et al., 1993a; Conrad et al., 1993b). Callender et al. (1957) modified the mucosal theory to suggest that heme Fe is directly absorbed into the mucosal cells with the porphyrin complex intact.

**Storage**

Iron in excess of body needs or requirements are stored intracellularly as ferritin and hemosiderin, principally in the macrophage reticuloendothelial system of the liver, spleen, bone marrow, and other organs (Fairbanks, 1999). In the liver and spleen of normal animals, there is a slightly greater amount of ferritin Fe over hemosiderin Fe. With increasing
concentrations of tissue Fe, this ratio tends to reverse, and high concentrations shifts Fe storage to be deposited as hemosiderin. When the need for Fe mobilization arises, both forms, ferritin and hemosiderin, can be utilized to meet the needs for hemoglobin synthesis (Fairbanks, 1999).

**Deficiency**

Iron deficiency is the most common mineral deficiency in swine. Dallman (1986) noted that it is easier to define an Fe deficiency than it is to characterize its effect on health and well-being. Several factors influence animal health and well being in relation to Fe deficiency, including low Fe concentration in sows milk, and the hepatic Fe stores of a newborn pig are low. Together these stores and Fe sources are not sufficient to meet the requirements for increased growth rate and blood volume (Rincker et al., 2004).

The use of exogenous source of Fe to combat Fe deficiency in neonatal pigs is well documented (Ullrey et al., 1959; Kernkamp et al., 1962). With an increased emphasis on improving growth performance and carcass leanness, the potential for Fe deficiency in suckling pigs increases. The increase in animal tissue, means an increase in hemoglobin, oxygen carrying capacity, and cellular energy requirements that must be met. In order to meet this demand supplemental Fe must be delivered.

Post-weaning dietary Fe requirement is 80 mg/d (NRC, 1998). The recommendation is based on early experiments conducted by Pickett et al. (1960) who reported decreased growth in pigs weaned at 10 to 14 d of age and fed diets containing 60 mg of supplemented Fe per kg diet and decreased hemoglobin (Hb) and hematocrit (Hct) in pigs fed diets containing 80 mg of added Fe per kg diet. Rincker et al. (2004) reported many commonly added feed ingredients may meet Fe post-weaning requirements (80 mg per d), however
these Fe sources were not sufficient to maintain liver stores of growing pigs. This decrease in liver Fe stores could result in decreased animal performance. Three factors have been reported (Kornegay, 1972) to influence Fe status. These factors are Fe status of the animal, Fe concentration, and various nutritional and non-nutritional elements within the diet.

Iron deficiency is often described in the baby pig by labored and spasmodic breathing referred to as the “thumps”, loss of appetite and weight, and ultimately death (Underwood, 1977). However, this is rarely seen in commercial swine production. Pigs at the age of 1 to 3 days of age are given a 1 cc intramuscular injection of Fe, the most commonly injected Fe source is Iron Dextran Complex 200 mg Fe per cc administered intramuscularly. Orally administered Fe can also be utilized; however, if not given within the first 24 h of birth, gut closure may reduce availability (Hill et al., 1999).

Performance

With performance being emphasized and with the current genetics being selected for maximum lean weight gain and efficiency, Fe deficiency must be evaluated. The Fe requirements for pigs 1 to 5 and 20 to 50 kilograms of live weight are 100 and 60 ppm respectively, which are equivalent to Fe intakes of 25 and 115 milligrams (NRC, 1988). Iron must be supplemented to young pigs in order to meet the requirement of Fe for hemoglobin formation. Maximum growth rate was acquired through supplementation of 100 mg in the form of injectable iron dextran to pigs weaned at three wk of age (Zimmerman et al., 1959). The dietary Fe requirement decreases with an increase in age and weight of the animal due to a decrease in blood volume per unit weight, i.e. hemoglobin formation, and higher dietary Fe intakes.
Bioavailability and Chelation

Research into bioavailability of Fe in feedstuffs is limited due to the fact that anemia is of little significance in other farm species. A deficiency of Fe is primarily associated with young animals whose diets consist of milk-based products. This deficiency issue is extremely important in confinement animals or more importantly baby or nursing pigs. Underwood (1981) reported several factors that compound this susceptibility to anemia including: very low Fe stores at birth, absence of the polycythemia of birth common to other animals, particularly low concentrations of Fe in sow’s milk, and very rapid growth rates compared to other species. Sow’s milk is a very poor source of Fe (1 to 3 ppm) (Venn et al., 1947). Piglets normally quadruple their birth weight by the time they are 3 wk of age, indicating a need for further evaluation of Fe bioavailability needs.

However, some estimates of Fe bioavailability for animal by-products range from 50-60%, with blood meals possibly being higher (Conrad et al., 1980).

Environmental

Because Fe is one of the most abundant metals on earth and in the universe, nearly all the Fe in the environment is insoluble, existing as iron oxides or as metallic iron (Fairbanks, 1999). Thus, little Fe is available for biological needs, and living organisms conserve Fe as a trace element. Due to the insoluble nature of Fe as it exists in nature, Fe accumulation in the environment has not been a topic of research.

Ultrasonic body composition evaluation

Prior to 1985, 90 percent of hogs marketed were sold as traditional ‘commodity pork’ where price was determined on a live weight basis (Hayenga, 1985). The adoption of incentive-based marketing systems became increasingly important to producers seeking an
added value to the hogs produced, and corresponded to increased selection for lean percentage. As a result, the percentage of hogs sold on a carcass basis rose to 28 percent in 1988 and to 78 percent in 1997 (Brorsen et al., 1998). As the livestock industry moves closer to the concept of value-based marketing, producers are becoming more concerned with carcass traits.

Hazel and Kline (1952) developed the metal backfat probe, an invasive method to measure backfat depth, and reported correlations above 0.80 between live and carcass measures of backfat. Although high correlations and relatively high accuracy was achieved using the backfat probe, the potential for infection at the points of incision and need for animal restraint were difficult, consequently this method was undesirable. The first report of ultrasound in measuring backfat (Claus, 1957) was quickly followed by additional research evaluating this new, noninvasive technology.

Although livestock producers are realizing the importance of carcass trait predictability, they are faced with the dilemma of accurately measuring carcass values and characteristics prior to slaughter. Real-time ultrasound has become the method of choice to estimate body composition in live swine to select individuals to retain as breeding animals, as well as determine carcass composition non-invasively.

Ultrasound technology was introduced early in the 1950’s as a means for estimating compositional differences among livestock (Wild, 1950; Claus, 1957; Panier, 1957; Price et al., 1958; Hazel and Kline, 1959). Advances in ultrasound technology during the 1970’s and early 1980’s have dramatically improved the quality of equipment utilized for estimating compositional differences. Real-time ultrasound is now the most commonly accepted ultrasonic instrumentation that is utilized in the livestock industry.
The procedure for utilizing ultrasound to capture a cross-sectional image of the 10th rib longissimus muscle and backfat requires the use of a mineral oil applied to desired area and placement of the sensor or transducer. The basic principle of ultrasound is to measure an echo rebounding from soft tissues. After the transducer is placed in contact with the animal, the ultrasonic pulses are in the form of high frequency sound waves, are reflected from boundaries between different densities of the tissues (Moeller, 2002). The resulting rebounding of the sound waves are translated back through the transducer and projected onto the screen of the ultrasound unit. This image can then be saved as a digitized image for later interpretation.

Proper interpretation of the ultrasound image is important for accurate measurements. Accurate estimates of BF and LMA are generally not difficult to obtain by a trained ultrasound technician.

**Prediction Equations**

In order to access the carcass characteristics of pigs on test ultrasonic measurements were taken on the 10th rib longissimus muscle. Backfat and LMA between the 10th and 11th ribs will be estimated from the image and placed into formulas to predict overall carcass composition. Images from the Aloka 500V ultrasound machine equipped with a 12.5-cm, 3.5 MHz linear array transducer. Kilograms of lean at market weight and at trial entry will be estimated using the following fat-free lean prediction equations developed by the National Pork Producers Council (NPPC, 2000):

\[
\text{Market weight lean (kg)} = 0.3782 \times \text{sex (barrow} = 1; \text{gilt} = 2) - 2.9488 \times (10\text{th BF, cm}) + 0.3817 \times (\text{LMA, cm}^2) + 0.291 \times (\text{live weight, kg}) - 0.2424
\]

\[
\text{Trial Entry Lean (kg)} = 0.188 \times (\text{live weight, kg}) - 1.644
\]
Lean gain on test (LGOT) will be calculated by subtracting the estimate of trial entry lean from market weight lean and dividing by days on test.

This formula allows for the prediction of carcass composition using ultrasound technology. Within the formula the consideration for adjustment for barrows and gilts can be taken into account.
CHAPTER 3. THE EFFECT OF INORGANIC AND ORGANIC TRACE MINERAL SUPPLEMENTATION ON THE PERFORMANCE AND CARCASS CHARACTERISTICS OF PHASE-FED, GROW-FINISH SWINE

A paper to be published in the Journal of Animal Science

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ABSTRACT

Two experiments were conducted to compare the effect of inorganic and organic trace mineral supplementation on performance and carcass characteristics of phase-fed, grow-finish swine. Crossbred pigs (EXP. 1, Iowa State University Lauren Christian Farm, Atlantic, IA (n=528); EXP. 2, Wilson’s Prairie View Farms, Burlington, WI (n=560)) were blocked by weight, penned by sex, and randomly assigned to treatment pens at approximately 18 kg BW. Pigs were housed in two identical, totally-slatted, confinement barns and provided ad libitum access to feed and water. Dietary treatments were allocated in a general randomized complete block design with 12 replicate pens per treatment (TRT) and 9-12 pigs per pen throughout the grow-finish period. In EXP. 1, the control diet (TRT 1) contained

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Cu, Fe, and Zn from inorganic sources at concentrations of 85, 169, and 163 mg/kg, respectively. Treatment 2 (TRT 2) contained Cu, Fe, and Zn from organic sources at concentrations of 19, 131, and 91 mg/kg, respectively. Organic Cu, Fe, and Zn concentrations from TRT 2 were reduced by 25 and 50% for TRT 3 and TRT 4, respectively. In EXP. 2, TRT 5 contained 25% of the Cu, Fe, and Zn concentrations found in TRT 1. Treatments 6 and 7 (TRT 6, TRT 7) contained Cu, Fe, and Zn at concentrations that were reduced by 50% and 75% from the levels in TRT 2, respectively. Microminerals were removed from TRT 8, which served as a negative control. Off-test weights and estimates of ultrasonic tenth-rib backfat (BF10) and loin muscle area (LMA) were collected in both experiments on all pigs prior to harvest (BW = 118 kg). In EXP. 1, pigs fed the control diet had lower ($P < 0.05$) ADFI when compared to pigs fed the other three treatments. In EXP. 1, BF10, LMA, ADG, lean efficiency (LE), percent lean live, percent lean carcass, and kilograms of lean were not different ($P > 0.05$) among treatments. In EXP. 2, pigs fed TRT 8 had poorer ($P < 0.01$) ADG, lean gain on test, and LE, and lower ADFI when compared to pigs fed the other dietary treatments. Organic Cu, Fe, and Zn trace minerals can be supplemented at reduced levels in diets fed to grow-finish swine and similar performance and carcass composition can be achieved when compared to pigs that are fed diets containing commonly supplemented levels of the inorganic forms of these minerals.

**Key Words:** Carcass characteristics, Growth, Pigs, Trace minerals

**INTRODUCTION**

Modern genetic lines of pigs require nutritionally dense diets to meet their requirements for lean tissue deposition (Schinckel and deLange, 1996; Thompson et al., 1996). Additionally, pigs have been fed concentrated diets, formulated to typically provide
an excess margin of nutrients to maximize performance and to allow the pig to withstand various biological stress events (Carlson et al., 1999; Hill et al., 2000). Until recently, producers have not been concerned with the concentration and/or the volume of nutrients excreted.

Large commercial swine operations tend to concentrate manure production and storage in a relatively small geographical area. Manure production and storage from such operations can lead to nutrient accumulations that often exceed the requirements in the surrounding crop production area. Excess microminerals, namely Cu, Fe, and Zn, can become toxic to some species (Besser, 2001), while bioaccumulation of other nutrients may occur in lagoons and watersheds.

Leeson (2003) reported that chelated trace minerals (e.g. Bioplex™) are at least 30% more bioavailable when compared to inorganic trace mineral salts when fed to broilers. The inclusion of organically complex or chelated trace mineral products into mineral supplements for grow-finish swine diets has been suggested due to their increased bioavailability over inorganic mineral salts. Therefore, the objective of this study was to compare the performance and carcass composition of pigs fed diets containing differing supplemental concentrations of inorganic and organic forms of Cu, Fe, and Zn throughout the grow-finish phase of production.

MATERIALS AND METHODS

Two experiments were conducted to evaluate the effect of differing sources and concentrations of Cu, Fe, and Zn supplementation on growth performance and carcass characteristics of grow-finish swine. Experimental protocols for this study were approved by the Iowa State University Institutional Animal Care and Use Committee.
Animals

In both experiments, crossbred pigs (EXP. 1, Iowa State University Lauren Christian Farm, Atlantic, IA (n=528); EXP. 2, Wilson’s Prairie View Farms, Burlington, WI (n=560)) were blocked by weight, penned by sex, and randomly assigned to treatment pens at approximately 18 kg BW. Each pen began the experiment with 9-12 pigs per pen.

Housing

Pigs were housed in two adjacent, totally-slatted, environmentally controlled confinement facilities. Pigs were provided ad libitum access to feed through a 2-hole feeder and to water through a 2-nipple hanging drinker in each pen. Each pig was provided 0.9 to 1.3 m² of floor space in each pen. An anthelminthic (Ivermectin, Merial Inc., Duluth, GA) was used in both experiments to treat pigs prior to initiation of the test period. Pigs that were unhealthy or injured during the experiments were removed from the test. Number of pigs removed and reason for removal was documented to make comparisons of treatment effects.

Dietary Treatments

A four-phase, grow-finish feeding program was utilized for all pigs in each experiment according to the following regimen: Phase 1 (18 to 37 kg), Phase 2 (37 to 55 kg), Phase 3 (55 to 82 kg) and Phase 4 (82 to 118 kg).

A complete basal diet (meal form) was formulated and different sources and concentrations of Cu, Fe, and Zn were used to develop the experimental dietary treatments. Formulated total lysine content (as fed) of the diets was 1.12%, 1.05%, 0.93%, and 0.79% during the four phases, respectively. Formulated nutrient composition (as fed) of the diets utilized in this study is presented in Table 1. Formulated concentrations of the experimental trace minerals Cu, Fe, and Zn, are presented in Table 2. In EXP. 1, the control diet (TRT 1)
contained Cu as CuSO₄, Fe as FeSO₄, and Zn (of which 25% was ZnO and 75% was ZnSO₄) at concentrations of 85, 169, and 163 mg/kg, respectively. These concentrations of Cu, Fe, and Zn are 13.40, 1.74, and 1.75 times the NRC (1998) recommendations, respectively. Treatment 2 (TRT 2) contained Cu, Fe, and Zn from organic sources (Bioplex™, Alltech Inc., Nicholasville, KY) at concentrations of 19, 131, and 91 mg/kg, respectively. These concentrations of Cu, Fe, and Zn are 3.00, 1.36, and 0.97 times the NRC (1998) recommendations, respectively. Organic Cu, Fe, and Zn concentrations from TRT 2 were reduced by 25 and 50% for TRT 3 and TRT 4, respectively. In EXP. 2, TRT 5 contained 25% of the Cu, Fe, and Zn (inorganic sources) concentrations found in TRT 1. Treatment 6 (TRT 6) contained the experimental microminerals at concentrations that were identical to TRT 4 from EXP. 1. Treatment 7 (TRT 7) contained Cu, Fe, and Zn concentrations that were reduced by 75% from the levels found in TRT 2 of EXP. 1. Treatment 8 (TRT 8) contained no supplemental microminerals and served as a negative control for EXP. 2. Experimental trace mineral premixes were manufactured commercially (Kent Feeds Inc., Muscatine, IA) and diets were mixed by a commercial feed manufacturer (Nevada Feed and Seed, Nevada, IA).

Samples of all experimental diets in the study were analyzed (Dairy One Inc., Ithaca, NY) for trace mineral and DM content. All experimental dietary microminerals (Cu, Fe, and Zn) were analyzed using a Thermo Jarrell Ash IRIS Advantage HX Inductively Coupled Plasma (ICP) Radial Spectrometer (Thermo Electron Corporation, Waltham, MA). Dry matter analysis of feed samples was performed by Near Infrared Reflectance Spectroscopy (NIRS) (AOAC 991.03, 1995).
Measurements

Pigs were weighed and feed disappearance was recorded at 2-week intervals to monitor growth performance and feed efficiency. Pigs completed the experiment and were removed from test at a mean BW of 118 kg. A National Swine Improvement Federation-certified technician collected ultrasonic measurements of backfat thickness (BF10) and loin muscle area (LMA) at the 10th rib. Measurements were collected with the use of an Aloka 500V ultrasound machine equipped with a 12.5 cm, 3.5 MHz linear array transducer (Corometrics Medical Systems, Inc., Wallingford, CT). Kilograms of lean (KL) at market weight and at trial entry were estimated using the following fat-free lean equations developed by the National Pork Producers Council (NPPC, 2000):

\[
\text{Market weight lean (kg)} = 0.3782 \times \text{sex (barrow }= 1; \text{ gilt }= 2) - 2.9488 \times (\text{BF10}, \text{cm}) + 0.3817 \times (\text{LMA}, \text{cm}^2) + 0.291 \times (\text{off-test weight, kg}) - 0.2424
\]

\[
\text{Trial entry lean (kg)} = 0.188 \times (\text{on-test weight, kg}) - 1.644
\]

Lean gain on test (LGOT) was calculated by subtracting the estimate of trial entry lean from market weight lean and dividing by days on test. Additionally, percent lean on a live basis (PLL) and on a carcass basis (PLC) were calculated from ultrasonic measurements using the NPPC formula (National Pork Producers Council, 2000). Pen feed intake was recorded and used to calculate average daily feed intake (ADFI), G:F, and efficiency of lean gain (LE). Efficiency of lean gain (LE) was calculated by dividing feed intake (pen basis) by weight gain on test (pen basis).

Statistical Analysis

Pigs were allocated in a general randomized complete block design with 4 dietary treatments and 12 replicate pens per treatment within each experiment. Pen was the
experimental unit in all analyses. Data were analyzed using the PROC MIXED procedure in SAS (SAS, 2003). The model included fixed effects of barn, treatment, and sex, and all two- and three-way main effect interactions. Pen nested within barn, sex, and treatment was included as a random effect. Off-test weight was a covariate for the analyses of BF10 and LMA. On-test weight was a covariate in the analyses of ADG, LGOT, ADFI, G:F, and LE. Interactions of main effects found to be non-significant were eliminated from the final model. When a model effect was a significant source of variation, least squares means were compared using the PDIF option of SAS. Pigs removed from test were analyzed by treatment using the PROC FREQ procedure in SAS. Significance was declared at $P < 0.05$.

**RESULTS**

Analyzed Cu, Fe, and Zn content of all diets is presented in Table 3. Least squares means for performance and carcass traits by treatment are presented in Table 4 for both EXP. 1 and EXP. 2.

**Average Daily Gain**

In EXP. 1, there were no treatment differences ($P = 0.36$) for ADG during the grow-finish period. In EXP. 2, pigs fed TRT 8 had lower ($P < 0.01$) ADG when compared to pigs fed the other three diets in the experiment. No differences in ADG ($P > 0.40$) were observed among the three diets containing Cu, Fe, and Zn supplementation in EXP. 2. In both experiments, barrows had significantly greater ADG when compared to gilts while having poorer LE ($P < 0.01$) (data not shown).

**Average Daily Feed Intake**

In EXP. 1, pigs fed the diet containing inorganic forms of Cu, Fe, and Zn (TRT 1) consumed less ($P < 0.05$) feed per day when compared to pigs fed the other three
experimental diets that were supplemented using organic forms of the same microminerals. In EXP. 2, pigs fed the diet containing no supplemental microminerals (TRT 8) had lower ADFI ($P < 0.01$) when compared to pigs fed the other diets in the experiment. Furthermore, pigs fed TRT 7 consumed less feed ($P < 0.05$) when compared to pigs fed TRT 5. Barrows in both experiments consumed more feed ($P < 0.01$) than gilts (data not shown).

**Pigs Removed From Test**

There were no treatment differences for the number of pigs removed from test ($P > 0.05$) in EXP. 1. In EXP. 2, pigs fed TRT 8 that showed signs of parakeratosis, listlessness, and weight loss were removed ($n=38$) from the experiment. The number of pigs removed from test by treatment was not different among TRT 5 ($n=1$), TRT 6 ($n=3$), and TRT 7 ($n=4$), however, all three were different from TRT 8 ($n=38$) ($P < 0.01$).

**Carcass Composition**

In EXP. 1, there were no differences among treatment means ($P > 0.10$) for LGOT, LE, G:F, PLL, PLC, and KL. Additionally, in EXP. 2, no differences among treatments means ($P > 0.10$) for PLL, PLC, and KL were observed. Pigs fed TRT 8 had the lowest ($P < 0.01$) LGOT and the poorest ($P < 0.01$) LE and G:F. In both experiments, no treatment differences were observed for BF10 and LMA ($P > 0.05$). Barrows were fatter and had less LMA ($P < 0.01$) when compared to gilts in both experiments, however, gilts had more KL, and higher PLL and PLC ($P < 0.01$) (data not shown). Contrasting results were found for LGOT in the current experiments; where barrows had higher LGOT in EXP. 1, and gilts had higher LGOT ($P < 0.05$) in EXP. 2 (data not shown).
DISCUSSION

Average Daily Gain and Average Daily Feed Intake

In EXP. 1, there were no differences among treatments for ADG during the grow-finish period. These results agree with previous work by Henman (2001), who reported no performance differences between grower and finishing pigs fed 100 mg/kg organic Cu (proteinate, Bioplex™) and those fed 200 mg/kg inorganic copper as CuSO₄, indicating that the inorganic copper could be replaced with lower levels of organic Cu with no adverse effect on performance. Similar results were presented by Smits and Henman (2000), who evaluated the performance of grower and finisher pigs fed diets supplemented with either CuSO₄ at a concentration of 150 mg/kg, or organic Cu (Bioplex™) at a concentration of 40 mg/kg. Pigs consuming the organic form of Cu achieved similar ADG to the pigs fed diets containing inorganic Cu as CuSO₄, in agreement with the present findings.

No differences in performance of grow-finish pigs fed diets containing supplemental Zn, regardless of source, were observed in the present study. Wedekind et al. (1994) conducted a study in which all diets were adequate in all minerals (NRC, 1998) except zinc. Therefore, ZnSO₄·H₂O was supplemented to provide 0, 5, 10, 20, 40, and 80 mg/kg Zn in the diet, consequently, no differences in ADG, ADFI, or G:F differences in growing or finishing pigs were reported.

In finishing pig studies, no ADG, ADFI, and G:F differences were reported with removal of vitamin and trace mineral supplementation for either 17 or 36 d (Patience and Gillis, 1995), or when vitamins were removed 35 d prior to slaughter (Patience and Gillis, 1996). In EXP. 2 of the current study, pigs fed TRT 8 had lower ADFI when compared to
TRT 5 and TRT 6. Removal of micromineral supplementation from the diet for the entire grow-finish period appeared to adversely affect ADG, ADFI, and efficiency of performance.

Pigs fed TRT 8 in EXP. 2 of the present study had a lower ADG for the entire grow-finish period when compared to pigs fed the other experimental diets. This depression in ADG is not consistent with other studies which have reported no evidence of an adverse effect on performance when deleting supplemental minerals and vitamins from typical grain-soybean meal diets for the late finishing period (17 to 45 d prior to slaughter) (Kim et al., 1997; Mavromichalis et al., 1999). McGlone (2000) reported no pig performance and pork quality differences when vitamin and trace mineral supplements were omitted from the diet for the last 30 d of the finishing period. The aforementioned studies removed trace mineral supplementation from the diet during the late finishing phase (17 to 45 d prior to slaughter), thus the differences from the present study may be due to feeding diets without supplemental Cu, Fe, and Zn throughout the entire grow-finish period (18 to 118 kg LW).

Pigs fed diets with no trace mineral supplementation in the present study exhibited hyperkeratinization of the skin, a classic sign of zinc deficiency (Kernkamp and Ferrin, 1953; Tucker and Salmon, 1955). Deficiency of Zn can be induced when the concentration of one or more nutrients, such as Ca and phytate, is increased beyond the necessary requirement. However, in the present study, it is unlikely the concentration of Ca in the diet was high enough to impede the availability of dietary Zn.

Reduced appetite is typically one of the first observable signs of a zinc deficiency in animals which is consistent with the observations of the current study (Kernkamp and Ferrin, 1953; Tucker and Salmon, 1955). The reduced growth rate experienced by Zn-deficient pigs cannot be fully accounted for by depressions in feed intake (Swinkels et al., 1996). Since Zn
plays a role in over 200 zinc-dependent enzymes in all major biochemical pathways of the body and is a necessary component of both DNA and RNA polymerase enzymes (Berger, 2001), a reduction in zinc-dependent enzyme activity could lead to the accumulation of one or more metabolites from these pathways, causing a marked change in eating behavior of the zinc-deficient animal. This appetite sensitivity to nutrient supply is unique to Zn and is expressed in food animal species, and reflects the key role of Zn in nutrient metabolism (Berger, 2001). These results are consistent with the reduction in ADFI of pigs consuming TRT 8 in EXP. 2 of the current study.

Supplemental zinc concentrations fed by Spears et al. (2000) did not affect ADG, ADFI, or G:F during phase 2 (d 15 to 35) or for the entire nursery period (d 0 to 35) in agreement with the current study. However, in pigs fed diets containing 50 mg/kg of total zinc from a combination of organic (ZnP) and inorganic sources (ZnSO₄), gains and feed intake improved during phase 1 (d 0 to 14), which is in contrast to the grow-finish performance findings of the current study. Spears et al. (2000) also reported that pigs fed diets containing 150 mg/kg of total zinc, from a combination of organic and inorganic sources (50% of the overall supplementation of zinc from ZnP), had a higher ADG and G:F when compared to pigs fed diets containing only 25% of the supplemental zinc from ZnP over the entire nursery period. Although the nursery diet concentrations of Zn fed by Spears et al. (2000) were similar to those in the present study, no differences were detected for ADG and ADFI above those of pigs fed diets containing no trace mineral supplementation. This suggests that dietary organic Zn supplementation may play a role in early nursery pig performance, and to a lesser extent in grow-finish pigs, as age and weight increase or that
sufficient reserves can be established early in life, such that if diets are Zn deficient, sufficient reserves exist and deficiency symptoms are prevented.

Results of the current experiments indicated that growth performance by grow-finish pigs was not affected by reduced concentrations of organic mineral supplements in the diet. Previous research with organic sources of Zn, in contrast to the current experiment, indicated 250 mg/kg of Zn as Zn-methionine increased weanling pig growth performance equal to that of Zn as ZnO (Ward et al., 1996). Additionally, research reported by Case and Carlson (2002) stated that feeding weanling pigs a diet containing 500 mg/kg of Zn as Zn polysaccharide increased growth performance equal to that of diets containing 3000 mg/kg of Zn as ZnO in two of three experiments, whereas feeding a diet containing 500 mg/kg of Zn as a Zn-amino acid complex did not improve growth performance compared to control pigs. Nursery pig diets containing pharmacological doses of Zn by Case and Carlson (2002) were much higher than the more conservative concentrations of Zn found in the grow-finish diets in the current experiment, which could explain the difference in performance, regardless of source.

Recent studies in swine have suggested that replacing inorganic trace minerals with more bioavailable chelated forms of the minerals could improve overall performance (Ward et al., 1996; Spears et al., 2000). Ward et al. (1996) reported that supplementing pig starter diets with 250 mg/kg of Zn from Zn methionine resulted in equal performance with pigs fed diets containing 2,000 mg/kg of Zn from ZnO when both diets were supplemented with 160 mg/kg of Zn from ZnSO4. Nursery pigs that were fed diets containing a combination of organic and inorganic Fe, Zn, Cu, and Mn (having 36% of the total mineral supplementation in the form of chelated metal proteinates) experienced increased (P < 0.05) gain and
gain:feed (Veum et al., 1995). These results are not consistent with the present study as it may be that nursery pig performance is more easily influenced by dietary micromineral manipulation in the diet than that of grow-finish pigs.

Previous research conducted in nursery pigs (Ward et al., 1996; Hoover et al., 1997) has demonstrated that the beneficial effect on growth from supplementation of high concentrations of ZnO could also be achieved by feeding lower concentrations of organic Zn along with a basal amount (250 or 160 mg/kg) of Zn as ZnSO4. In the current grow-finish study, no difference in performance was found when pigs were fed diets containing organic Zn compared to pigs fed diets containing the inorganic form of the mineral as ZnSO4. In contrast with the current study, Fakler et al. (1998) suggested that when organic mineral complexes are utilized, nursery pig performance may be improved over those pigs fed standard inorganic sources. Pharmacological doses (80 to 100 mg/kg) used in Fakler et al. (1998) were closer to the micromineral concentrations supplemented in the current study.

Although studies have shown improved ADFI and G:F in nursery pigs fed diets containing organic trace mineral supplementation, no recent investigations of organic minerals and their influence on grow-finish performance have been conducted. Stansbury et al. (1990) reported no differences in ADFI and G:F in weanling pigs fed diets containing organic chelated Cu (OCC) at concentrations of 62.5, 125, and 250 mg/kg when compared to pigs fed diets containing Cu as CuSO4 (CS) at similar concentrations. These results are not consistent with the current study in which pigs fed diets containing organic chelated Cu had higher ADFI in EXP. 1 and lower ADFI in EXP. 2. Results for G:F from the current study were consistent, however, with those of Stansbury et al. (1990), with the exception of the pigs fed diets containing no supplemental Cu, Fe, and Zn (TRT 8) in EXP. 2. In contrast to
In the current study, Veum et al. (2004) reported ADG and ADFI in weanling pigs were improved with dietary supplementation of Cu-proteinate (organic Cu) at concentrations of 25, 50, and 100 mg/kg Cu when compared to pigs fed diets containing Cu as CuSO₄. Results from the current study are reported for grow-finish swine and contained similar dietary concentrations (EXP. 1, 63 mg/kg, EXP 2, 23 mg/kg) as Veum et al. (2004).

In contrast to the current study, Veum et al. (2004) reported that ADG for nursery pigs fed 50 or 100 mg/kg Cu as Cu-proteinate was greater \( P < 0.05 \) through phase 1 (d 0 to 14), phase 2 (d 14 to 28), and overall (d 0 to 28) compared to pigs fed a control diet containing 250 mg/kg Cu from CuSO₄. Furthermore, Close and Jacques (1998) reported that nursery pig performance was increased \( P < 0.07 \) when 100 mg/kg Cu as Cu-proteinate replaced 100 mg/kg Cu as CuSO₄. Growth improvement found in nursery studies in Veum et al. (2004) and Close and Jacques (1998), when pigs were fed diets containing Cu as Cu-proteinate, is in contrast to results reported for the current grow-finish study.

In both experiments of the present study, barrows had significantly higher ADG than did gilts while having poorer conversion of feed to lean. This is consistent with previous research findings that demonstrate if barrows and gilts are fed the same diet, barrows are expected to have a greater ADG and be less efficient (Cline and Richert, 2001).

**Carcass Composition**

In experiments conducted by Edmonds and Arentson (2001), no differences were observed in carcass lean, backfat, or dressing percentage from withdrawing supplemental vitamin and trace minerals for 6 or 12 wk prior to slaughter. Carcass and performance values reported by Edmonds and Arentson (2001) are consistent with the results of the present study as well as others (Patience and Gillis, 1995; Kim et al., 1997; Mavromichalis et al., 1999).
contrast to the current study, Shelton et al. (2004) reported an increase in BF10 and decrease in carcass length and ham weight in grow-finish pigs fed diets containing no trace mineral premix from 22 to 109 kg of body weight, although no differences in pork quality were observed.

**Conclusions**

Based on data from the current study, phase-fed, grow-finish swine can achieve similar performance and carcass composition when fed diets supplemented with organic Cu, Fe, and Zn at reduced concentrations when compared to pigs fed diets containing commonly supplemented concentrations of the inorganic forms of these minerals.

**IMPLICATIONS**

Organic trace mineral supplementation (Cu, Fe, and Zn) can provide an alternative feeding strategy to traditional mineral supplements in pig diets without adversely affecting performance or carcass characteristics. Further studies should include an economic evaluation of organic vs. inorganic trace mineral supplementation in grow-finish swine. Additionally, studies should focus on redefining the nutritional requirements for trace minerals in pigs, particularly when organic forms of trace minerals are utilized in diets, during times of health and other biological and environmental stresses.
LITERATURE CITED


Table 1. Composition (as-fed basis) of the basal diet for two experiments in a study comparing the effects of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn on the performance and carcass characteristics of phase-fed, grow-finish swine (18 to 118 kg BW).

<table>
<thead>
<tr>
<th>Ingredient Composition</th>
<th>Phase 1 (18 to 37 kg)</th>
<th>Phase 2 (37 to 55 kg)</th>
<th>Phase 3 (55 to 82 kg)</th>
<th>Phase 4 (82 to 118 kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Yellow Dent Corn, %</td>
<td>67.25</td>
<td>69.50</td>
<td>73.50</td>
<td>78.75</td>
</tr>
<tr>
<td>Soybean Meal (47.5%), %</td>
<td>26.75</td>
<td>24.50</td>
<td>21.00</td>
<td>15.75</td>
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<tr>
<td>Trace mineral mix a, %</td>
<td>3.00</td>
<td>3.00</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Choice White Grease, %</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Celite b, %</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<tr>
<td>Formulated Content</td>
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<tr>
<td>Crude Fat, %</td>
<td>4.91</td>
<td>4.97</td>
<td>5.09</td>
<td>5.24</td>
</tr>
<tr>
<td>Crude Fiber, %</td>
<td>2.74</td>
<td>2.73</td>
<td>2.71</td>
<td>2.68</td>
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<td>Lysine, %</td>
<td>1.12</td>
<td>1.05</td>
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<td>Available Lysine, %</td>
<td>0.94</td>
<td>0.88</td>
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<td>Trp, %</td>
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<td>0.21</td>
<td>0.19</td>
<td>0.15</td>
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<td>Thr, %</td>
<td>0.75</td>
<td>0.71</td>
<td>0.66</td>
<td>0.59</td>
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<tr>
<td>Met, %</td>
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<td>0.31</td>
<td>0.29</td>
<td>0.27</td>
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<tr>
<td>Ash, %</td>
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<td>4.90</td>
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<td>NaCl, %</td>
<td>0.52</td>
<td>0.52</td>
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<td>Analyzed Content</td>
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<tr>
<td>DM, %</td>
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<td>86.56</td>
<td>85.66</td>
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<td>17.93</td>
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<td>13.88</td>
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<td>Ca, %</td>
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<td>0.71</td>
<td>0.68</td>
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<td>P, %</td>
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<td>0.55</td>
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<td>0.85</td>
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<tr>
<td>Mn, %</td>
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<td>22.88</td>
<td>22.00</td>
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<td>Mo, %</td>
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<td>1.31</td>
<td>1.08</td>
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<td>ME, kcal/kg</td>
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<td>3420</td>
<td>3380</td>
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a Inorganic trace minerals were supplemented from a commercially available trace mineral premix which contained Cu as CuSO₄, Fe as FeSO₄, and Zn (of which 25% was ZnO and 75% was ZnSO₄). Organic trace minerals (Cu, Fe, and Zn) were supplemented in the form of Bioplex™ products (Alltech Inc., Nicholasville, KY).

b Celite diatomaceous earth was added as an indigestible marker (World Minerals Inc., Santa Barbara, CA).
Table 2. Formulated concentration (as fed) of Cu, Fe, and Zn supplemented in the diets in two experiments of a study comparing the effects of source (inorganic vs. organic) and concentration of trace mineral supplementation on the performance and carcass characteristics of phase-fed, grow-finish swine (18 kg to 118 kg BW).

<table>
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<th>Experiment 1</th>
<th>Treatment&lt;sup&gt;b&lt;/sup&gt;</th>
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<th>3</th>
<th>4</th>
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<td></td>
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<td></td>
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<tr>
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<td>10</td>
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<table>
<thead>
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<th>Experiment 2</th>
<th>Copper, mg/kg</th>
<th>5</th>
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<sup>a</sup>Phase 1 - diet fed from 18-37 kg BW; Phase 2 - diet fed from 37-55 kg BW; Phase 3 - fed from 55-82 kg BW; Phase 4 - diet fed from 82-118 kg BW.<br>
<sup>b</sup>Treatment 1 (control) - 100% of Cu, Fe, and Zn from inorganic sources (Cu as CuSO<sub>4</sub>, Fe as FeSO<sub>4</sub>, and Zn (25% as ZnO and 75% as ZnSO<sub>4</sub>)); Treatment 2 - 100% of Cu, Fe, and Zn from organic sources; Treatment 3 - 25% reduction in micromineral concentration from TRT 2; Treatment 4 - 50% reduction in micromineral concentration from TRT 2; Treatment 5 - 75% reduction in Cu, Fe, and Zn from inorganic sources (Cu as CuSO<sub>4</sub>, Fe as FeSO<sub>4</sub>, and Zn (25% as ZnO and 75% as ZnSO<sub>4</sub>)) of those concentrations found in TRT 1; Treatment 6 - 50% reduction of organic Cu, Fe, and Zn concentrations of those found in TRT 2; Treatment 7 - 25% reduction in micromineral concentration from TRT 6; Treatment 8 - No Cu, Fe, Zn, and Se supplementation. (All organic minerals were Bioplex™ products, Alltech Inc., Nicholasville, KY).<br>
<sup>c</sup>NRC - values are extrapolated using a polynomial function of the requirement in NRC (1998) based on the average weight for the phase and the requirement reported for that phase.
Table 3. Analyzed concentration of Cu, Fe, and Zn (DM basis) supplemented in the diets in two experiments of a study comparing the effects of source (inorganic vs. organic) and concentration of trace mineral supplementation on the performance and carcass characteristics of phase-fed, grow-finish swine (18 kg to 118 kg BW).

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*bPhase 1 - diet fed from 18-37 kg BW; Phase 2 - diet fed from 37-55 kg BW; Phase 3 - fed from 55-82 kg BW; Phase 4 - diet fed from 82-118 kg BW.

*bTreatment 1 (control) - 100% of Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)); Treatment 2 - 100% of Cu, Fe, and Zn from organic sources; Treatment 3 - 25% reduction in micromineral concentration from TRT 2; Treatment 4 - 50% reduction in micromineral concentration from TRT 2; Treatment 5 - 75% reduction in Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) of those concentrations found in TRT 1; Treatment 6 - 50% reduction of organic Cu, Fe, and Zn concentrations of those found in TRT 2; Treatment 7 - 25% reduction in micromineral concentration from TRT 6; Treatment 8 - No Cu, Fe, Zn, and Se supplementation. (All organic minerals were Bioplex™ products, Alltech Inc., Nicholasville, KY).
Table 4. Least squares means (on a pen basis) for performance and carcass traits in two experiments of a study comparing the effects of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn supplementation to the diets of phase-fed, grow-finish swine (18 kg to 118 kg BW).

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*Treatment 1-(control) 100% of Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)); Treatment 2 – 100% of Cu, Fe, and Zn from organic sources; Treatment 3 – 25% reduction in micromineral concentration from TRT 2; Treatment 4 – 50% reduction in micromineral concentration from TRT 2; Treatment 5 – 75% reduction in Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) of those concentrations found in TRT 1; Treatment 6 – 50% reduction of organic Cu, Fe, and Zn concentrations of those found in TRT 2; Treatment 7 – 25% reduction in micromineral concentration from TRT 6; Treatment 8 – No dietary micromineral supplementation. (All organic minerals were Bioplex™ products, Alltech Inc., Nicholasville, KY).

*LMA = loin muscle area, BF10 = tenth-rib backfat, ADG = average daily gain, LGOT = lean gain on test, ADFI = average daily feed intake, LE = lean efficiency, G:F = feed efficiency, KL = kilograms of lean, PLL = percent lean live, PLC = percent lean carcass.

Means reported with different superscripts within a row differ (P < 0.05).

Means reported for all performance traits only reflect pigs that remained in the experiment for the entire test period.

(SEM = 0.004)

(SEM = 0.25)

(SEM = 0.34)
CHAPTER 4. THE EFFECT OF INORGANIC AND ORGANIC TRACE MINERAL SUPPLEMENTATION ON FECAL EXCRETION AND APPARENT DIGESTIBILITY OF PHASE-FED, GROW-FINISH SWINE

A paper to be published in the Journal of Animal Science


ABSTRACT

Two experiments were conducted to compare the effect of inorganic and organic trace mineral supplementation on fecal excretion and apparent digestibility of phase-fed, grow-finish swine. Crossbred pigs [EXP. 1, (n=528); EXP. 2, (n=560)] were housed in two identical, totally-slatted, confinement barns, blocked by weight, penned by sex, and randomly assigned to pens at approximately 18 kg BW. Dietary treatments were allocated in a general randomized complete block design with 12 replicate pens per treatment (TRT) and 9-12 pigs per pen throughout the grow-finish period. In EXP. 1, the control diet (TRT 1) contained Cu, Fe, and Zn from inorganic sources at concentrations of 85, 169, and 163 mg/kg, respectively. Treatment 2 (TRT 2) contained Cu, Fe, and Zn from organic sources at concentrations of 19, 131, and 91 mg/kg, respectively. Organic Cu, Fe, and Zn concentrations from TRT 2 were

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1This journal paper of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, Project No. 3614, was supported by State of Iowa funds. Additional funding and support was provided by Alltech Inc., Nicholasville, Kentucky 40356. The authors would like to acknowledge Kent Feeds Inc., Muscatine, Iowa; Nevada Feed and Seed Company, Nevada, Iowa; and Allflex Inc., Dallas-Ft. Worth Airport, Texas, for their contributions to this project.

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**Department of Statistics, Iowa State University, Ames 50011

†Alltech Inc., Nicholasville, Kentucky 40356

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reduced by 25 and 50% for TRT 3 and TRT 4, respectively. In EXP. 2, TRT 5 contained 25% of the Cu, Fe, and Zn concentrations found in TRT 1. Treatments 6 and 7 (TRT 6, TRT 7) contained Cu, Fe, and Zn at concentrations that were reduced by 50% and 75% from the levels in TRT 2, respectively. Microminerals were removed from TRT 8, which served as a negative control. In EXP. 1, pigs fed TRT 1 excreted greater ($P < 0.01$) concentrations of Cu during all four phases when compared to pigs fed the other dietary treatments in the experiment. In EXP. 1, fecal concentrations of Fe and Zn were greater ($P < 0.01$) for the first three collection phases and for the entire test period for pigs fed TRT 1 when compared to pigs fed the other dietary treatments. In EXP. 2, no differences among treatment means for fecal Cu excretion ($P > 0.05$) were observed by phase, however, pigs fed TRT 8 excreted the lowest overall concentration of fecal Cu ($P < 0.05$) when compared to pigs fed diets containing supplemental trace minerals. In EXP. 2, no differences among treatment means for fecal Fe concentration ($P > 0.05$) were observed during collection phase 1 and overall. Pigs fed TRT 6 in EXP. 2 excreted the highest concentration ($P < 0.01$) of Zn for the entire grow-finish period. Results from both experiments indicated that organic trace minerals could be supplemented and result in significant reductions in fecal mineral concentrations.

**Key Words: Environment, Fecal excretion, Pigs, Trace minerals**

**INTRODUCTION**

With an increasing awareness of environmental contamination, heavy metals and trace minerals have emerged as an issue of concern in swine production systems. Pig diets are usually supplemented with excess trace minerals, which often largely exceed their physiological requirements in order to promote performance (Hahn and Baker, 1993; Carlson et al., 1999; Hill et al., 2000). Trace minerals exceeding the animals’ requirements are
excreted, which can lead to bioaccumulation in the soil and potentially threaten water sources due to runoff (Besser et al., 2001).

Organic trace mineral supplements have been introduced in livestock and pig feeding because they may be more bioavailable to animals. Trace minerals that are commonly supplemented in pig diets include Zn, Fe, Cu, Se, I, Mn, and many others. These minerals may be added as salts, but in recent years, organic forms have also been used (Jondreville et al., 2002; Revy et al., 2003). Wedekind et. al. (1992) reported a greater bioavailability for organic minerals than that observed for inorganic forms, leading to increased interest in these products. With increased emphasis on environmental issues, the livestock industry must look at ways to improve not only efficiencies, but also reduce environmental impact. Therefore, the objectives of this study were to compare the fecal excretion and apparent digestibility of pigs fed diets containing differing supplemental concentrations of inorganic and organic forms of Cu, Fe, and Zn throughout the grow-finish phases of production and to assess the environmental impact of these feeding strategies.

MATERIALS AND METHODS

Two experiments were conducted to evaluate the effect of differing concentrations of trace mineral supplementation (Cu, Fe, and Zn) on the fecal excretion and apparent digestibility of grow-finish pigs. Pigs fed diets containing reduced concentrations of organic Cu, Fe, and Zn (Bioplex™, Alltech, Inc., Nicholasville, KY) were compared to pigs fed diets supplemented with a commercially available inorganic trace mineral premix at or in excess of NRC recommendations for trace mineral supplementation. All protocols in these experiments were approved by the Iowa State University Animal Care and Use Committee.
Animals

In both experiments, crossbred pigs (EXP. 1, Iowa State University Lauren Christian Farm, Atlantic, IA (n=528); EXP. 2, Wilson’s Prairie View Farms, Burlington, WI (n=560)) were blocked by weight, penned by sex, and randomly assigned to treatment pens at approximately 18 kg BW. Each pen began the experiment with 9-12 pigs per pen.

Housing

Pigs were housed in two adjacent, totally-slatted, environmentally controlled confinement facilities. Pigs were provided ad libitum access to feed through a 2-hole feeder and to water through a 2-nipple hanging drinker in each pen. Each pig was provided 0.9 to 1.3 m² of floor space in each pen. An anthelminthic (Ivermectin, Merial Inc., Duluth, GA) was used in both experiments to treat pigs prior to initiation of the test period. Pigs that were unhealthy or injured during the experiments were removed from the test. Number of pigs removed and reason for removal was documented to make comparisons of treatment effects.

Dietary Treatments

A four-phase, grow-finish feeding program was utilized for all pigs in each experiment according to the following regimen: Phase 1 (18 to 37 kg), Phase 2 (37 to 55 kg), Phase 3 (55 to 82 kg), and Phase 4 (82 to 118 kg).

A complete basal diet (meal form) was formulated and different sources and concentrations of Cu, Fe, and Zn were used to develop the experimental dietary treatments. Nutrient composition of the diets utilized in this study is presented in Table 1. Formulated total lysine content (as fed) of the diet was 1.12%, 1.05%, 0.93%, and 0.79% during the four phases, respectively. Formulated trace mineral concentrations (as fed) of Cu, Fe, and Zn are presented in Table 2. In EXP. 1, the control diet (TRT 1) contained Cu as CuSO₄, Fe as
FeSO₄, and Zn (of which 25% was ZnO and 75% was ZnSO₄) at concentrations of 85, 169, and 163 mg/kg, respectively. These concentrations of Cu, Fe, and Zn were 13.40, 1.74, and 1.75 times NRC (1998) recommendations, respectively. Treatment 2 (TRT 2) contained Cu, Fe, and Zn from organic sources (Bioplex™, Alltech Inc., Nicholasville, KY) at concentrations of 19, 131, and 91 mg/kg, respectively. These concentrations of Cu, Fe, and Zn were 3.00, 1.36, and 0.97 times NRC (1998) recommendations, respectively. Organic Cu, Fe, and Zn concentrations from TRT 2 were reduced by 25% and 50% for TRT 3 and TRT 4, respectively. In EXP. 2, TRT 5 contained 25% of the Cu, Fe, and Zn (inorganic sources) concentrations found in TRT 1. Treatment 6 (TRT 6) contained the experimental microminerals at concentrations that were identical to TRT 4 from EXP. 1. Treatment 7 (TRT 7) contained Cu, Fe, and Zn concentrations that were reduced by 75% from the levels found in TRT 2 of EXP. 1. Treatment 8 (TRT 8) contained no supplemental microminerals and served as a negative control for EXP. 2. Experimental trace mineral premixes were manufactured commercially (Kent Feeds Inc., Muscatine, IA) and the diets were mixed by a commercial feed manufacturer (Nevada Feed and Seed, Nevada, IA).

**Measurements**

Fecal grab samples (approximately 100 g of DM) were collected from every pig in both experiments during each of the four growth phases. Feed and fecal samples were ground in a sample mill (Cyclotec Sample Mill, Model 1093, Foss Tecator, Hoganas, Sweden) to 1 mm to achieve a homogenous sample for analysis. Fecal samples were dried in an oven (Lab Line Instruments, Inc., Melrose Park, IL) at 55°C for 48 h. Diatomaceous earth (Celite®, World Minerals Inc., Santa Barbara, California) was added to all diets at 1% as an
indigestible marker. Dried samples were pooled by pen and experiment on an equal weight basis and the pooled sample was stored for compositional analysis.

Samples of all diets and fecal samples from both experiments were sent to Dairy One Inc. (Ithaca, NY) for trace mineral analysis and evaluation of DM content. All experimental minerals were analyzed using a Thermo Jarrell Ash IRIS Advantage HX Inductively Coupled Plasma (ICP) Radial Spectrometer (Thermo Electron Corporation, Waltham, MA). Dry matter of feed and fecal samples was evaluated by Near Infrared Reflectance Spectroscopy (NIRS) (AOAC 991.03, 1995).

Apparent digestibility for each mineral during each collection phase was calculated according to the procedures outlined by Dove et al. (1995) as follows:

\[
\text{Apparent nutrient digestibility} = 100 \times \frac{\text{total period intake} - \text{period feces excretion}}{\text{total period intake}}
\]

**Statistical Analysis**

Pigs were allocated in a general randomized complete block design with 4 dietary treatments and 12 replicate pens per treatment within each experiment. Pen was the experimental unit in all analyses. Data were analyzed using the PROC MIXED procedure in SAS (SAS, 2003). The model included fixed effects of barn, treatment, sex, and phase, and all two- and three-way main effect interactions. Average daily feed intake was a covariate for the analyses of fecal concentrations of Cu, Fe, and Zn. Interactions of main effects found to be non-significant were eliminated from the final model. When a fixed effect was a significant source of variation, least squares means were compared using the PDIFF option of SAS. Pigs removed from test were analyzed by treatment using the PROC FREQ procedure in SAS.
RESULTS

Analyzed Cu, Fe, and Zn content of all diets is presented in Table 3. Least squares means for fecal mineral concentration and apparent digestibility of Cu, Fe, and Zn are presented in Tables 4, 5, and 6, respectively. Fecal mass and fecal dry matter for both experiments are presented in Table 7.

Copper

In EXP. 1, pigs fed TRT 1 (inorganic trace minerals) excreted significantly greater concentrations of fecal Cu ($P < 0.01$) across all four collection phases. Pigs fed TRT 4 excreted less ($P < 0.05$) Cu during the last two collection phases and overall. Apparent digestibility of Cu was greater ($P < 0.01$) for pigs fed diets containing the three experimental concentrations of organic trace minerals during collection phases 2, 4, and overall when compared to pigs fed the diet containing inorganic trace minerals. Negative apparent digestibility values were realized for pigs fed the control diet (TRT 1) for phases 1, 2, and 4 as well as for the overall apparent digestibility of Cu. Pigs fed TRT 2, 3, and 4 experienced greater ($P < 0.01$) overall apparent digestibility when compared to TRT 1.

In EXP. 2, no differences among treatment means for fecal Cu excretion were observed by phase ($P = 0.52$), however, pigs fed TRT 8 excreted the lowest concentration of fecal Cu over the entire test period ($P < 0.01$) when compared to pigs fed diets containing supplemental trace minerals. Pigs fed TRT 5 (inorganic minerals) excreted the greatest overall concentration of Cu ($P < 0.01$) when compared to pigs fed the other experimental diets. Apparent digestibility of Cu was the lowest and least favorable ($P < 0.01$) for pigs fed diets containing the inorganic trace mineral supplements (TRT 5).
Iron

Pigs in EXP. 1 fed TRT 1 excreted the highest fecal concentration of Fe ($P < 0.01$) across collection phases 1, 2, 3, and overall. Organic trace mineral supplementation at 50% of commonly added trace mineral concentration to the diet (TRT 4) appeared to be the most effective in lowering fecal Fe concentration. Additionally, pigs fed TRT 4 experienced the best overall apparent digestibility ($P < 0.05$) when compared to pigs fed the other experimental diets.

No differences among treatment means for fecal Fe concentration ($P > 0.05$) were observed during collection phase 1 and overall in EXP. 2. Pigs receiving no trace mineral supplementation (TRT 8) excreted the lowest fecal concentration of Fe during phase collection 3.

Zinc

In EXP. 1, pigs fed TRT 1 excreted higher fecal concentration ($P < 0.01$) of zinc in all four collection phases. Pigs fed TRT 4 had the lowest ($P < 0.01$) fecal concentration of Zn over the entire test period. Pigs fed the diets containing the experimental organic trace minerals experienced greater apparent digestibility during phases 2, 3, 4, and overall when compared to TRT 1. During the first collection phase, pigs fed TRT 2 had a negative apparent digestibility for Zn. There were no treatment differences for the number of pigs removed from test ($P > 0.05$) in EXP. 1.

Pigs fed TRT 6 in EXP. 2 excreted the highest concentration ($P < 0.01$) of Zn for the entire grow-finish period. Pigs fed the diet containing no trace mineral supplementation (TRT 8) excreted the lowest ($P < 0.01$) concentration of Zn in the feces, however, some pigs receiving this treatment displayed symptoms of parakeratosis and were removed from test
upon diagnosis. The number of pigs removed from test by treatment in EXP. 2 was not
different among TRT 5 (n=1), TRT 6 (n=3), and TRT 7 (n=4), however, all three were
different from TRT 8 (n=38) (P < 0.01).

**DISCUSSION**

Numerous research studies have shown reduction in trace mineral supplementation in
weanling pig diets can be accomplished when organic trace minerals are utilized in place of
the inorganic form of the mineral (Armstrong et al., 2004; Carlson et al., 2004; Veum et al.,
2004). However, very few studies have compared the use of inorganic and organic forms of
different trace minerals at differing concentrations supplemented during the grow-finish
period.

Very little information is available to demonstrate the effect of organic Fe
supplementation on the performance of weanling, growing, or finishing pigs. Lewis et al.
(1995) reported that the Fe in iron-methionine was less bioavailable than the Fe in ferrous
sulfate, but the Fe from iron-proteinates was similar to the Fe in ferrous sulfate (Lewis et al.,
1999). The findings from Lewis et al. (1999) are not in agreement with the present study
which stated that pigs fed diets containing organic Fe (proteinates – BioplexTM) had
improved apparent digestibility when compared to pigs fed diets containing inorganic Fe
(FeSO₄). In addition, pigs fed organic Fe supplementation had reduced fecal Fe excretion
and maintained similar performance when compared to pigs fed diets containing inorganic
Fe.

Pigs fed diets containing organic trace minerals in the current study excreted
markedly less Cu, Fe, and Zn in the manure compared with pigs fed diets containing
inorganic forms of these trace minerals. Similar results were reported in other experiments,
however, pigs were fed pharmacological doses of organic Cu and Zn (Case and Carlson, 2002; Carlson et al., 2004; Creech et al., 2004). In the aforementioned studies, fecal excretion of Zn (mg/d) was directly related to the quantity of Zn consumed (mg/d), regardless of the Zn source (Carlson et al., 2004). Due to the fact pharmacological concentrations were supplemented in these studies, similar reductions were reported when compared to the lower dietary concentrations of the minerals in the present study.

In the current study, pigs fed diets containing organic trace minerals excreted 72% to 82% less fecal Cu in EXP. 1 and 49% to 77% less in EXP. 2 when compared to pigs fed diets containing inorganic trace mineral supplementation. Veum et al. (2004) reported similar reductions in fecal Cu excretion in their balance experiment which stated feeding 50 or 100 ppm organic Cu reduced fecal Cu excretion in swine waste by 77% and 61%, respectively, compared with feeding 250 ppm of inorganic CuSO₄. Diets in the current study contained less dietary organic Cu supplementation (21 to 13 ppm in EXP. 1 and 12 to 7 ppm in EXP. 2), however, reductions in fecal Cu excretion by pigs fed diets containing the organic mineral form were similar to those reported by Veum et al. (2004). This reduction in fecal mineral excretion could help prevent bioaccumulation of excess minerals in areas surrounding production facilities. Excess Cu causes undesirable effects on plant growth and will impair lagoon bacteria activity which is responsible for waste degradation (Matoes et al., 2005).

Reduction in dietary Cu concentration from 175 to 6 ppm in piglet feeds and from 100 to 4 ppm in finishing diets resulted in a Cu slurry concentration reduction of 911 to 31 mg Cu/kg DM (Jondreville et al., 2002).

Similar reduction in fecal Cu excretion was reported by Pierce et al. (2001), who found a 46% decrease in fecal Cu concentration from pigs fed organic Cu (Bioplex™) when
compared to those fed a control diet which contained Cu supplementation as CuSO₄. Greater reductions in Cu excretion were reported by on farm research conducted by Smits and Henman (2000), who reported Cu proteinate (Bioplex™) fed at 40 ppm decreased fecal Cu concentration by 3 to 4 times when compared to pigs fed diets containing 150 ppm Cu as CuSO₄, without sacrificing growth performance. These reductions in fecal Cu concentration were much greater than those presented in the current study.

Veum et al. (2004) demonstrated no significant difference in growth rate in nursery pigs fed Bioplex™ organic Cu and inorganic CuSO₄, however, fecal output of Cu was reduced by a factor of 4. Much lower reductions were reported in the current experiment, however, numerous studies (Armstrong et al., 2004; Veum et al., 2004; Pierce et al. 2001) have suggested that organic Cu can be utilized to reduce the environmental impact swine effluent has without sacrificing growth and performance.

Creech et al. (2004) reported fecal Zn concentrations were higher (P < 0.01) in pigs that were fed a control diet containing inorganic Zn in the sulfate form when compared to pigs that were fed diets containing organic Zn, consistent with the current experiment. In the current study, overall Zn concentration in the feces was decreased 37% to 60% in EXP. 1 and 21% to 51% in EXP. 2 by feeding diets containing organic trace mineral supplementation (Cu, Fe, and Zn) when compared to pigs fed diets containing traditional trace minerals. Revy et al. (2003) reported pigs fed diets containing 100 to 250 ppm Zn would produce a slurry that contained between 850 and 1300 mg Zn/kg DM. Dietary reduction in Zn supplementation from 150 ppm to 90 ppm can reduce Zn in feces by 40% (Paboeuf et al., 2001). Additionally, Revy et al. (2003), indicated a reduction in Zn in finishing pigs’ diets
from 100 to 60 ppm, and a reduction in piglet diets from 3000 to 150 ppm, would reduce Zn slurry concentration from 1860 to 450 mg Zn/kg DM.

Apparent digestibility of Zn was improved for pigs fed diets containing organic mineral supplementation, regardless of concentration, in the current studies. In contrast, Wedekind et al. (1994) reported that neither inorganic Zn as ZnO nor organic Zn as Zn-methionine or Zn-lysine (amino acid complexes) provided more bioavailable Zn than ZnSO₄ when three different concentrations of each source were fed to pigs from 25 to 90 kg BW.

Pigs in EXP. 2 of the current study (n= 38) displayed symptoms of parakeratosis and had decreased ADFI and overall ADG when the diet contained 36, 68, 33, and 33 mg/kg for phases 1, 2, 3, and 4, respectively. The possible Zn deficiency observed in TRT 8 (EXP. 2) is in agreement with Creech et al. (2004), who stated Zn requirements of growing and finishing pigs, based on growth, do not exceed 50 mg/kg. Liptrap et al. (1970) also reported lowered ADG and ADFI in pigs fed diets low in dietary Zn supplementation. Bioavailability of Zn may be limited by high dietary Ca. When Ca levels are increased in a diet with low dietary Zn, the incidence of parakeratosis is increased dramatically (Lewis et al., 1956; Luecke et al., 1956). In the current study, Ca was supplied in the diets at concentrations higher than NRC (1998) recommended requirements. The relatively high Ca levels may have contributed to increased signs of parakeratosis in EXP. 2 (TRT 8) through an adverse effect on Zn bioavailability.

Conclusions

Utilization of organic trace minerals in the current study has demonstrated that organic minerals can be utilized at much lower concentrations in the diet, greatly reducing fecal mineral concentrations, without affecting growth and performance of grow-finish pigs.
IMPLICATIONS

Organic trace mineral supplementation in grow-finish swine diets can be utilized as a feeding strategy to reduce environmental contamination from commercial pork production. With increasing pressure to reduce the concentration of minerals used in animal feed, organic trace minerals may serve as a viable alternative to traditional dietary formulations. Grow-finish diets can be formulated with lower concentrations of organic trace minerals without adversely affecting performance, but at the same time significantly reducing trace mineral excretion.
LITERATURE CITED


Table 1. Composition (as-fed basis) of the basal diet for two experiments in a study comparing the effects of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn on the performance and carcass characteristics of phase-fed, grow-finish swine (18 to 118 kg BW).

<table>
<thead>
<tr>
<th>Ingredient Composition</th>
<th>Phase 1 18 to 37 kg</th>
<th>Phase 2 37 to 55 kg</th>
<th>Phase 3 55 to 82 kg</th>
<th>Phase 4 82 to 118 kg</th>
</tr>
</thead>
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<tr>
<td>Ground Yellow Dent Corn, %</td>
<td>67.25</td>
<td>69.50</td>
<td>73.50</td>
<td>78.75</td>
</tr>
<tr>
<td>Soybean Meal (47.5%), %</td>
<td>26.75</td>
<td>24.50</td>
<td>21.00</td>
<td>15.75</td>
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<tr>
<td>Trace mineral mix a, %</td>
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<td>3.00</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Choice White Grease, %</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
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<tr>
<td>Celite b, %</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<tr>
<td>Formulated Content</td>
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<tr>
<td>Crude Fat, %</td>
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<td>4.97</td>
<td>5.09</td>
<td>5.24</td>
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<tr>
<td>Crude Fiber, %</td>
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<td>2.73</td>
<td>2.71</td>
<td>2.68</td>
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<tr>
<td>Lysine, %</td>
<td>1.12</td>
<td>1.05</td>
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<td>0.79</td>
</tr>
<tr>
<td>Available Lysine, %</td>
<td>0.94</td>
<td>0.88</td>
<td>0.78</td>
<td>0.65</td>
</tr>
<tr>
<td>Trp, %</td>
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<td>0.21</td>
<td>0.19</td>
<td>0.15</td>
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<tr>
<td>Thr, %</td>
<td>0.75</td>
<td>0.71</td>
<td>0.66</td>
<td>0.59</td>
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<tr>
<td>Met, %</td>
<td>0.32</td>
<td>0.31</td>
<td>0.29</td>
<td>0.27</td>
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<tr>
<td>Ash, %</td>
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<td>4.90</td>
<td>4.34</td>
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<td>NaCl, %</td>
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<td>0.52</td>
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<tr>
<td>Analyzed Content</td>
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<td></td>
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<td>CP, %</td>
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<td>17.93</td>
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<tr>
<td>Mg, %</td>
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<td>0.14</td>
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<td>0.12</td>
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<tr>
<td>K, %</td>
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<td>0.85</td>
<td>0.72</td>
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<td>Na, %</td>
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<td>Mn, %</td>
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<td>22.88</td>
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<td>1.31</td>
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<td>ME, kcal/kg</td>
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aInorganic trace minerals were supplemented from a commercially available trace mineral premix which contained Cu as CuSO₄, Fe as FeSO₄, and Zn (of which 25% was ZnO and 75% was ZnSO₄). Organic trace minerals (Cu, Fe, and Zn) were supplemented in the form of Bioplex™ products (Alltech Inc., Nicholasville, KY).

bCelite diatomaceous earth was added as an indigestible marker (World Minerals Inc., Santa Barbara, CA).
Table 2. Formulated concentration (as fed) of Cu, Fe, and Zn supplemented in the diets in two experiments of a study comparing the effects of source (inorganic vs. organic) and concentration of trace mineral supplementation on the performance and carcass characteristics of phase-fed, grow-finish swine (18 kg to 118 kg BW).

<table>
<thead>
<tr>
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<td>NRC</td>
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<td><strong>Iron, mg/kg</strong></td>
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<tr>
<td><strong>Zinc, mg/kg</strong></td>
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*Phase 1 - diet fed from 18-37 kg BW; Phase 2 - diet fed from 37-55 kg BW; Phase 3 - fed from 55-82 kg BW; Phase 4 - diet fed from 82-118 kg BW.

*Treatment 1 (control) - 100% of Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)); Treatment 2 - 100% of Cu, Fe, and Zn from organic sources; Treatment 3 - 25% reduction in micromineral concentration from TRT 2; Treatment 4 - 50% reduction in micromineral concentration from TRT 2; Treatment 5 - 75% reduction in Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) of those concentrations found in TRT 1; Treatment 6 - 50% reduction of organic Cu, Fe, and Zn concentrations of those found in TRT 2; Treatment 7 - 25% reduction in micromineral concentration from TRT 6; Treatment 8 - No Cu, Fe, Zn, and Se supplementation. (All organic minerals were Bioplex™ products, Alltech Inc., Nicholasville, KY).

*NRC - values are extrapolated using a polynomial function of the requirement in NRC (1998) based on the average weight for the phase and the requirement reported for that phase.
Table 3. Analyzed concentration of Cu, Fe, and Zn (DM basis) supplemented in the diets in two
experiments of a study comparing the effects of source (inorganic vs. organic) and concentration of
trace mineral supplementation on the performance and carcass characteristics of phase-fed, grow-
finish swine (18 kg to 118 kg BW).

<table>
<thead>
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<th>3</th>
<th>4</th>
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<td>53</td>
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<td>78</td>
<td>70</td>
<td>61</td>
</tr>
</tbody>
</table>

| Experiment 2 | Copper, mg/kg | 5     | 23    | 21    | 14    | 13    |
|              | 6           | 12    | 14    | 12    | 14    |
|              | 7           | 10    | 11    | 8     | 10    |
|              | 8           | 7     | 8     | 6     | 5     |
| Iron, mg/kg  | 5           | 263   | 306   | 264   | 250   |
|              | 6           | 321   | 337   | 278   | 255   |
|              | 7           | 251   | 302   | 249   | 237   |
|              | 8           | 274   | 259   | 291   | 231   |
| Zinc, mg/kg  | 5           | 64    | 77    | 77    | 65    |
|              | 6           | 67    | 86    | 79    | 83    |
|              | 7           | 81    | 72    | 51    | 59    |
|              | 8           | 36    | 68    | 33    | 33    |

*aPhase 1 - diet fed from 18-37 kg BW; Phase 2 - diet fed from 37-55 kg BW; Phase 3 - fed from 55-
82 kg BW; Phase 4 - diet fed from 82-118 kg BW.

*bTreatment 1 (control) - 100% of Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄,
and Zn (25% as ZnO and 75% as ZnSO₄)); Treatment 2 - 100% of Cu, Fe, and Zn from organic
sources; Treatment 3 - 25% reduction in micromineral concentration from TRT 2; Treatment 4 -
50% reduction in micromineral concentration from TRT 2; Treatment 5 - 75% reduction in Cu, Fe,
and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as
ZnSO₄)) of those concentrations found in TRT 1; Treatment 6 - 50% reduction of organic Cu, Fe,
and Zn concentrations of those found in TRT 2; Treatment 7 - 25% reduction in micromineral
concentration from TRT 6; Treatment 8 - No Cu, Fe, Zn, and Se supplementation. (All organic
minerals were Bioplex™ products, Alltech Inc., Nicholasville, KY).
Table 4. Least squares means (±SE) for fecal Cu concentration (DM basis) and apparent digestibility (Cu) measured in two experiments of a study comparing the effects of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn supplementation to the diet of phase-fed, grow-finish swine (18 to 118 kg BW).

<table>
<thead>
<tr>
<th>Trait</th>
<th>Treatment&lt;sup&gt;a&lt;/sup&gt;</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecal Cu, mg/kg</td>
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<td>488.56&lt;sup&gt;c&lt;/sup&gt; ± 9.27</td>
<td>474.69&lt;sup&gt;d&lt;/sup&gt; ± 5.69</td>
<td>436.38&lt;sup&gt;f&lt;/sup&gt; ± 5.87</td>
<td>417.29&lt;sup&gt;f&lt;/sup&gt; ± 7.70</td>
<td>454.23&lt;sup&gt;f&lt;/sup&gt; ± 2.75</td>
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<tr>
<td></td>
<td>2</td>
<td>135.75&lt;sup&gt;d&lt;/sup&gt; ± 8.93</td>
<td>124.65&lt;sup&gt;d&lt;/sup&gt; ± 5.58</td>
<td>113.51&lt;sup&gt;e&lt;/sup&gt; ± 6.30</td>
<td>133.93&lt;sup&gt;f&lt;/sup&gt; ± 8.28</td>
<td>126.96&lt;sup&gt;f&lt;/sup&gt; ± 2.73</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>122.47&lt;sup&gt;ed&lt;/sup&gt; ± 9.12</td>
<td>89.84&lt;sup&gt;e&lt;/sup&gt; ± 5.55</td>
<td>88.02&lt;sup&gt;d&lt;/sup&gt; ± 6.13</td>
<td>82.82&lt;sup&gt;d&lt;/sup&gt; ± 7.83</td>
<td>95.79&lt;sup&gt;d&lt;/sup&gt; ± 2.72</td>
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<tr>
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<td>4</td>
<td>115.39&lt;sup&gt;cd&lt;/sup&gt; ± 8.99</td>
<td>84.52&lt;sup&gt;d&lt;/sup&gt; ± 5.59</td>
<td>70.77&lt;sup&gt;c&lt;/sup&gt; ± 6.02</td>
<td>60.26&lt;sup&gt;c&lt;/sup&gt; ± 8.31</td>
<td>82.74&lt;sup&gt;d&lt;/sup&gt; ± 2.72</td>
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<td>-12.05&lt;sup&gt;d&lt;/sup&gt; ± 6.65</td>
<td>5.07&lt;sup&gt;d&lt;/sup&gt; ± 6.65</td>
<td>-47.30&lt;sup&gt;d&lt;/sup&gt; ± 6.65</td>
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<td>41.03&lt;sup&gt;c&lt;/sup&gt; ± 6.65</td>
<td>19.75&lt;sup&gt;cd&lt;/sup&gt; ± 6.65</td>
<td>29.76&lt;sup&gt;c&lt;/sup&gt; ± 6.66</td>
<td>24.11&lt;sup&gt;c&lt;/sup&gt; ± 3.33</td>
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<td>-1.14 ± 6.65</td>
<td>37.37&lt;sup&gt;c&lt;/sup&gt; ± 6.65</td>
<td>34.01&lt;sup&gt;c&lt;/sup&gt; ± 6.65</td>
<td>18.68&lt;sup&gt;c&lt;/sup&gt; ± 6.65</td>
<td>22.23&lt;sup&gt;c&lt;/sup&gt; ± 3.33</td>
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<td>-9.15 ± 6.65</td>
<td>46.53&lt;sup&gt;c&lt;/sup&gt; ± 6.65</td>
<td>12.69&lt;sup&gt;d&lt;/sup&gt; ± 6.65</td>
<td>27.86&lt;sup&gt;c&lt;/sup&gt; ± 6.65</td>
<td>19.48&lt;sup&gt;c&lt;/sup&gt; ± 3.33</td>
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Experiment 2

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<th>6</th>
<th>7</th>
<th>8</th>
<th>Overall</th>
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<tbody>
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<td>132.34 ± 3.37</td>
<td>132.89 ± 3.85</td>
<td>140.59&lt;sup&gt;f&lt;/sup&gt; ± 1.51</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>87.94 ± 4.42</td>
<td>68.20 ± 3.10</td>
<td>66.32 ± 3.34</td>
<td>63.58 ± 3.92</td>
<td>71.51&lt;sup&gt;f&lt;/sup&gt; ± 1.51</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>67.13 ± 4.40</td>
<td>55.39 ± 3.10</td>
<td>45.72 ± 3.35</td>
<td>40.38 ± 3.74</td>
<td>52.15&lt;sup&gt;f&lt;/sup&gt; ± 1.51</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>49.02 ± 4.40</td>
<td>32.53 ± 3.19</td>
<td>26.08 ± 3.39</td>
<td>24.55 ± 3.30</td>
<td>33.05&lt;sup&gt;f&lt;/sup&gt; ± 1.55</td>
</tr>
<tr>
<td>Apparent Digestibility, %</td>
<td>5</td>
<td>-47.05&lt;sup&gt;e&lt;/sup&gt; ± 6.30</td>
<td>-12.80&lt;sup&gt;d&lt;/sup&gt; ± 6.30</td>
<td>-51.50&lt;sup&gt;d&lt;/sup&gt; ± 6.30</td>
<td>-33.90&lt;sup&gt;d&lt;/sup&gt; ± 6.30</td>
<td>-36.31&lt;sup&gt;d&lt;/sup&gt; ± 3.15</td>
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<tr>
<td></td>
<td>6</td>
<td>-17.02&lt;sup&gt;d&lt;/sup&gt; ± 6.30</td>
<td>13.80&lt;sup&gt;e&lt;/sup&gt; ± 6.30</td>
<td>18.35&lt;sup&gt;e&lt;/sup&gt; ± 6.30</td>
<td>39.74&lt;sup&gt;c&lt;/sup&gt; ± 6.30</td>
<td>13.72&lt;sup&gt;e&lt;/sup&gt; ± 3.15</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0.88&lt;sup&gt;c&lt;/sup&gt; ± 6.31</td>
<td>20.99&lt;sup&gt;c&lt;/sup&gt; ± 6.31</td>
<td>18.42&lt;sup&gt;d&lt;/sup&gt; ± 6.31</td>
<td>36.74&lt;sup&gt;c&lt;/sup&gt; ± 6.31</td>
<td>19.26&lt;sup&gt;c&lt;/sup&gt; ± 3.16</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-18.65&lt;sup&gt;d&lt;/sup&gt; ± 6.31</td>
<td>20.98&lt;sup&gt;c&lt;/sup&gt; ± 6.31</td>
<td>32.90&lt;sup&gt;e&lt;/sup&gt; ± 6.31</td>
<td>29.23&lt;sup&gt;c&lt;/sup&gt; ± 6.31</td>
<td>16.12&lt;sup&gt;e&lt;/sup&gt; ± 3.16</td>
</tr>
</tbody>
</table>

<sup>a</sup>Phase 1 - diet fed from 18-37 kg BW; Phase 2 - diet fed from 37-55 kg BW; Phase 3 - fed from 55-82 kg BW; Phase 4 - diet fed from 82-118 kg BW.

<sup>b</sup>Treatment 1 (control) - 100% of Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)); Treatment 2 - 100% of Cu, Fe, and Zn from organic sources; Treatment 3 - 25% reduction in microminerai concentration from TRT 2; Treatment 4 - 50% reduction in microminerai concentration from TRT 2; Treatment 5 - 75% reduction in Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) of those concentrations found in TRT 1; Treatment 6 - 50% reduction of organic Cu, Fe, and Zn concentrations of those found in TRT 2; Treatment 7 - 25% reduction in microminerai concentration from TRT 6; Treatment 8 - No Cu, Fe, Zn, and Se supplementation. (All organic minerals were Bioplex™ products, Alltech Inc., Nicholasville, KY).

<sup>cdef</sup>Least squares means with different superscripts within a column (phase) and trait differ (P < 0.05).
Table 5. Least squares means (±SE) for fecal Fe concentration (DM basis) and apparent digestibility (Fe) measured in two experiments of a study comparing the effects of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn supplementation to the diet of phase-fed, grow-finish swine (18 to 118 kg BW).

<table>
<thead>
<tr>
<th>Experiment 1 Trait</th>
<th>Treatment</th>
<th>Phasea</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fecal Fe, mg/kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1890.01±</td>
<td>2126.60 ± 51.97</td>
<td>1858.25± 51.57</td>
</tr>
<tr>
<td>2</td>
<td>1596.78±</td>
<td>1776.70± 51.40</td>
<td>1667.31± 54.44</td>
</tr>
<tr>
<td>3</td>
<td>1637.39±</td>
<td>1647.96± 48.95</td>
<td>1569.12± 53.90</td>
</tr>
<tr>
<td>4</td>
<td>1582.64±</td>
<td>1548.08± 49.38</td>
<td>1468.33± 52.90</td>
</tr>
<tr>
<td>Apparent Digestibility, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>29.83±</td>
<td>28.80± 3.05</td>
<td>16.70± 2.92</td>
</tr>
<tr>
<td>2</td>
<td>5.16±</td>
<td>30.40± 3.05</td>
<td>39.39± 2.92</td>
</tr>
<tr>
<td>3</td>
<td>10.24±</td>
<td>28.12± 2.92</td>
<td>19.59± 2.92</td>
</tr>
<tr>
<td>4</td>
<td>29.01±</td>
<td>34.34± 2.92</td>
<td>21.05± 2.92</td>
</tr>
</tbody>
</table>

| Experiment 2 |                |         |          |          |          |          |
| Fecal Fe, mg/kg |           |         |          |          |          |          |
| 5              | 1504.99± 71.52 | 1565.09± 48.74 | 1348.64± 54.66 | 1244.09± 64.21 | 1415.70± 24.74 |
| 6              | 1543.05± 71.21 | 1510.49± 50.01 | 1354.91± 54.15 | 1263.36± 63.61 | 1417.95± 24.35 |
| 7              | 1522.13± 70.98 | 1493.42± 49.53 | 1253.49± 54.34 | 1350.70± 60.56 | 1404.93± 24.43 |
| 8              | 1409.47± 70.89 | 1379.02± 51.51 | 1109.05± 55.02 | 1570.96± 53.52 | 1523.13± 24.96 |
| Apparent Digestibility, % |           |         |          |          |          |          |
| 5              | 8.02± 4.89 | 19.13± 4.89 | 18.11± 4.89 | 29.24± 5.11 | 18.62± 2.47 |
| 6              | 21.93± 4.89 | 24.18± 4.89 | 26.76± 4.89 | 29.06± 4.89 | 25.48± 2.45 |
| 7              | 8.88± 4.90 | 23.21± 4.90 | 22.28± 4.90 | 3.48± 4.90 | 14.46± 2.46 |
| 8              | 23.02± 4.90 | 42.65± 4.90 | 37.92± 4.90 | 7.19± 4.90 | 27.00± 2.46 |

*aPhase 1 - diet fed from 18-37 kg BW; Phase 2 - diet fed from 37-55 kg BW; Phase 3 - fed from 55-82 kg BW; Phase 4 - diet fed from 82-118 kg BW.  
*bTreatment 1 (control) - 100% of Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)); Treatment 2 - 100% of Cu, Fe, and Zn from organic sources; Treatment 3 - 25% reduction in micromineral concentration from TRT 2; Treatment 4 - 50% reduction in micromineral concentration from TRT 2; Treatment 5 - 75% reduction in Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) of those concentrations found in TRT 1; Treatment 6 - 50% reduction of organic Cu, Fe, and Zn concentrations of those found in TRT 2; Treatment 7 - 25% reduction in micromineral concentration from TRT 6; Treatment 8 - No Cu, Fe, Zn, and Se supplementations. (All organic minerals were Bioplex™ products, Alltech Inc., Nicholasville, KY).  
*cdeLeast squares means with different superscripts within a column (phase) and trait differ (P < 0.05).
Table 6. Least squares means (±SE) for fecal Zn concentration (DM basis) and apparent digestibility (Zn) measured in two experiments of a study comparing the effects of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn supplementation to the diet of phase-fed, grow-finish swine (18 to 118 kg BW).

<table>
<thead>
<tr>
<th>Trait</th>
<th>Experiment 1</th>
<th>Treatment</th>
<th>Phasea</th>
<th>Overall</th>
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<tr>
<td></td>
<td>Treatmentb</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
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<td>Fecal Zn, mg/kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>987.60±20.16</td>
<td>934.61±12.37</td>
<td>860.92±12.76</td>
<td>845.63±16.73</td>
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<td>2</td>
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<td>555.22±12.14</td>
<td>557.93±13.71</td>
<td>607.90±18.00</td>
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<td>3</td>
<td>508.12±19.82</td>
<td>426.63±12.06</td>
<td>448.65±13.33</td>
<td>446.47±17.02</td>
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<td>4</td>
<td>424.50±19.54</td>
<td>362.53±12.16</td>
<td>343.55±13.09</td>
<td>319.36±18.08</td>
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<td>Apparent Digestibility, %</td>
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<tr>
<td>1</td>
<td>15.25±3.81</td>
<td>9.66±3.81</td>
<td>16.17±3.81</td>
<td>6.68±3.81</td>
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<td>29.27±3.81</td>
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<td>49.80±3.81</td>
<td>27.44±3.81</td>
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| Experiment 2 |               |           |         |         |
| Fecal Zn, mg/kg |               |           |         |         |
| 5      | 308.64±14.51 | 335.85±10.00 | 362.71±11.04 | 278.02±12.61 | 321.31±4.95 |
| 6      | 351.71±14.45 | 335.63±10.13 | 333.90±10.93 | 340.19±12.84 | 340.36±4.93 |
| 7      | 270.94±14.40 | 275.27±10.03 | 236.57±10.97 | 234.01±12.23 | 254.20±4.95 |
| 8      | 184.19±14.39 | 161.07±10.44 | 140.12±11.11 | 148.45±10.81 | 158.46±5.06 |
| Apparent Digestibility, % |               |           |         |         |
| 5      | 20.58±2.37   | 31.57±2.37 | 24.38±2.37 | 42.21±2.37 | 29.68±1.19 |
| 6      | 11.49±2.37   | 33.26±2.37 | 38.04±2.37 | 44.51±2.37 | 31.82±1.19 |
| 7      | 42.18±2.38   | 41.62±2.38 | 30.79±2.38 | 39.47±2.38 | 38.51±1.19 |
| 8      | 22.74±2.38   | 59.99±2.38 | 34.93±2.38 | 37.90±2.38 | 38.89±1.19 |

aPhase 1 - diet fed from 18-37 kg BW; Phase 2 - diet fed from 37-55 kg BW; Phase 3 - diet fed from 55-82 kg BW; Phase 4 - diet fed from 82-118 kg BW.
bTreatment 1 (control) - 100% of Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)); Treatment 2 - 100% of Cu, Fe, and Zn from organic sources; Treatment 3 - 25% reduction in micromineral concentration from TRT 2; Treatment 4 - 50% reduction in micromineral concentration from TRT 2; Treatment 5 - 75% reduction in Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) of those concentrations found in TRT 1; Treatment 6 - 50% reduction of organic Cu, Fe, and Zn concentrations of those found in TRT 2; Treatment 7 - 25% reduction in micromineral concentration from TRT 6; Treatment 8 - No Cu, Fe, Zn, and Se supplementation. (All organic minerals were Bioplex™ products, Alltech Inc., Nicholasville, KY).

cd Least squares means with different superscripts within a column (phase) and trait differ (P < 0.05).
Table 7. Least squares means (±SE) of fecal dry matter content (%) and fecal mass (kg) measured in two experiments of a study comparing the effects of source (inorganic vs. organic) and concentration of Cu, Fe, and Zn supplementation to the diet of phase-fed grow-finish swine (18 to 118 kg BW).

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<tr>
<th>Experiment 1</th>
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<th>Overall</th>
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</thead>
<tbody>
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<td>Trait</td>
<td>Treatment</td>
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<td></td>
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<tr>
<td>Fecal Dry Matter (%)</td>
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<td>24.60 ± 0.326</td>
<td>26.10 ± 0.326</td>
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<tr>
<td></td>
<td>2</td>
<td>25.10 ± 0.326</td>
<td>25.90 ± 0.326</td>
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<td>3</td>
<td>24.00 ± 0.326</td>
<td>25.50 ± 0.326</td>
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<td>0.26 ± 0.0054</td>
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<td>0.24 ± 0.0054</td>
<td>0.24 ± 0.0054</td>
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<tr>
<td></td>
<td>3</td>
<td>0.21 ± 0.0054</td>
<td>0.24 ± 0.0054</td>
</tr>
<tr>
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<td>4</td>
<td>0.20 ± 0.0054</td>
<td>0.23 ± 0.0054</td>
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<td>6</td>
<td>24.40 ± 0.405</td>
<td>26.20 ± 0.405</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>25.00 ± 0.412</td>
<td>25.40 ± 0.412</td>
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<tr>
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<td>8</td>
<td>24.50 ± 0.412</td>
<td>25.70 ± 0.412</td>
</tr>
<tr>
<td>Fecal Mass (kg, DM basis)</td>
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<td>0.25 ± 0.011</td>
<td>0.34 ± 0.011</td>
</tr>
<tr>
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<td>6</td>
<td>0.26 ± 0.011</td>
<td>0.35 ± 0.011</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0.24 ± 0.012</td>
<td>0.33 ± 0.012</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.25 ± 0.012</td>
<td>0.34 ± 0.012</td>
</tr>
</tbody>
</table>

*Phase 1 - diet fed from 18-37 kg BW; Phase 2 - diet fed from 37-55 kg BW; Phase 3 - diet fed from 55-82 kg BW; Phase 4 - diet fed from 82-118 kg BW.
*Treatment 1 (control) - 100% of Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)); Treatment 2 - 100% of Cu, Fe, and Zn from organic sources; Treatment 3 - 25% reduction in microminerals concentration from TRT 2; Treatment 4 - 50% reduction in micronutrient concentration from TRT 2; Treatment 5 - 75% reduction in Cu, Fe, and Zn from inorganic sources (Cu as CuSO₄, Fe as FeSO₄, and Zn (25% as ZnO and 75% as ZnSO₄)) of those concentrations found in TRT 1; Treatment 6 - 50% reduction of organic Cu, Fe, and Zn concentrations of those found in TRT 2; Treatment 7 - 25% reduction in microminerals concentration from TRT 6; Treatment 8 - No Cu, Fe, Zn, and Se supplementation. (All organic minerals were Bioplex™ products, Alltech Inc., Nicholasville, KY).
*Excess Least squares means with different superscripts within a column (phase) and trait differ (P < 0.05).
CHAPTER 5. GENERAL SUMMARY

The environmental impact of pork production will likely be a topic of debate and concern in future years. In many cases federal, state, and local laws have already imposed regulations designed to reduce the environmental impact of livestock production and have forced producers to comply. Producers have turned to nutritional methods that may help to contend with imposed regulations. Many of the nutritional methods have the added benefit of reducing costs and environmental impact without adversely affecting overall performance and efficiency. The inclusion of organically complex or chelated trace mineral products into mineral supplements for grow-finish swine diets has been suggested due to their increased bioavailability over inorganic mineral salts.

The underlying objective of this thesis was to evaluate the effect of feeding pigs diets containing differing supplemental concentrations of inorganic and organic forms of Cu, Fe, and Zn, and to assess the environmental impact of these feeding strategies. This objective involved two specific goals: 1.) compare the fecal excretion and apparent digestibility of pigs fed the experimental diets; and 2.) confirm that performance and carcass composition of pigs fed diets containing differing supplemental concentrations of inorganic and organic forms of Cu, Fe, and Zn throughout the grow-finish phase of production did not differ.

Two experiments were conducted to evaluate the effect of dietary trace mineral supplementation on the performance and fecal excretion of grow-finish pigs. In the first experiment (EXP. 1), pigs fed the control diet containing the traditional inorganic trace mineral supplement had lower ADFI when compared to pigs fed the other three treatments. However, pigs fed the control diet excreted the highest concentrations of fecal Cu, Fe, and Zn for the entire grow-finish period. No differences in backfat, loin muscle area, ADG, lean
efficiency (LE), percent lean live, percent lean carcass, and kilograms of lean were observed among the experimental treatments. In experiment 2 (EXP. 2), pigs fed the diet containing no trace mineral supplementation had the poorest ADG, lean gain on test, and LE, lower ADFI, and excreted the lowest overall level of Cu for the grow-finish period when compared to pigs fed the other dietary treatments. No other treatment differences were observed for fecal Cu excretion, overall fecal Fe excretion, and performance traits in EXP. 2.

Results from this study illustrate that organic Cu, Fe, and Zn can be supplemented at reduced levels in diets fed to grow-finish swine, and similar performance and carcass composition can be achieved when compared to pigs that are fed diets containing commonly supplemented levels of the inorganic forms of these minerals. More importantly, the inclusion of organic trace minerals in pig diets resulted in significant reductions in fecal mineral concentrations when compared to pigs fed diets containing the traditional inorganic trace mineral premix.

The use of organic trace mineral supplements is certainly a viable nutritional method to reduce the bioaccumulation and nutrient wastage from animal feeding operations. Further studies should include economic evaluation of organic vs. inorganic trace mineral supplementation in grow-finish swine. Additionally, studies should focus on redefining the nutritional requirements for trace minerals in pigs, particularly when organic forms of trace minerals are utilized in diets, during times of health and other biological and environmental stresses.
CHAPTER 6. REFERENCES CITED


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