Effect of Reducing Micromineral Supplementation to Grower-Finisher Pigs on Growth Performance, Hematological Status, Carcass traits and Pork Quality

THESIS

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ABSTRACT

Grower pigs (n = 237) initially weighing 24.3 kg BW were used to evaluate the effects of reduced micromineral supplementation and varying levels of Fe and Zn on growth, feed efficiency, hematology, carcass characteristics and pork quality. A randomized complete block design with 7 dietary treatments replicated 7 times was used in the study. Treatments consisted of 1) basal diet with no added microminerals, 2) basal + 25% of NRC micromineral requirements, 3) basal + 50% of NRC micromineral requirements, 4) basal + 100% NRC micromineral requirements, 5) basal + 25 ppm Zn, 6) basal + 50 ppm Zn and 7) basal + 50 ppm Fe. Minerals were fed as mineral-proteonates and all diets incorporated organic Se-yeast at 0.3 ppm. When the average pen weight was 55, 80 and 115 kg BW pigs were bled with hemoglobin (Hb) and hematocrit (Hct) determined. At the end of the trial 3 pigs per pen were killed with carcass characteristics and meat quality measurements determined. The ADG, ADFI, and G:F for each of the 3 dietary phases and overall trial were not affected by dietary treatment (P > 0.10). The concentration of Hb and Hct volume were not different (P > 0.10) due to dietary treatment at each of the three dietary phases or the average of the trial. There were no differences in carcass characteristics such as hot carcass weight or fat free lean index (P > 0.10) due to dietary treatment. Loin pH, color (L*, a*, and b*), and moisture loss
were not different (P > 0.10) by dietary treatment. The subjective marbling scores and IMF content of loin samples were also not different due to dietary treatment. Firmness scores decreased cubically (P < 0.05) as the level of all microminerals was increased. Also, loins from pigs supplemental Fe had greater (P < 0.05) firmness and wetness scores. These results indicate that there are sufficient microminerals available in a corn-soybean meal based diet to meet the grower-finisher pig’s requirement for growth and hemoglobin synthesis. There are no detrimental effects of reducing micromineral, Zn or Fe supplementation on carcass characteristics and pork quality.

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# TABLE OF CONTENTS

Abstract.............................................................................................................................................................................ii
Acknowledgements.........................................................................................................................................................iv
Vita.....................................................................................................................................................................................vi
List of Tables....................................................................................................................................................................ix
List of Figures..................................................................................................................................................................x
Chapter 1:
  1.1. Introduction.........................................................................................................................................................1
  1.2. The Role of Microminerals in the Body......................................................................................................................2
    1.2.1. Description of Microminerals.............................................................................................................................2
    1.2.2. The Role of Cu.....................................................................................................................................................2
    1.2.3. The Role of Fe......................................................................................................................................................3
    1.2.4. The Role of Mn...................................................................................................................................................3
    1.2.5. The Role of Se....................................................................................................................................................3
    1.2.6. The Role of Zn....................................................................................................................................................4
  1.3. The U.S. Soil Mineral Content.................................................................................................................................4
  1.4. Factors Effecting Plant Acquisition of Minerals......................................................................................................6
  1.5. Bioavailability............................................................................................................................................................8
    1.5.1. Definition of Bioavailability.............................................................................................................................8
    1.5.2. Techniques to Assess Bioavailability................................................................................................................9
  1.6. Availability of Minerals in Grain Based Diets........................................................................................................10
    1.6.1. Availability of Macrominerals in Grain Based Diets.........................................................................................10
Table 1. Macromineral Content of Feed Ingredients .......................................................... 12
Table 2. Micromineral Content of Feed Ingredients ......................................................... 13
Table 3. NRC requirements for microminerals ................................................................. 24
Table 4. Composition of Basal diets for each phase ......................................................... 50
Table 5. Analyzed micromineral concentration (ppm) of Basal diets by phase .............. 51
Table 6. Effects of reduced dietary micromineral supplementation on growth performance ........................................................................................................... 52
Table 7. Effect of low dietary micromineral supplementation on hemoglobin and hematocrit .......................................................................................................................... 53
Table 8. Effects of reduced micromineral supplementation on Carcass Traits and Meat Quality .................................................................................................................. 54
LIST OF FIGURES

Figure 1. Influence of pH on soil mineral availability.........................................................7
Figure 2. Corn production by county in U.S. .................................................................32
Figure 3. Soybean production by county in U.S. .............................................................32
Figure 4. Color axis, L*, a*, b*.........................................................................................33
Figure 5. Avg. U.S. Slaughter Live Weigh of Pigs..............................................................33
CHAPTER 1
REVIEW OF THE LITERATURE

1.1 Introduction

In commercial swine production, the greatest cost of production is feed for the pig during the grower and finisher stages of production (approximately 20 kg to 115 kg of BW). To maximize profit potential, producers, feed companies, and nutritionists formulate swine diets on a least cost basis while attempting to maintain growth rate and feed conversion efficiency. In the United States this has traditionally led to swine diets that mainly comprise corn and soybean meal, particularly during the grower-finisher stage. Corn and soybean meal are generally regarded as cost effective feed sources as they are largely responsible for supplying nutrients in the form of energy from carbohydrates and fat, protein, vitamins, and minerals to pigs.

In 1927 at the Ohio Agriculture Experiment Station, Bohstedt et al. reported that when limestone was substituted for purified calcium carbonate (CaCO$_3$, chalk) in swine diets that the pigs grew faster and were thriftier. The authors concluded that this was due to limestone containing and supplying minerals other than Ca, such as Fe that are necessary to enhance growth rate in pigs. Iron, Cu, Mn, Se, and Zn, in animal nutrition are known as trace or microminerals and are required for optimal growth. Microminerals,
because they represent a portion of the diet that is small, are presented as parts per
million (ppm) rather than as a percent of the diet.

Since these early findings additional research has been conducted to quantify the
micromineral content of common feed ingredients, assess their bioavailability for use by
pigs, and determine the requirement of the pig by stage of production.

1.2 The Role of Microminerals in the Body

1.2.1 Description of Microminerals

Four of the essential microminerals (Cu, Fe, Mn, and Zn) are located in the d-
block section of the periodic table and are metals. Selenium is a non-metal located under
Oxygen and Sulfur on the periodic table. The metal microminerals readily form cations
and when in the body are incorporated into enzymes or other proteins and help to
maintain the structure of proteins or bind and carry negatively charged molecules.

1.2.2 The Role of Cu

Copper in the blood is bound to a carrying protein called ceroluplasmin, which
aids in the oxidation of Fe$^{2+}$ to Fe$^{3+}$ which is a better suited oxidation state for transferrin,
the primary Fe-carrying protein, to bind to. Also, Cu is a major constituent of the
superoxide dismutase (SOD) family of enzymes. The SOD enzyme family is responsible
for the oxidation of superoxide (O$_2^-$) species to O$_2$, H$_2$O, and H$_2$O$_2$. Superoxide’s have
the potential to cause oxidative damage to tissues in the body during times of
inflammation. Inside of the cell, Cu is largely found in the mitochondrial protein
Cytochrome c Oxidase; the enzyme involved in aerobic respiration (oxidative
phosphorylation) which is responsible for the efficient production of ATP energy
1.2.3 The Role of Fe

Iron’s primary function in the body is incorporation into the heme-groups of hemoglobin and myoglobin. Hemoglobin is responsible for the transportation of \(O_2\) in the body via the bloodstream. Myoglobin is responsible for the delivering \(O_2\) to muscle proteins and is a protein that gives meat its characteristic red color, because of Fe-O bonding. Oxygen forms a complex with the heme group of these proteins. Similar to Cu, Fe is also found in mitochondrial proteins involved in oxidative phosphorylation. Iron is unique in that large amounts can be stored in the liver, bound to the protein ferritin, which can buffer against Fe toxicity.

1.2.4 The Role of Mn

Manganese’s role in the body is broad, with roles in carbohydrate metabolism, production of sex hormones, and bone formation. Manganese, like Cu and Zn, has an integral part in preventing oxidative damage to tissues as it is incorporated into and SOD forming Mn-SOD.

1.2.5 The Role of Se

Selenium’s well noted primary function in the body of mammals is to be incorporated into glutathione peroxidase, an enzyme responsible for the oxidation of harmful oxidative species in the body. Selenium after being absorbed by plants is incorporated into the amino acids cysteine or methionine forming selenocysteine and selenomethionine, as a substitute for sulfur in these amino acids. These amino acids can then form the selenoproteins in the body. Selenium is also found in Selenoprotein P (Burk and Hill, 1994) and involved in the formation of thyroid hormone (Arthur et al.,
Deficiencies of Selenium include white muscle disease in calves and sheep and occasionally pigs. Mulberry Heart disease, also caused by a Se deficiency is of greater concern for pigs.

1.2.6 The Role of Zn

Zinc has a very diverse role in the body. Zinc serves as a coordination element in the body’s enzymatic pathways such as alcohol metabolism, removal of CO$_2$ from the body and protein degradation. Of particular importance, Zn has an integral role in gene expression. Zinc is used in the DNA binding domain, also called Zn fingers, of many transcription factors. Zinc fingers attach to DNA and help bind the transcription factor to the DNA to regulate transcription and gene expression.

1.3 The U.S. Soil Mineral Content

Swine nutrition starts with the soil mineral content and continues with the grain mineral content and bioavailability when determining the requirement of essential microminerals to the pig. Minerals that are supplied to swine, through cereal grains, are affected by the composition of minerals in the soil. Factors that contribute to the variation in mineral content of soil include the climate, remnants from glaciers, or proximity to volcanoes. Human influences can also contribute to soil mineral concentration through industrial waste such as vehicle exhaust or mining.

There are regional differences in soil mineral content across the U.S. Shacklette and Boerngen (1984) determined that the United States soil mineral composition can be divided east and west by the 96th meridian. Western U. S. soils are high in most of the
heavy metals, whereas soils in the eastern U.S. have relatively low mineral concentrations.

In two geochemical surveys from the United States Geological Survey (USGS) Shacklette and Boergen (1984) and Gustavsson et al. (2001) reported that soil Ca levels in areas east and south of the Ohio River are low, with concentrations near 0.2 percent; whereas, soils in the Midwest and plains states contain approximately 1-2% Ca and an even greater Ca concentration in the western U.S.

Shacklette and Boergen also reported that soil Fe in the Pacific Northwest is high (5%) which is similar to results by Gustavsson et al (2001). Soil Fe content in most of the continental U.S. has anywhere from 2-3% with the exception of Northern Michigan and parts of Texas where soil Fe is reported to be low (<1% Fe). Soil Cu concentration is reported to be highest (63 ppm) in Northern California and Cu is considered medium at 20-30 ppm in most of the rest of the U.S. Shacklette and Boerngen (1984) showed that the Midwestern plains states and the eastern U.S. had Zinc concentrations in the range of 40-80 ppm, while Gustavsson reported high Zn concentrations (greater than 80 ppm) in Ohio, Pennsylvania and Upstate New York.

Both Gustavsson et al. (2001) and Shacklette and Boerngen (1984) reported that soil Mn concentration in the Pacific Northwest and much of the eastern U.S. is greater than 500 ppm. In general, soil Zn and Mn concentration are fairly uniform across the United States. Soil Se concentration tends to be greater in the western plain states while, in contrast, the great lakes states are considered deficient for soil Se (Kubota et al., 1967). The coastal plains of the Atlantic region have low concentrations of many of the 50
elements analyzed and reported (Shacklette and Boerngen, 1984; Gustavsson et al 2001). Also, many of the soil element concentrations analyzed in Florida and West Texas are extremely low. Since there are regional differences in soil mineral concentrations, it is reasonable to expect that cereal grain mineral content will vary according to growing regions in the United States (Pond et al., 1964; Mahan et al., 2005).

1.4 Factors Effecting Plant Acquisition of Nutrients

Most minerals, both macro and micro, are absorbed by plant roots as ions. It is usually thought that the mineral concentration of the soil alone can be enough to determine the status of mineral availability and uptake by the plant. However, this is not always the case. Mineral ions in the soil are subjected to losing their charge and may be bound to other elements or organic material in the soil and therefore, the ion may not readily enter the soil solution and may not be available for uptake and utilization by the plant. Ions must enter the soil solution (water and solute), in order to be available to the plant.

Soil pH is the predominant determining factor of minerals entering the soil solution and their subsequent availability to plants. The microminerals Fe, Mn, and Zn are more available to plants at a pH between 4.5 and 5.0 and quickly become less available as the pH increases. In contrast, the availability of Cu is not as dependent upon soil pH (Figure 1) as other minerals because, Cu has a high affinity for organic matter, therefore not allowing Cu to readily enter the soil solution across a greater range of pH unless Cu is deficient (Foth and Ellis, 1997). Therefore, the addition of chemicals or fertilizers that alter soil pH can greatly influence micromineral availability.
A high concentration of a mineral relative to another mineral may result in mineral interactions in the soil at the root tip and reduce micromineral availability to plants. High soil P lowers the availability of Zn (Alloway, 2008); however, adding Zn to the soil may rectify this interaction (Judy et al., 1964). When soil Cu concentration is high reports indicate reduced Zn uptake by plant, most likely due to competition for the same transport site at the root. A Mn x Fe interaction exists where the availability of Mn generally decreases as the soil content of Fe increases. Sommers et al. (1942) attributed this interaction to the need of the plant for these two minerals in cellular respiration and found that CO$_2$ concentration, which is needed for photosynthesis, in the roots was highest with a soil Fe:Mn ratio of 1.5 to 2.5 for growing soybeans.

**Figure 1.** Influence of pH on soil mineral availability
Soil texture also contributes to the total uptake of micronutrients. Clay-type soils and soils with more organic matter have a greater cation exchange capacity than sandy type soils. Greater cation exchange capacity allows minerals to stay in the soil solution longer and allows for a greater quantity to be available to the plant. In contrast, sandy or course soils are prone to soil mineral loss due to water movement through the soil profile which results in leaching and movement of minerals away from the plant.

In addition to mineral concentration of the soil, plant factors such as the roots can influence mineral absorption. Root density and length of roots is a major contributor to nutrient uptake. As the number of roots increases the amount of minerals absorbed also increases. Root hairs increase the surface area of the root, which may increase absorption, although some data suggests this may not be true as root hair may develop from decreased soil mineral content (Clarkson, 1985). Also, roots can change the soil profile by secreting organic compounds in an effort to slow mobile nutrients and increase absorption.

1.5 Bioavailability

1.5.1 Definition of Bioavailability

Not every mineral, macro or micro, in feed ingredients, is absorbed and utilized by the pig. Bioavailability is the term used to describe how much of a mineral in a diet is absorbed. Factors that determine mineral bioavailability include the amount bound to compounds in plant cells, antagonistic interactions with other minerals that can occur within lumen the gastrointestinal tract, and the chemical form of the mineral.
In order to evaluate the bioavailability of a mineral, different sources of a particular mineral are fed; this can include evaluating supplemental mineral sources, or comparing mineral availability of different feed ingredients. Supplemental micromineral sources can be either inorganic or organic. Inorganic microminerals are fed as salt forms including, sulfates (SO₄), or oxide forms such as with Zn and Mn (ZnO, MnO), while inorganic Se is fed as sodium selenite (Na₂SeO₃). Organic microminerals are mineral ions that can be chelated to a protein, bound or incorporated into an amino acid, such as Se in seleniomethionine or bound to saccharides (AAFCO, 2005).

**1.5.2 Techniques to Assess Bioavailability**

Mineral bioavailability is commonly assessed using digestibility or retention trials. Mineral absorption is the difference in mineral intake minus the concentration of the feces. Mineral retention in the pig is measured as the difference in mineral absorbed from a diet minus mineral excretion from the urine. Using these methods, the apparent total tract digestibility can be measured (Adeola, 2001). Also, standardized total tract digestibility can be measured by accounting for endogenous losses from the pig. Differences in digestibility of a mineral would be indicative of a difference in absorption and hence bioavailability.

Koch and Mahan (1985) evaluated methods to asses low P diets in growing swine and found that bone weights of the organic matrix and mineralization of bones, in particular the femur, metacarpal or metatarsal, may be better parameters for assessing P needs when compared with weight gain. This concept can be transferred to other minerals as well.
Measuring the blood or plasma content are highly accepted ways to measure the availability of a mineral. Measuring the hemoglobin concentration and hematocrit volume or the percent of erythrocytes in blood are ways to assess the bioavailability of Fe. Blood and plasma measurements are used to assess how readily a mineral is absorbed. Typically, as dietary mineral levels are increased, plasma mineral levels increase in response until the requirement is met (Hedges and Kornegay, 1973; Meyer et al., 1981; Wedekind et al., 1994; Mahan et al., 1999), indicating that serum mineral concentration is a useful parameter to measure and compare the availability of minerals from alternative sources.

1.6 Availability of Minerals in Grain Based Diets

Traditionally as the swine industry has developed, to maximize profit potential the lowest cost grains were utilized by producers and, until recently, corn and soybean meal have largely been the lowest cost feed resources in the Midwestern U.S. and thus most widely used. The top five corn producing states are Iowa, Nebraska, Minnesota, Illinois and Indiana which contribute over 60% of the corn grown in the United States. Peripheral portions of adjacent states such as western Ohio, southern Michigan, northern Missouri, Kansas, Wisconsin and South Dakota add another 30% of the corn grown in the United States (Figure 2). Likewise, the top five soybean producing states include Iowa, Illinois, Minnesota, Indiana, and Nebraska and the same aforementioned surrounding regions collectively produce 81% of the soybeans grown in the United States (Figure 3). Therefore, it is likely that the grain fed to pigs that is grown in the United States will have
a nutrient composition that reflects the soil nutrient profiles present in the Midwestern and northern plain states.

1.6.1 Availability of Macrominerals in Grain Based Diets

Listed in Tables 1 and 2 are the macro and micromineral contents of select common feed ingredients used in grower-finisher pig diets. The Ca concentration of corn is very low (0.03%) and could not possibly supply the Ca requirement for grower-finisher pigs (0.80%) reported by Chapman et al. (1962). While P content is greater than the Ca content in corn, only about 15% of the total P is available for absorption by the pig (NRC, 1998) because it is bound to the plant product phytate. Soybean meal, 44% crude protein, does contain greater concentrations of both Ca and P than corn; however, soybean meal is not commonly included in diets at a level greater than 30% for the grower-finisher pig when attempting to meet their protein requirement. Therefore, because corn and soybean meal supply low levels or less available forms of dietary Ca and P to pigs, other sources of these macrominerals are added to diets to meet the pig’s requirement.

1.6.2 Availability of Microminerals in Grain Based Diets

The copper requirement listed by the NRC (1998) suggests that 3 to 4 ppm of dietary Cu is sufficient for grower-finisher pigs, and reported research indicates that the concentration of Cu in commonly fed grains may meet this requirement (Bradley et al., 1983). For nursery pigs, feeding pharmacological levels of Cu (100 to 250 ppm) stimulates the rate of BW gain (Cromwell et al., 1989). A series of trials by Wallace et al. (1960) reported that growing pigs fed added dietary levels of Cu, as copper sulfate
(CuSO₄), above 100 ppm did not enhance growth rate, while feeding 250 ppm of added dietary Cu resulted in Cu toxicity. Wallace et al. (1960) also reported that feeding 200 ppm of added dietary Cu reduced hemoglobin levels in growing pigs. Interestingly, Wallace et al. (1960) reported in one trial that diets with no added Zn or Cu, when fed to grower pigs resulted in the development of parakeratosis, hypothesized to be due to insufficient Zn in the non-supplemented diet. However, this was not reported in another study from the same report. It appears that Cu may aid in reducing parakeratosis-like symptoms caused by Zinc deficiency; however, data suggests that fortification of grower or finisher diets with Cu may not have any beneficial effect.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Calcium</th>
<th>Phosphorus</th>
<th>Potassium</th>
<th>Magnesium</th>
<th>Sodium</th>
<th>Chlorine</th>
<th>Sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>0.03</td>
<td>0.28</td>
<td>0.33</td>
<td>0.12</td>
<td>0.02</td>
<td>0.05</td>
<td>0.13</td>
</tr>
<tr>
<td>Soybean Meal, 44%</td>
<td>0.32</td>
<td>0.65</td>
<td>1.96</td>
<td>0.27</td>
<td>0.01</td>
<td>0.05</td>
<td>0.43</td>
</tr>
<tr>
<td>Limestone</td>
<td>35.84</td>
<td>0.01</td>
<td>0.11</td>
<td>2.06</td>
<td>0.06</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Dicalcium Phosphate</td>
<td>20-24</td>
<td>18.50</td>
<td>0.15</td>
<td>0.80</td>
<td>0.18</td>
<td>0.47</td>
<td>0.80</td>
</tr>
<tr>
<td>Distillers Grains, soluables</td>
<td>0.20</td>
<td>0.77</td>
<td>0.84</td>
<td>0.19</td>
<td>0.25</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>Wheat, red hard</td>
<td>0.05</td>
<td>0.36</td>
<td>0.41</td>
<td>0.16</td>
<td>0.02</td>
<td>0.09</td>
<td>0.17</td>
</tr>
<tr>
<td>Barley, 2 row</td>
<td>0.06</td>
<td>0.35</td>
<td>0.45</td>
<td>0.14</td>
<td>0.04</td>
<td>0.12</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Table 2. Micromineral Content of Feed Ingredients (ppm), NRC, 1998

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Copper</th>
<th>Iron</th>
<th>Manganese</th>
<th>Zinc</th>
<th>Selenium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>3</td>
<td>29</td>
<td>7</td>
<td>18</td>
<td>0.07</td>
</tr>
<tr>
<td>Soybean Meal, 44%</td>
<td>20</td>
<td>202</td>
<td>29</td>
<td>50</td>
<td>0.32</td>
</tr>
<tr>
<td>Limestone</td>
<td>-</td>
<td>600</td>
<td>200</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>Dicalcium Phosphate</td>
<td>-</td>
<td>7900</td>
<td>1400</td>
<td>92</td>
<td>-</td>
</tr>
<tr>
<td>Distillers Grains, solubles</td>
<td>57</td>
<td>257</td>
<td>24</td>
<td>80</td>
<td>0.39</td>
</tr>
<tr>
<td>Wheat, red hard</td>
<td>7</td>
<td>64</td>
<td>42</td>
<td>43</td>
<td>0.30</td>
</tr>
<tr>
<td>Barley, 2 row</td>
<td>7</td>
<td>78</td>
<td>18</td>
<td>25</td>
<td>0.19</td>
</tr>
</tbody>
</table>

The neonate pig’s requirement for Fe is extremely high, so high that the Fe concentration in sow’s milk is unable to supply enough Fe to prevent anemia. Therefore, the industry standard is to provide 200 mg supplemental Fe, in the form of Fe Dextran, by intramuscular injection within three days of birth to improve livability and growth rate.

When pigs were offered a low iron creep feed instead of an Fe injection, during the nursing period, growth rate, hemoglobin and hematocrit values have been reported to be greater in piglets fed diets supplemented with Fe (Kornegay, 1972; Ammerman et al., 1974) compared to diets with no Fe supplementation. However, in recent studies where nursing pigs were fortified with Fe via injections and subsequently fed a complex nursery diet, dietary Fe level influenced hemoglobin or hematocrit values but not growth rate (Rincker et al., 2004 and 2005). This is most likely because pigs may have high Fe stores so weight gain may not be as responsive during early Fe deficiency.
Jolliff and Mahan (2011) further studied the effects of pig BW at birth, amount of Fe injection and dietary Fe level post weaning. Heavier BW pigs at birth given 300mg compared with 200 mg responded to increasing dietary Fe levels from 80 to 240 ppm. Lighter BW pigs injected with 200 mg of Fe responded to increased levels of dietary Fe from 80 to 160 ppm post weaning.

These studies indicate that Fe supplementation is needed in weanling pig diets for maximizing growth rate when creep feed supplies Fe and not Fe injections to nursing pigs. However, hematology measurement for pigs fed a non-Fe fortified diet does not maintain pig’s iron stores, independent of receiving an Fe injection, because Fe required for hemoglobin synthesis is considered to be greater than the requirement for maximizing growth. Also, heavier BW pigs may require more Fe than their contemporaries. All this together suggests that the indigenous Fe content of an unfortified Fe diet does not maintain Fe stores, hemoglobin synthesis or body weight gain.

Few studies have been conducted evaluating Mn availability at any stage of production in swine. The NRC (1998) lists the dietary requirement of Mn for 20 to 120 kg pigs to be 2 ppm. Increasing graded levels Mn from 0 to 320 mg/kg as Availa-Mn has been reported to improve feed efficiency but not gain when fed to grower-finisher pigs (Apple et al, 2004). When formulating standard least cost swine diets without a mineral premix, often the Mn level may be in excess of 20 ppm, depending on the stage of production specific diets. Therefore, a diet may be able to meet the Mn requirement of pigs for BW gain without the need for dietary supplementation.
Numerous times it has been reported that nursery pigs fed diets without Zn supplementation, developed parakeratosis-like symptoms (Smith et al., 1958; Pond et al., 1964; Martin et. al. 2011); this condition was quickly reversed as pigs were given a diet fortified with Zn. The NRC requirement for Zn is 60 ppm for grower pigs and 50 ppm for finisher pig for adequate growth and development. The NRC requirement levels of dietary Zn were established from studies in the 1950’s and early 1960’s and at that time parakeratosis was an indicator of Zn status (Smith et al., 1958; Lewis et al., 1956). Lewis et al. (1956) found that grower pigs supplemented with 50 ppm Zn vastly outgrew pigs fed diets that were devoid of added Zn. The authors noted no morbidity due to parakeratosis-like symptoms, but symptoms still persisted in pigs fed Zn supplemented diets. These results may be explained by the weights of pigs used in the trial, where the pigs were started at weights between 30 and 40 lbs, a weight that currently would represent a nursery stage in the swine industry. Today 30 to 40 lbs. pigs would likely be fed diets supplemented with greater Zn levels and thus not show parakaratotic symptoms.

With respect to standard corn-soybean meal based diets fed to pigs, the total concentrations of Cu and Mn in corn and soybean meal are well above the requirement for grower-finisher pigs. However, there are industry concerns regarding the bioavailability of Mn in cereal grains (Hill and Spears, 2001). In contrast, Fe and Zn concentrations in these ingredients are moderate when compared to the pig’s requirement; therefore, dietary supplementation is commonly necessary for Fe and Zn.

Selenium concentration is considered low in corn although the concentration may be adequate in soybean meal; however, a pig’s diet would have to consist entirely of
soybean meal to meet the requirement currently listed for grower-finisher pigs by the NRC (1998). Therefore, Se is added to swine diets; however, government regulations only allow Se addition up to 0.30 ppm. In the 1950’s the FDA forbade the addition of Se to livestock diets since toxic levels were responsible for alkali disease to grazing livestock in the northern plain states. Because of high soil and plant Se concentrations meat would contain greater Se and therefore may cause detrimental effects to humans, which was known to be carcinogenic (Ullrey, 1992).

In summary, research indicates that macro and micromineral compositions are relatively low in cereal grains or not highly available to meet the requirement of pigs during the stages of production. Consequently, swine nutritionists typically incorporate alternative supplemental sources of minerals in addition to corn and soybean meal, into swine diets to supply the pig’s dietary requirement by stage of life.

1.7 Phytate

1.7.1 Phytate and Phosphorus

In all cereal grains most of the P is bound to myo-inostitol hexaphosphate, a compound known colloquially as phytate. Approximately 71 to 88% of all P in corn is bound to phytate and 50 to 70% of P is bound in soybeans (Reddy et al., 1989). Adding phytate to an animal protein based diet was reported to cause a marked reduction in ADG and decrease efficiency (Oberleas et al., 1962). Pigs are unable to make sufficient amounts, if any, of the enzyme phytase (Pointillart et al., 1984), so swine nutritionists, in order to increase the availability of P, add phytase to diets. Phytase aids in liberating P from phytate. The dietary additions of phytase to swine diets have been reported to
increase available P in soybean meal from 25% to 58% and from 15% to 43% in corn-soybean meal diets (Cromwell, 1993). The addition of phytase to a diet with adequate P levels improves rate of BW gain and feed efficiency compared with pigs fed low dietary P. Bone breaking strength increases with the addition of phytase to grower-finisher pig’s diets. Similarly, pigs fed diets low in available P, increasing the level of dietary phytase improved BW gain and bone breaking strength (Cromwell et al., 1993). Dietary additions of phytase also increases the amount of dietary P absorbed and retained by the pig (Lei et. al., 1993; Adeola et. al. 1995) lessening P via excretion to the environment.

1.7.2 Phytate and Microminerals

In addition to P, phytase can also bind to Ca, Zn, and Fe, which reduces their availability to the pig. Calcium absorption and retention are increased when nursery pigs are fed phytase (Adeola et al., 1995), however, plasma Ca concentration was unaffected. This is because plasma Ca is tightly regulated (Coalson et al 1974). When phytase is added to weanling pig diets with no Zn fortification, plasma Zn was similar (Lei et al., 1993) along with, greater Zn absorption and retention compared with pigs fed added dietary Zn (Adeola et al., 1995). In contrast, Lei et al. (1993) found no difference in Zn absorption or retention when comparing a basal diet, a diet with 30 ppm added dietary Zn or a diet with added phytase.

Phytase inclusion in diets for nursery pigs increased hemoglobin concentration and hematocrit volume to a level similar to that of pigs fed a diet with added FeSO₄ alone, following 4 weeks of feeding (Stahl et. al, 1999). Stahl et al. (1999) also reported that there were no differences in weight gain of pigs fed diets with additions of either 50
ppm Fe or 1200 phytase units alone were added to a corn soy protein concentrate diets. However, adding 70 ppm of Fe to a diet resulted in weight gain that was greater during weeks 3 and 4 post-weaning when compared to a diet with added phytase. Because it is currently commonplace to add phytase to swine diets to improve P availability and reduce its excretion, the effects of adding phytase to diets on micromineral availability to the pig which could change the amount of microminerals that needs to be added to a diet to meet the pig’s requirement.

1.8 Common Macromineral Sources

Limestone is a principle source of Ca, as calcium carbonate (CaCO$_3$) while mono and dicalcium phosphate (Ca(H$_2$PO$_4$)$_2$ and CaHPO$_4$, respectively) are sources of dietary Ca and highly available P. However, these macromineral sources are not pure and do contain essential microminerals particularly Fe, Mn and Zn (Tables 1 and 2).

1.9 Availability of Microminerals in Sources Other than Grain

Data on the availability of Cu from various supplemental sources does not appear to be consistent. Recently, in trials involving nursery pigs fed diets with added organic Cu sources and fed at lower (less than 250 ppm) levels than Cu sulfate, weight gain, absorption and retention of Cu was better (Veum et al. 2004), suggesting that organic Cu-proteinate may be a more available source. Conversely, other trials involving nursery pigs (10-20 kg) have reported that organic Cu sources compared with Cu sulfate were equally available (Coffey et al., 1994; Apgar et al. 1995; Angelov et al., 2007). In a balance trial with grower pigs Apgar and Kornegay (1996) reported that pigs fed diets containing 200 ppm of added Cu as Cu-Lys had greater BW gains compared with pigs fed a diet with
200 ppm added Cu sulfate; however, neither diet was different from a basal diet with no supplemental Cu. Moreover, the absorption of Cu in this trial was not different between any of the dietary treatments.

Inorganic Fe as FeSO$_4$ has been reported to have a greater bioavailability than other sources. The bioavailability of Fe in defluorinated phosphate appears to be less than FeSO$_4$ if supplied at levels less than 80 ppm (Kornegay, 1972). Ammerman et al. (1974) compared additions of Fe as carbonate or sulfate in two experiments. In one experiment weight gain, hemoglobin, and hematocrit values increased in pigs fed a diet with supplemental Fe sulfate compared to Fe carbonate, while the other experiment reported no difference between the two sources. Therefore, FeSO$_4$ is more commonly fed in diets and is considered as a reference.

Data regarding the availability of organic forms of Fe is in its infantile stage. Performance of nursery age pigs fed an amino acid-Fe complex had increased weight gain, hemoglobin synthesis, hematocrit volume, and plasma Fe than pigs fed FeSO$_4$ at a level of 120 ppm added Fe (Yu et al., 2000). Similarly, Feng et al. (2007) indicated Fe-Gly was as bioavailable as FeSO$_4$. In contrast, Fe bound to methionine was reported to be less bioavailable than FeSO$_4$ when fed in a corn-based diet to Fe-depleted nursery pigs (Lewis et al., 1996).

Recent studies have compared the bioavailability of inorganic manganese sulfate (MnSO$_4$) and Availa-Mn (ZINPRO, Eden Prairie, Mn), an amino acid-Mn complex. In two trials by Apple et al. (2004) weight gain and feed intake were not different between the two Mn sources. When pigs were fed diet supplemented with 350 ppm MnSO$_4$ or 700
ppm Availa-Mn added to the diet, G:F for the overall grower-finisher period was the highest, indicating that MnSO₄ was more available to improve feed efficiency. In chicks, it has been reported that when an amino acid-Mn chelate was fed compared with MnSO₄ the availability was the same between the two sources (Miles et al, 2003).

Zinc has for a long time been added to swine diets as zinc sulfate (ZnSO₄). In nursery pig diets, pharmacological (500-3000 ppm) levels of added dietary Zn as Zn oxide (ZnO) improves growth (Hill et al. 2000; Case and Carlson, 2002) and reduces scours (Poulsen, 1989). The bioavailability of different sources of Zn fed to nursery pigs has been variable. Case and Carlson (2002) reported that feeding 500 ppm of SQM-Zn (QualiTech, Chaska, MN) a Zn-polysaccharide complex, Availa-Zn (ZINPRO, Eden Prairie, MN) or ZnO that Zn excreted in the feces and urine or serum Zn were not different, indicating the absorption and utilization of these sources are similar. Interestingly, supplementing SQM-Zn had similar growth promoting effects as when 3,000 ppm ZnO was fed. Wedekind et al. (1994) demonstrated that increasing the dietary levels of added ZnSO₄ from 0 to 80 ppm (0, 5, 10, 20, 40, 80) in diets to growing pigs, previously deprived of Zn supplementation in the nursery, resulted in ADG, ADFI and G:F that were not different between dietary levels. However, plasma and bone Zn concentrations increased linearly as Zn supplementation increased. A regression of the bone Zn concentration on dietary Zn level, determined that the slope of 40 to 80 ppm added Zn was less than from 0 to 20 ppm, with a break point at around 45 ppm, suggesting a requirement of 50 ppm. Another experiment by Wedekind et al. (1994) evaluated the availability of different supplemental Zn sources. Comparing diets with no
added Zn to diets supplemented with ZnSO₄, ZnO, Zn-Methionine, or Zn-Lysine it was reported that growth performance was not different due to treatments. Analysis of the Zn content of the metacarpal bone of pigs suggested that ZnSO₄ was much more available than the other sources; whereas, analysis of coccygeal bone Zn content suggested that the availability of ZnSO₄ and Zn-Met were similar. Analysis of plasma Zn concentrations demonstrated that Zn bioavailability was not different between these sources. These studies indicate that grower-finishing pigs can have adequate growth when fed a diet with no supplemental Zn and that ZnSO₄ may have the greatest bioavailability of supplemental Zn sources; however, performance may not be the best method to assess Zn availability.

As mentioned earlier, the Se requirement of pigs is approximately 0.3 ppm. This level was established for nursery pigs by Meyer et al. (1981) in response to the finding that Se injections reduced morbidity in Se deficient pigs (Mahan et al, 1973). For grower and finisher pigs the established requirement may be closer to 0.1 ppm (Groce et al., 1973; Mahan et al., 1999); however, because this level is low for weanling pigs the FDA allows up to 0.3 ppm added Se to all swine diets. Dietary Se supplemented to grower-finisher pigs results in increased GSH-Px formation when inorganic sodium selenite is fed whereas; organic Se was better retained in organs (Mahan and Parrett, 1996; Mahan et al., 1999). Absorption of selenite appears to be greater than Selenomethionine; however, more Se is excreted by pigs fed selenite. These studies suggest that organic Se is better retained by the pigs after being absorbed.

Data describing the availability of microminerals from sources like dicalcium phosphate, or premixes is limited for the grower-finisher pig. Studies have investigated
the effects of removing all of the dietary microminerals, supplied from premixes, on
growth performance of grower and finisher pigs. Results from studies investigating
supplemental micromineral removal from diets are not consistent. Studies have found no
differences in overall ADG between pigs supplemented with microminerals and those
receiving an unfortified diet (Mavromichalis et al., 1999; Shelton et al., 2005), while
other trials have reported growth performance differences (Edmonds and Arentson, 2001;
Veum et al, 2009). Mavromichalis et al. (1999) reported that ADFI, 30 days prior to
slaughter, was lowered in pigs fed diets not supplemented with microminerals yet, feed
efficiency was not different. Contrary to those findings, Edmonds and Arentson (2001)
found that pigs fed diets supplemented with microminerals for 12 weeks prior to
slaughter had greater weight gain compared with pigs not supplemented with dietary
microminerals for 12 weeks as well as greater feed efficiency compared with pigs not
supplemented with dietary microminerals for either 12 or 6 weeks prior to slaughter.

1.10 Requirements

1.10.1 Assessment of Requirement for Swine

Mineral requirements are determined for pigs by feeding a diet that has no
supplementation of the mineral(s) of interest. This diet would be considered inadequate
for the mineral(s) of interest. Then diets similar to the mineral depleted diet are fed with
added levels of the mineral of interest and parameters chosen to assess the requirement.
Swine producers grow pigs primarily for market, so weight gain and feed efficiency
parameters are the driving economical forces to measure industry efficiency. These
variables are easy to collect and are not expensive relative to other parameters and thus
are widely employed. The requirement of a nutrient is determined using slope-regression analysis. At a point when the regression plateaus, or rather is shown to have no or minimal effect between levels of a mineral, the lower dietary level would be considered as the pig’s requirement. Roberson and Schaible, (1958) used weight gain of chicks, as a response variable for assessing the Zn requirement and reported it could be effective to evaluate requirement.

Other parameters can be measured and can be employed to measure the requirements of a nutrient. Bone mineralization has proven to be excellent in assessing the pig’s mineral status. For nursery pigs feeding high levels of Zn and Cu can stimulate gain, because at high levels they have been shown to be antimicrobial in nature. Thus, high Zn and Cu levels are enhancing beneficial gastrointestinal microbial populations of the weanling pig. The requirements of minerals for bone mineralization and immune function are often greater than for gain or feed efficiency. Therefore, the true requirement may be harder to assess given limited resources.

1.10.2 Past and Current Mineral Requirements for Grower-Finisher Pigs

Table 3 shows the requirements for the essential microminerals for grower-finisher pigs from 20 kg to 120 kg of body weight from the last 4 editions of the NRC. The changes in requirements over the last 30 years have been static.

As the swine industry adapts to the ever changing market the genetics of pigs has changed drastically. Pigs were once used as a source of lard, thus fat was valued. Today however, lard is not as widely used and consumers desire lean pork with less fat than in the past. Genetic changes of pigs raised for slaughter may influence the micromineral
requirement. Wiseman and Mahan (2010) compared two lines of pigs with different fat-free lean gain per day. One line gained 280 g fat-free lean/d and the other 375 g/d. Although differences were small, whole body micromineral content of pigs was greater in high lean gain pigs, and the differences were greater as body weight increased.

Table 3. NRC requirements for microminerals, in parts per million (ppm)

<table>
<thead>
<tr>
<th>Weight, kg</th>
<th>Copper</th>
<th>Iron</th>
<th>Manganese</th>
<th>Zinc</th>
<th>Selenium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998 NRC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20- 50</td>
<td>4</td>
<td>60</td>
<td>2</td>
<td>60</td>
<td>0.15</td>
</tr>
<tr>
<td>50- 80</td>
<td>3.5</td>
<td>50</td>
<td>2</td>
<td>50</td>
<td>0.15</td>
</tr>
<tr>
<td>80- 120</td>
<td>3</td>
<td>40</td>
<td>2</td>
<td>50</td>
<td>0.15</td>
</tr>
<tr>
<td>1988 NRC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20- 50</td>
<td>4</td>
<td>60</td>
<td>2</td>
<td>60</td>
<td>0.15</td>
</tr>
<tr>
<td>50- 80</td>
<td>3</td>
<td>40</td>
<td>2</td>
<td>50</td>
<td>0.10</td>
</tr>
<tr>
<td>80- 120</td>
<td>3</td>
<td>40</td>
<td>2</td>
<td>50</td>
<td>0.10</td>
</tr>
<tr>
<td>1979 NRC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20- 35</td>
<td>4</td>
<td>60</td>
<td>2</td>
<td>60</td>
<td>0.15</td>
</tr>
<tr>
<td>35- 60</td>
<td>3</td>
<td>50</td>
<td>2</td>
<td>50</td>
<td>0.15</td>
</tr>
<tr>
<td>60- 100</td>
<td>3</td>
<td>40</td>
<td>2</td>
<td>40</td>
<td>0.15</td>
</tr>
<tr>
<td>1964 NRC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All pigs</td>
<td>10</td>
<td>80</td>
<td>40</td>
<td>50</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Management of hogs has continually changed over the last century with changes in housing being most influential on micromineral requirements. Today in the United States about 85% of pigs are reared in barns on concrete as opposed to on pasture or open
dirt floor barns (Gentry et al., 2002). Hemoglobin synthesis has been found to be lower in pigs reared indoors vs. outdoors (Kleinbeck and McGlone, 1999); Furthermore, bone breaking strength and percent bone ash are greater in pasture vs. indoor reared pigs (Svajgr et al., 1969). Pigs reared indoors loose access to minerals from the soil or plant sources in addition to dietary Fe. Therefore, minerals most likely need to be supplemented to meet the pig’s requirement.

1.11 Tissue Mineral Concentration

Different tissues in the body have different functions and therefore have different mineral contents. The diverse functions of tissue include movement (muscle) which eventually becomes an edible product as meat, or the heart which is responsible for the movement of blood throughout the body. Some tissues are responsible for removing waste and regulating blood pressure (kidney) or detoxification, protein synthesis and storage of nutrients (liver). The liver is the principle storage site for Cu and Fe evidenced by the fact that the liver Cu or Fe concentration is sensitive to increases of dietary levels of Cu and Fe. Copper supplementation to Cu deficient neonatal swine at levels as low as 5 or 10 ppm significantly increased Cu concentration in the heart (Hill et al., 1983). The authors concluded from that paper that Cu was being used in the enzyme Cytochrome C Oxidase which is used during oxidative phosphorylation. This would seem to suggest that Cu is needed for proper heart function, but a level of 5 ppm added Cu to a diet would seem more than sufficient. The concentration of Cu in muscle is lower than other tissues and does not respond to increasing the dietary level of Cu (Bradley et al., 1983). Iron concentration in muscle is lower than the kidney or liver concentration and results
between researchers show this consistency (Bradley et al., 1983; Shelton et al., 2004; Apple et al. 2007). Similar to the other essential microminerals, the kidney and liver have the highest concentrations of Zn. Of the discussed microminerals Zn has the highest concentration in muscle (Doyle and Spaulding, 1978; Shelton et al., 2004). Selenium concentration of organs is lower in all tissue than the other essential microminerals by nature of its low concentration in feed. The kidney and liver may be the principle storage site of Se compared with other tissues; little data exists on the concentration of Se in the heart.

1.1.1 Factors Effecting Tissue Mineral Concentration

When increasing dietary levels of a micromineral fed to pigs typically there is an increase of the concentration of that mineral in the tissues of the body. There are also other nutritional factors that can alter the body tissue concentration. Interaction with other minerals can affect absorption in the lumen of the gastrointestinal tract as well as inside the body. High Cu (greater than 200 ppm) when supplemented to swine diets causes Fe liver concentration to decrease (Ritchie et al., 1963; Hedges and Kornegay, 1973), Zn has been reported to reduced liver Cu stores (Ritchie et al., 1963), but liver and kidney Zn concentration is not affected by Cu or Fe level (Hedges and Kornegay, 1973).

Feeding pharmacological levels of Zn to nursery pigs has increased liver stores of Zn. The feeding of different sources of Zn (ZnSO₄, ZnMet, or ZnLys) did not affect the concentration of liver Zn in weanling pigs (van Heugten et al., 2003) and most of the Zn was found in the cytosol of cells, suggesting that Zn found in the liver is most likely incorporated into metalloenzymes or stored as opposed to acting as a transcription factor.
Rincker et al. (2005) reported that low levels of dietary Zn raised Zn levels in the kidney, most likely as the last chance to retain Zn when low available Zn was fed.

1.12 Carcass Characteristics and Meat Quality

The ultimate goal of pig producers is to market a grower-finisher pig whose muscle can be converted to a saleable, edible meat product. Carcass characteristics are measurements used to estimate the percentage of fat-free lean, which determines the price of a pig. Meat quality traits are characteristics which consumers use to determine whether a piece of meat is acceptable to purchase and then how enjoyable the eating experience is.

Producers get paid by weight and the percent of lean tissue (muscle without fat) on a market hog. The percent of lean can best be predicted by measuring the back fat and loin eye area between the tenth and eleventh ribs. Muscle quality factors include pH, color, drip or moisture loss and the amount of intramuscular fat. The pH of meat can alter the water holding capacity of a piece of meat, which influences how juicy or tender the meat is. A pH in the range of 5.4-5.7 is considered to be normal for pork. When the rate pH declines rapidly within 4 hours post-mortem pork can become pale in color, soft in texture and exudative with respect to water loss. When pH values greater than 6.2, pork are can be dark, firm and dry. Both of these characteristics of pork can be undesirable to consumers. Many procedures pre and post-harvest procedures are taken by abattoirs to control the rate and extent of pH decline however, it is also widely accepted that
nutritional factors may influence the rate and extent of pH decline as well as other meat quality factors.

Iron in muscle is contained within myoglobin, similar to hemoglobin; myoglobin contains a heme group, containing Fe, and is responsible for the movement and storage of oxygen in muscle cells. There are different states of myoglobin which depend on the presence of oxygen and the oxidation state of the Fe ion. Myoglobin, when oxygen is bound to it is known as oxymyoglobin and is responsible for giving meat its characteristic red color. Apple et al. (2007) reported that feeding 50, 100 or 150 ppm of an organic amino-acid Fe source had no effect on hot carcass weight (HCW), dressing percentage or loin muscle area (LMA) compared to a basal, unfortified Fe diet or when 50 ppm FeSO₄ was added to a diet. They did report that back fat at the 10th rib tended to increase as the level of dietary iron increased, which also tended to make the percent of fat-free lean decrease linearly. Apple et al. (2007) also found that muscle quality, measured by subjective color scores, drip loss percentage, and pH did not differ by the source or inclusion level of Fe.

Studies have investigated the effects of level and source of Mn, comparing inorganic MnSO₄ or organic chelated Mn-amino acid (AvailaMn, Zinpro Corp. Eden Prairie, MN) source on carcass composition and pork quality. When Mn was fed at 350 ppm there was a tendency for backfat depth at the first and last rib to be increased. There were no reported differences on other carcass characteristics such as loin muscle area, marbling score, or fat free lean yield for level or source of Mn. The pH of muscle was reduced as levels of Mn increased and b* color score was decreased when AvailaMn was
fed (Apple, 2004). When Mn was included in a premix HCW tended to be greater and loin muscle depth was increased compared to pig fed a diet with no Mn in a micromineral premix (Sawyer et al. 2007). At 2 days post mortem the cooking loss was decreased when the AvailaMn source was fed. Cooking loss is the amount of water lost after cooking a piece of meat, which could affect the eating experience of the consumer.

Mahan et al. (1999) reported no effects of Se level or source on carcass characteristics, but organic selenomethionine reduced 48 hour drip loss especially when dietary supplementation was 0.2 or 0.3 ppm. Additionally, the authors reported Se supplementation increased loin L* values toward a less desirable pale color.

A few trials have evaluated the effects of removing all of the essential microminerals from the finisher phase, the last 30 to 40 days prior to slaughter on carcass characteristics and meat quality. Generally, removal of a micromineral premix from a diet for 85 to 115 kg pigs has had no deleterious effects on carcass characteristics such as dressing percentage, back fat at the 10th rib or loin muscle area. Similarly, pork quality factors such as color, firmness, pH and water holding capacity were not affected by pigs fed diets not supplemented with microminerals compared with pigs fed diets that were. One study indicated that removal of supplemental minerals increase backfat at the 10th rib (Mavromichalis et al, 1999). Edmonds and Arentson (2001) reported that grower-finisher pigs, fed a diet devoid of micromineral supplementation for 6 or 12 weeks prior to slaughter had similar last-rib backfat, loin muscle area, fat free lean index and dressing percentage compared to pigs fed vitamins and micromineral premixes for 12 weeks prior to slaughter.
1.13 Research Rational and Objectives

Considerable research has been conducted with nursery pigs to establish the proper micromineral requirement for pigs of that age and weight. Previous research has indicated that the essential microminerals Zn and Se are the most limiting microminerals to nursery pigs. For the grower-finisher pig some research has evaluated the effects of a specific micromineral, but with the other microminerals added at NRC requirements to the diet. Also, some trials have investigated removing all microminerals supplemented in swine diets for only the last month prior to slaughter. Evaluating specific minerals of interest without other micromineral supplementation is important since there may be some mineral interaction confounding the results. Also, because the average slaughter live weight of pigs has increased since the 1950’s (Figure 4) it is possible that dietary Fe supplementation is needed for the grower-finisher pig due to an expected increase in hemoglobin synthesis to meet the need of heavier BW pigs. Therefore, the objective of this study was to evaluate the effects of reduced dietary micromineral supplementation with varying levels of Zn and Fe supplementation individually for the grower-finisher period on growth performance, hematology, organ mineral concentration, carcass characteristics and meat quality.
United States: Corn

Yellow numbers indicate the percent each state contributed to the total national production. States not numbered contributed less than 1% to the national total.

Note: The agricultural data used to create the map and crop calendar were obtained from the National Agricultural Statistics Service at: http://www.usda.gov/nass/.

- Major areas combined account for 75% of the total national production.
- Major and minor areas combined account for 99% of the total national production.
- Major and minor areas and state production percentages are based upon averaged NASS county-level and state production data from 2000-2004.

Corn crop calendar for most of the United States

Crop calendar dates are based upon NASS crop progress data from 2000-2004. The field activities and crop development stages illustrated in the crop calendar represent the average time period when national progress advanced from 10 to 90 percent.

USDA World Agricultural Outlook Board
Joint Agricultural Weather Facility
United States: Soybeans

Yellow numbers indicate the percent each state contributed to the total national production. States not numbered contributed less than 1% to the national total.

Note: The agricultural data used to create the map and crop calendar were obtained from the National Agricultural Statistics Service at: http://www.usda.gov/nass/.

- Major areas combined account for 75% of the total national production.
- Major and minor areas combined account for 99% of the total national production.
- Major and minor areas and state production percentages are based upon averaged NASS county-level and state production data from 2000-2004.

Soybean crop calendar for most of the United States

Crop calendar dates are based upon NASS crop progress data from 2000-2004. The field activities and crop development stages illustrated in the crop calendar represent the average time period when national progress advanced from 10 to 90 percent.
Figure 4. Color axis, $L$, $a$, $b$.

Figure 5. Avg. U.S. Slaughter Live Weigh of Pigs by Year, USDA
CHAPTER 2

EFFECT OF LOW ESSENTIAL DIETARY MICROMINERAL SUPPLEMENTATION ON GROWTH PERFORMANCE, HEMATOLICAL STATUS, CARCASS CHARACTERISTICS AND PORK QUALITY ON GROWER-FINISHER SWINE

2.1 Introduction

Formulating cost effective swine diets has used the lowest cost grains available and if nutrients are deficient adding other ingredients. Soybean meal is used to supply crude protein to swine diets. Corn-soybean meal mixtures have a low concentration or availability of the macrominerals Ca and P. Historically, ground limestone, mono or dicalcium phosphate have been added to swine diets which provide highly available sources of Ca and P. However, these sources are impure and contain appreciable amounts of microminerals, particularly Fe and Mn. Therefore, when diets are formulated by this procedure dietary micromineral concentrations are often greater than the NRC requirement, except for Zn and Se.

The NRC (1998) states that the listed essential dietary micromineral requirements take into account the innate concentrations in all dietary ingredients. However, it has been assumed that the bioavailability of the essential microminerals in grains is low and
thus disregarded. It is therefore, commonplace to add microminerals to diets as a safety margin further increasing the dietary concentration of microminerals.

Edmonds and Arentson (2001) reported that pigs fed diets without micromineral supplementation had reduced gain and feed intake but not feed efficiency for a period of 12 weeks, however, there were no differences in carcass characteristics. Conversely, Shelton et al. (2004) reported that grower-finisher pigs fed diets with no micromineral supplementation there were no differences on growth performance, carcass characteristics or pork quality. The aforementioned diets withdrew all micromineral supplementation making it difficult to study the effects of one mineral of interest.

Therefore, the objective was to investigate the effect of Zn, Fe and level of dietary microminerals supplemented to grower-finisher swine on growth performance, hematology, carcass characteristics, and pork quality.

2.2 Materials and Methods

2.2.1 Animal Care and Use

The experimental use of animals and procedures followed were approved by The Ohio State University Animal Care and Use committee.

2.2.2 Animals

Grower-finisher pigs (n=237) were used to evaluate the effects of Zn, Fe, and reduced dietary micromineral supplementation on growth performance, hematology, carcass characteristics and pork quality. Grower pigs with an average initial BW of 24.3 ± 2.3 kg were randomly allotted by weight, sex, and litter to treatments and evaluated through 118.5 ± 5.8 kg. All pigs were progeny of Yorkshire x Landrace sows (Temple
Genetics, Gentryville, IN) mated to PIC line 280 boars (Birchwood Genetics Inc, West Manchester, OH).

2.2.3 Treatment and Diets

Pigs were fed varying levels of dietary essential microminerals (Cu, Fe, Mn and Zn), in three dietary phases. Dietary treatments were: 1) Basal which was a corn-soybean meal based diet with no added microminerals, 2) Basal + micromineral premix at 25% of NRC requirements for grower pigs 3) Basal + micromineral premix at 50% of NRC requirements, 4) Basal + micromineral premix at 100% of NRC requirements, 5) Basal + 25 ppm Zn, 6) Basal + 50 ppm Zn, and 7) Basal + 50 ppm Fe. Only for replicate blocks 5 through 7 was the Basal + 25% NRC diet fed. The 100% NRC premix provided per kg: 3.5 mg Cu, 50 mg Fe, 2 mg Mn and 50 mg Zn. The 50% and 25% of NRC requirement premixes were fed at half and one quarter of the 100% NRC concentrations, respectively. Micromineral premixes were added to the diet at the expense of cornstarch (Table 4).

Diets for the first phase were formulated to contain 0.81% Ca, 0.65% P, 1.20% Lysine (Lys), and 0.23% Methionine (Met). Second phase diets contained 0.81 % Ca, 0.59 % P, 1.10 % Lys, and 1.10 % Met. Third phase diets contained 0.70 % Ca, 0.55 % P, 1.10 % Lys, and 1.10 % Met. Calcium and P levels were supplied from ground limestone and dicalcium phosphate. Supplemental Cu, Fe, Mn, and Zn were fed as mineral proteinates (Bioplex, Alltech, Inc., Nicholasville, KY). All diets in each phase contained Se added at 0.3 ppm as a yeast source, (Sel-Plex, Alltech, Inc., Nicholasville, KY) and all third phase diets contained ractopamine hydrochloride (Paylean, Elanco Animal Health, a division of Eli Lilly and Co., Greenfield, IN) at 10 ppm.
2.2.4 Animal Housing and Sample Collection

Six pigs per pen were used in replicates 1 and 2 and due to availability, 5 pigs per pen for the subsequent replicates. Within replicates the same barrow to gilt ratio was maintained in pens. Pens (1.52 m x 4.22 m) comprised 50% solid concrete floors in the front and 50% slatted floors in the rear of the pen. Pens were separated by metal rod-gates. Pigs had ad libitum access to feed and water via a 3-hole feeder (Smidley, Washington Court House, OH) and a nipple waterer, respectively.

Pig weights and feed disappearance were measured every 2 weeks for growth performance and feed efficiency measurements. When the average pen weight was approximately 55, 80, and 115 kg, three pigs per pen were bled via jugular venipuncture for hemoglobin and hematocrit determination. Blood was drawn into a syringe using 10.2 cm, 18-gauge needles (Cadence, Inc., Cranston, R.I.), then transferred to a 10 ml Vacutainer (Becton, Dickson and Co., Franklin Lakes, N.J.) containing 158 USP units of Sodium Heparin. Blood samples were placed on ice, transported to the laboratory and analyzed the day of collection. Also, when the average replicate pen weight was 55 and 80 kg of BW, dietary phase changes were made.

Hemoglobin concentration was determined by the cyanmethemoglobin method by Crosby et al. (1954) using a spectrophotometer (Spectronic 20 +, model 333182, Thermo Electron Corp., Waltham, MA) set at 540 nm. Hematocrit was determined using the microhematocrit method of Turgeon (2005; Micro-hematocrit capillary tubes and Hemato-seal tube sealing compound, Fisher Scientific, Pittsburgh, PA). Capillary tubes
were filled with blood and centrifugated (14,000 x g for 3 min at room temp.) using a micro-capillary centrifuge (model MB, International Equipment Co., Boston, MA).

At approximately 115 kg of BW, 3 pigs per pen (equal distribution of gender) that weighed close to the average pen weight were chosen to be slaughtered at The Ohio State University Meat Science Laboratory. At 0900, pigs were weight off test and were tattooed for identification, at 1500; pigs were transported 13.0 km to the university meat lab and held in lairage for approximately 15 h. At 0600 the next day immediately before being stunned, pigs were weighed to obtain a preslaughter weight. Pigs were electrically stunned and exsanguinated. Hot carcass weight (HCW) was measured prior to carcasses being stored in a cooler for 24 h.

2.2.5 Carcass Characteristics and Meat Quality Measurements

At 24 h postmortem, carcass backfat and loin muscle area measurements were collected between the 10\textsuperscript{th} and 11\textsuperscript{th} rib on the right side of each of the carcasses. The HCW, backfat, and loin muscle area were then placed into an equation according to NPPC (2000) to determine the percent of fat free lean of each carcass. A portion of the loin was removed from the measured side of the carcass and de-boned. Objective color measurements (L*, a* and b*) were collected using a Minolta Colorimeter (CR-310, 50 mm diameter orifice, 10\textsuperscript{°} standard observer, D\textsubscript{65} light source, calibrated against a white tile; Minolta Company, Ramsey, New Jersey). Subjective color, marbling, firmness, and wetness measurements (NPPC, 2000) were evaluated by the same trained evaluator on the exposed surface of each loin following a 30 minute bloom.
Ultimate pH (taken 24 h post mortem) was taken using a pH meter (H198140 Hanna Instruments, Italy) with a glass-tipped electrode placed 1 cm under the exposed loin surface. Moisture loss analysis was assessed on a sample of the loin which was weighed, placed on a fish hook, suspended in a zip lock bag for 48 hours at 4°C, and reweighed following the procedure by Apple et al. (2000). Loin intramuscular fat (IMF) percentage was determined using the Soxlet procedure (method 954.02; AOAC, 2012), whereby samples were extracted of fat with petroleum ether as the solvent, cyclically for 16 h. Samples were allowed to air-dry before reweighing. The lost weight equaled the amount of fat and was divided by the loin’s wet weight for a percent of IMF.

A 2.5 cm thick chop was cut from the anterior portion of the loin, corresponding to the 9th through 10th ribs, chops from all loins were vacuum sealed, and placed in a cooler for 7 d and then frozen at -20°C. Thawed loin chops were cooked on a clam-style cooker (George Forman Grill, Applica Consumer Products, Bedford Heights, OH) to an internal temperature of 71.1°C. The internal temperature was monitored using copper constant thermocouples (Digi-sense, K-type probe, 30.48 cm x 1.016 cm diameter, Code 93631-11 or equivalent) inserted into the center of each chop. After chops were allowed to cool a drill press was used to obtain 6 to 7, 1.27 cm in diameter cores parallel to the muscle fiber orientation for Warner-Bratzler Shear Force (WBSF) assessment. Shear force was determined using a Warner-Bratzler shearing device (Model TA TX\textsuperscript{plus}, head speed of 3.33 mm/sec), recording maximum force. The average WBSF of all cores from a chop was used in analysis.
2.2.6 Statistical Analysis

Data were analyzed as a randomized complete block by a one-way ANOVA using the MIXED procedure of SAS (SAS Inst., Inc., Cary, N.C.). The pen served as the experimental unit. Serial measurements of BW, ADG, ADFI, G:F, Hb, and Hct were analyzed as repeated measures. The model was as follows: \( Y_{ijk} = \mu + r_i + T_j + P_k + TP_{jk} + e_{ijk} \), where \( Y_{ijk} \) is the continuous dependent variable, \( \mu \) is the population mean, \( r_i \) is the random effect of the ith block (replicate), \( T_j \) was the fixed effect of jth dietary treatment, \( P_k \) was the fixed effect of the kth phase, \( TP_{jk} \) was the interaction of jth treatment and kth phase, and \( e_{ijk} \) the residual error. For non-serial measurements the model was as follows: \( Y_i = \mu + r_i + T_j + e_{ij} \), where \( Y_i \) is the continuous dependent variable, \( \mu \) the population mean, \( r_i \) is the random effect of the ith block (replicate), \( T_j \) the fixed effect of the jth treatment and \( e_{ij} \) residual error. A Priori single-degree of freedom polynomial contrasts evaluated the NRC levels of all dietary microminerals, the level of added Zn, the level of Fe and the effects of Zn without or in combination with all other microminerals. Contrast coefficients for unequal spacing of mineral levels were determined by PROC IML function of SAS. Significance was established at \( P < 0.05 \) and a trend at \( P < 0.10 \). Least squares means are presented in tabular form.

2.3 Results

2.3.1 Dietary Analysis

Chemical analysis of the 3 basal diets for each phase and the NRC (1998) microminerals requirements for the grower-finisher pig is presented in Table 5. All essential microminerals, except Zn and Se when expressed on a total basis met the pig’s
requirement for these nutrients. It is clear, however, that their bioavailability is unknown. Because Se’s effects are known (Mahan et. al. 1999) this element was added to all diets at 0.3 mg/kg of diet.

2.3.2 Growth Performance

Dietary treatments had no effect on the weight of pigs as well as ADG, ADFI and G:F during any of the 3 dietary phases as well as the overall grower-finisher period (Table 6).

2.3.3 Hematological Parameters

Hemoglobin concentration and Hct volume were not affected by dietary treatment in any of the dietary phases. Numerically, however the concentration of Hb and Hct volume was greatest for pigs fed the diet supplemented with 50 ppm added Fe during the third phase (Table 7). The average concentration of Hb and Hct over the three bleedings was also not affected by dietary treatment.

2.3.4 Carcass Characteristics

There were no effects of dietary treatment on HCW, backfat, loin muscle area, dressing percent or percentage of fat free lean index measurements of pig carcasses (Table 8).

2.3.5 Meat Quality

Ultimate pH and objectives color measurements (L*, a*, and b*) of pork loins did not differ due to dietary treatment. Similarly, subjective color measurements, based on the American color scale, also were found to not differ due to dietary treatment (Table 8). Dietary treatment had no effect on the chemical IMF content and measurement of
subjective loin marbling in loins from pigs. Firmness of loins decreased cubically (P < 0.05) as the level of all microminerals increased in the diet, however, increased when pigs were fed the diet with added Fe compared to the basal diet. Loins from pigs fed the diet with supplemental Fe had a greater wetness score (P < 0.05) compared to the basal diet; however, moisture loss, as a percent of the weight, was not different among the dietary treatments.

2.4 Discussion

A chemical analysis of the basal diets indicated that the Cu, Mn, and Fe concentrations are greater than the requirements listed by the NRC (1998) in a typical corn-soybean meal based diet when limestone and dicalcium phosphate serve as highly available Ca and P sources (Table 5) for 20 to 120 kg BW pigs. The Fe level in the diet decreased slightly in the third dietary phase, in response to the level of both limestone and dicalcium phosphate decreasing in these diets. The analysis indicates that Zn may be the most limiting micromineral in the basal diet as the dietary concentration did not meet the requirement outlined by the NRC (1998).

The claim then could be made that Cu, Fe, and Mn do not need to be supplemented to grower-finisher pig diets because the NRC (1998) iterates that the essential micromineral requirements of swine at any stage of production take into account the innate concentration of all feedstuffs as well as any exogenous mineral supplementation as a premix. In contrast, it has repeatedly been reported that the mineral concentration of a diet not fortified with Fe, Zn, and Se will not meet the requirement of the newly weaned piglet (Smith et al., 1958; Mahan, 1985; Rincker et al., 2004) as
measured by body weight gain, hematological measurements or select organ mineral concentrations. Although the bioavailability of minerals in grains is low or unknown, because the grower-finisher pig consumes large quantities of feed it may be possible that an unfortified micromineral diet will still meet the requirement of the grower-finisher pig because of greater consumption of available minerals.

Body weight gain and feed efficiency are the primary economic factors influencing industry profit potential and thus are widely employed when attempting to understand bioavailability of nutrients and dietary requirements. Body weight gain was not affected by dietary treatment during any of the three dietary phases or the overall trial. These results agree with Patience and Gillis (1995) and Mavromichalis et al. (1999) where pigs were fed a non-supplemented micromineral diet for 4 to 5 weeks prior to slaughter in which gain was not affected. In contrast, Edmonds and Arentson (2001) reported ADG was increased during the final 6 weeks of life when pigs were fed diets supplemented with microminerals and vitamins; however, for the entire 12 week study ADG, was not different between pigs fed a diet devoid and supplemented with a micromineral and vitamin premix, which is in agreement with our results. It may be that removal of the vitamin premix limited pig growth during the later stage of the experiment by Edmonds and Arentson (2001) because macromineral sources provide highly available sources of minerals like Fe and Mn, but not vitamins and therefore, body stores of vitamins may have been depleted and limited growth, similar to reports by Shaw et al. (2002).
In the present experiment reducing the level or removing some microminerals supplemented to diets did not affect feed intake. These results are similar to reports from Patience and Gillis (1995) in which there were no difference in feed intake and opposite of Mavromichalis et al. (1999) where diets with no micromineral supplementation resulted in greater feed intake during the last 4 weeks prior to slaughter. With no differences in BW gain and feed intake there were therefore, no differences in feed efficiency among pigs fed dietary treatments. These results are suggestive of the indigenous content of the essential microminerals in a corn-soybean meal diet with highly available macromineral sources being sufficient to maximize growth while being utilized efficiently by the pig.

In nursery pigs it has been established that Hb concentration and Hct volume increase in response to increasing levels of added dietary Fe (Yu et al., 2000; Rincker et al. 2004) even without observing a weight gain response. This finding is reflective of weight gain being one of the last indicators of Fe deficiency (Amine et al. 1972), particularly if pigs had adequate Fe stores prior to weaning (Rincker et al. 2004). Few reports have investigated the hematological status of grower and/ or finisher pigs. Since there were no differences in the concentration of Hb or Hct volume our results are indicative that a non-Fe supplemented diet has enough available Fe to meet the requirement for growth and Hb synthesis. While the bioavailability of Fe may in fact be different in the basal diet when compared to diets with supplemental Fe there are two possible reasons for this biological response: 1) homeostatic controls may down regulate facilitated absorption of Fe by pigs in these diets in order to reduce Fe absorption, or 2)
enough available Fe is absorbed but excess are not incorporated into hemoglobin. Results from the present study demonstrated that Hb concentration and Hct volume increased during each dietary phase. This indicates that the pig requires more hemoglobin in order to meet the demands of having a greater body mass. In nursery pigs it has been reported that Hb and Hct concentrations either decrease (Martin et al., 2011) or decrease and subsequently increase (Rincker et al. 2004; Jolliff and Mahan, 2011) throughout the course of the nursery period. As suggested by Rincker et al. (2004), dietary Fe fed to nursery pigs is unable to maintain Fe stores, as the pig grows. The inability to maintain Fe body stores will lead to decreased Hb levels however; this appears to be reversed during the later stages of the nursery period as feed intake increases which supports the increase in Hb concentration and Hct volume by dietary phase reported here for grower-finisher pigs as their feed intake increased by phase.

The diets used in this experiment contained the enzyme phytase, which liberates inorganic P from phytate in grains increasing its availability to pigs. Phytase has been shown to improve the availability of Zn and Fe in addition to P (Adeola et al. 1995; Stahl et al. 1999). In the swine industry it is commonplace to add phytase to swine diets, thus we attempted to simulate commercial conditions, by adding the enzyme. Therefore, addition of phytase to swine diets may readily make more Fe available in corn and soybean meal to meet the requirement for growth as well as Hb synthesis.

Few studies have investigated Zn during the growing and finishing stages. Growth and feed efficiency were not affected by source or level of Zn (Wedekind et al. 1994), which are in agreement with results from the present experiment. Parakaratosis has often
been used an indicator of Zn status of pigs. Reports by Ritchie et al. (1963) and Martin et al. (2011) demonstrated that as pigs fed a non-supplemented Zn diets during the nursery period recovered slightly from the deficiency by the early grower stage, likely from increased Zn consumption due to increased feed intake. Because phytase was added to these diets, it could readily make enough Zn available from the indigenous content of the basal diet feed ingredients to support proper growth of grower and finisher pigs without any detrimental effects on pig carcasses or pork quality.

Unlike cattle, hogs are not sold on a grid system which takes into account meat quality, thus swine producers profit potential is determined by the amount of saleable product, i.e. weight of carcasses and percent of fat free lean. There are currently few incentives by producers to improve pork quality while maintaining economic viability when raising hogs.

The results reported herein, when varying supplemental levels of all microminerals, Zn, or Fe were fed to pigs, did not have any effects on backfat, loin muscle area, dressing percentage and fat free lean index. This is similar to results reported by Patience and Gillis, 1995; Mavromichalis et al. 1999; Edmonds and Arentson, 2001; Shelton et al. 2004. When graded levels of Fe from 0 to 150 ppm of diet were fed to grower-finisher pigs, there was a tendency for backfat at the 10th rib to increase which inversely affected fat free lean index (Apple et al., 2007), however this may have resulted due to a greater response at the highest level (150 ppm) and our results would not support this at a lower level of supplemental dietary Fe.
The pH of meat is an important characteristic when assessing the quality of pork as it can affect color, water holding capacity, and firmness. The pH is a measurement of acidity, in meat this is caused by an increase in lactic acid synthesis in myofibers post-mortem. Normal pH values of pork 24 h post-mortem should be between 5.4 and 5.7. A rapid rate and extent of pH decline causes proteins to be denatured causing pork to become pale, soft, and exudative or PSE. PSE pork is of poor quality and consumer acceptance. Results from the present experiment indicate that Zn, Fe or the level of all microminerals will not affect pork pH, which support similar results from Mavromichalis et al. (1999), Shelton et al. (2004), and Apple et al. (2007).

The objective color assessment (L*, a*, b*) of loins from pigs remained the same between dietary treatments, these results are in agreement with others. Shelton et al. (2004) reported pigs fed diets devoid of microminerals with or without phytase did not affect L*, a* or b* values, conversely low Ca and available P with phytase did lower the L* value toward a less desirable pale color. With the level of Ca and P supplied by limestone and dicalcium phosphate in our diets color was not be affected. O’Sullivan et al. (2001) reported that increasing dietary Fe fed to grower and finisher swine for 13 weeks prior to slaughter had greater amounts of muscle Fe. Iron as oxymyoglobin in meat has a red color and as it is oxidized turns brown in color. Feeding pigs 3000 ppm of supplemental FeSO₄ caused meat to have a greater brown color and a lower a* or red color. Diets from the present experiment did not contain Fe at the level in these diets by O’Sullivan et al. (2001). After a week in retail display, Fe supplementation at levels from 0 to 150 did not alter color scores between treatments, which is in agreement with our
results at lower levels of supplemental Fe 24 h. after slaughter. Sawyer et al. (2007) reported that MnSO$_4$ was responsible for a greater red (a*) color as well as American color score compared with when Availa-Mn an amino acid chelate was fed. However, Mn was not fed at that great of a level in our diets, and therefore low levels of Mn did not cause a change in color scores.

When 50 ppm of Fe alone was added to pigs diets there was an increase in the subjective firmness and wetness measurements. Previous studies have reported no difference with increasing supplemental Fe (Apple et al. 2007). The number of studies reporting loin firmness and wetness results when evaluating dietary microminerals is limited. The results reported here are based on a revised scale from 1 to 3 separating firmness and wetness (NPPC, 2000), while older scales combined these variables on a 5 point scale. In general the results here are in the middle of the scale which is similar to reports by Apple et al. (2007) and Sawyer et al. (2007).

Warner-Bratzler shear force measures the amount of force it takes to cut through a cooked piece of meat. This is an objective measurement simulating how easy or tough it would be to chew a cooked piece of meat. Although reports by Shelton et al. (2004) on shear force were higher than reported here, Mavromichalis et al. (1999) reported results similar to those from the present experiment and neither in support of our results reducing microminerals had no effect when minerals where not fed for the grower and finisher periods.

In conclusion, results from this study demonstrate that a corn-soybean meal diet containing, limestone, dicalcium phosphate and phytase with no supplementary
microminerals, was able to meet the requirements of the pig for BW gain, Hb, and Hct. Feeding a basal level of minerals in diets has no deleterious effects on carcass traits or muscle quality, although loins from pigs fed supplemental Fe had improved loin firmness and wetness scores.

2.5 Implications

The availability of microminerals in feed ingredients in a basal non-supplemented diet is greater than what is currently recognized by nutritionists. When formulating swine diets, by not supplementing grower-finisher swine diets with the essential microminerals, swine producers may be able to reduce dietary costs while maintaining pig growth and efficient feed utilization and therefore, increase profit potential.
### Table 4. Composition of Basal diets by phase (% as fed basis)

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Phase I 1</th>
<th>Phase II</th>
<th>Phase III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>59.90</td>
<td>63.65</td>
<td>63.95</td>
</tr>
<tr>
<td>Soybean meal, 48% CP</td>
<td>29.50</td>
<td>25.80</td>
<td>25.80</td>
</tr>
<tr>
<td>Corn Starch</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Tallow</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.50</td>
<td>1.30</td>
<td>1.05</td>
</tr>
<tr>
<td>Limestone</td>
<td>1.00</td>
<td>1.15</td>
<td>1.00</td>
</tr>
<tr>
<td>Lysine HCl</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>DL-Methionine</td>
<td>0.10</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Salt</td>
<td>0.30</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Sel-Plex 3</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Vitamin Premix</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Bioplex Fe ± 8</td>
<td>±</td>
<td>±</td>
<td>±</td>
</tr>
<tr>
<td>Bioplex Zn ± ±</td>
<td>±</td>
<td>±</td>
<td>±</td>
</tr>
<tr>
<td>Bioplex microminerals ± ± ±</td>
<td>±</td>
<td>±</td>
<td>±</td>
</tr>
<tr>
<td>Phytase 5  ±</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Ractopamine 6</td>
<td>0.00</td>
<td>0.00</td>
<td>0.10</td>
</tr>
<tr>
<td>Antibiotic 7 ±</td>
<td>0.05</td>
<td>0.05</td>
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</tr>
</tbody>
</table>

Calculated Nutrient Content

<table>
<thead>
<tr>
<th></th>
<th>ME, Kcal/ kg</th>
<th>Total Lysine, %</th>
<th>Ca, %</th>
<th>P, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3515</td>
<td>1.20</td>
<td>0.81</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>3518</td>
<td>1.10</td>
<td>0.81</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>3531</td>
<td>1.10</td>
<td>0.70</td>
<td>0.55</td>
</tr>
</tbody>
</table>

1Phase I diets were fed from approx. 20 kg of BW until 50 kg of BW, phase II diets were fed from 50 kg to 82 kg of BW and Phase III diets were fed from 82 kg to approx. 115 kg of BW.

2Provided the following per kg of diet: 3.5 mg of Cu; and 2 mg of Mn as Bioplex (Alltech, Inc., Nicholasville, KY) at the 100% of NRC requirement. Other diets contained 50 and 25% of NRC requirements.

3Supplied 0.30 mg/ kg of diet of Se as a yeast source (Sel-Plex; Alltech Inc, Nicholasville, KY).

4Supplied 1,500 IU of vitamin A (acetate); 300 IU of vitamin D₃; 15 IU of vitamin E (DL-α-tocopheryl acetate); 0.50 mg of vitamin K (menadione); 10 mg of riboflavin; 13 mg of D₃-pantothenic acid; 10 mg of niacin; 0.4 mg of folacin; 1 mg of D₃-biotin; and 15 µg of vitamin B₁₂ per kg of diet.

5Supplied of units 1000 FTU per kg of diet as RONOZYME (DSM, Netherlands)

6Supplied Ractopamine Hydrochloride at 10 ppm (Paylean, Elanco, Inc, Greenfield, IN)

7Supplied 220 g/ kg of premix as Tylan 100 (Elanco, Inc, Greenfield, IN)

8Designateds that the percentage changed according to treatment
Table 5. Analyzed micromineral concentration (ppm) of Basal diets by phase\textsuperscript{1,2}

<table>
<thead>
<tr>
<th>Item, ppm</th>
<th>NRC</th>
<th>Phase I</th>
<th>Phase II</th>
<th>Phase III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>3.5</td>
<td>6.</td>
<td>9.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Fe</td>
<td>50</td>
<td>200</td>
<td>203</td>
<td>186</td>
</tr>
<tr>
<td>Mn</td>
<td>2</td>
<td>20.21</td>
<td>33.66</td>
<td>17.85</td>
</tr>
<tr>
<td>Zn</td>
<td>50</td>
<td>35.42</td>
<td>58.53</td>
<td>36.47</td>
</tr>
</tbody>
</table>

\textsuperscript{1}Diets for each phase were analyzed for micromineral concentration

\textsuperscript{2}Se was added to all diets at 0.3 ppm
Table 6. Effects of reduced dietary micromineral supplementation on growth performance.

<table>
<thead>
<tr>
<th>Item</th>
<th>Basal (0 %)</th>
<th>25%</th>
<th>50%</th>
<th>100%</th>
<th>25 ppm</th>
<th>50 ppm</th>
<th>50 SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pens</td>
<td>7</td>
<td>3</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
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</tr>
<tr>
<td>No. Pigs</td>
<td>37</td>
<td>15</td>
<td>37</td>
<td>37</td>
<td>37</td>
<td>37</td>
<td>37</td>
<td>-</td>
</tr>
<tr>
<td>Age, birth to market, d</td>
<td>144.2</td>
<td>144.4</td>
<td>144.3</td>
<td>143.7</td>
<td>143.9</td>
<td>143.9</td>
<td>143.8</td>
<td>2.9</td>
</tr>
<tr>
<td>Initial Wt, kg(^{1,2,3,4})</td>
<td>24.07</td>
<td>24.69</td>
<td>24.53</td>
<td>23.93</td>
<td>24.31</td>
<td>24.74</td>
<td>24.61</td>
<td>0.84</td>
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<tr>
<td>Phase I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight, kg(^{3,4,5,6})</td>
<td>54.00</td>
<td>57.02</td>
<td>54.73</td>
<td>54.24</td>
<td>55.19</td>
<td>55.70</td>
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<td>ADFI, kg(^{1,2,3,4})</td>
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<td>118.76</td>
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<td>118.81</td>
<td>119.97</td>
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<td>1.26</td>
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<td>0.37</td>
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<td>ADG, kg(^{1,2,3,4})</td>
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<td>ADFI, kg(^{1,2,3,4})</td>
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<td>G:F(^{2,3,5,7})</td>
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<td>0.42</td>
<td>0.41</td>
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<td>0.43</td>
<td>0.41</td>
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\(^1\)Effect of polynomial contrast for NRC levels not significant \(P > 0.10\)
\(^2\)Effect of polynomial contrast for Zn level not significant \(P > 0.10\)
\(^3\)Basal vs. 50 ppm Fe not significant \(P > 0.10\)
\(^4\)25 ppm + 50 ppm Zn vs. 50% NRC + 100% NRC not significant \(P > 0.10\)
\(^5\)Effect of polynomial contrast for NRC \(P < 0.05\)
\(^6\)Effect of polynomial contrast for Zn level \(P < 0.05\)
\(^7\)25 ppm + 50ppm Zn vs. 50% NRC + 100% NRC \(P < 0.05\)
Table 7. Effect of low dietary micromineral supplementation on hemoglobin and hematocrit.

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<thead>
<tr>
<th>Item</th>
<th>NRC</th>
<th>Zn</th>
<th>Fe</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basal (0 %)</td>
<td>25 %</td>
<td>50 %</td>
<td>100 %</td>
<td>25 ppm</td>
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<td>Hemoglobin, g/dl</td>
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<td>13.3</td>
<td>12.3</td>
<td>12.5</td>
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<td>Phase II</td>
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<td>13.2</td>
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<td>Avg.</td>
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<td>13.1</td>
<td>12.8</td>
<td>12.8</td>
<td>13.1</td>
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<td>Hematocrit, %</td>
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<tr>
<td>Phase I</td>
<td>40.3</td>
<td>39.5</td>
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<td>39.3</td>
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<td>Phase II</td>
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<tr>
<td>Phase III</td>
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<td>41.8</td>
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<td>40.6</td>
<td>39.5</td>
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1 Effect of polynomial contrast for NRC levels not significant P > 0.10
2 Effect of polynomial contrast for Zn level not significant P > 0.10
3 Basal vs. 50 ppm Fe not significant P > 0.10
4 25 ppm + 50 ppm Zn vs. 50% NRC + 100% NRC not significant P > 0.10
5 Effect of polynomial contrast for Zn level P < 0.05
Table 8. Effects of reduced micromineral supplementation on Carcass Traits and Meat Quality.

<table>
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<tr>
<th>Item</th>
<th>No. of Pig</th>
<th>Hot Carcass Weight, kg</th>
<th>Backfat, mm</th>
<th>Loin Muscle Area, cm²</th>
<th>Fat Free Lean, %</th>
<th>Dressing Percent, %</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>Color</th>
<th>Marbling</th>
<th>Firmness</th>
<th>Wetness</th>
<th>IMF, %</th>
<th>pH, 24 h</th>
<th>Moisture Loss, %</th>
<th>Shear Force, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatments</td>
<td>Basal (0%)</td>
<td>25 %</td>
<td>50 %</td>
<td>100 %</td>
<td>25</td>
<td>50</td>
<td>50</td>
<td>SEM</td>
<td>P-value</td>
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<td>50</td>
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<td>Loin Muscle Area, cm²</td>
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<td>46.89</td>
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<td>Dressing Percent, %</td>
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1Effect of polynomial contrast for NRC levels not significant P > 0.10
2Effect of polynomial contrast for Zn level not significant P > 0.10
3Basal vs. 50 ppm Fe not significant P > 0.10
425 ppm Zn + 50 ppm Zn vs. 50% NRC + 100% NRC not significant P > 0.10
5Effect of polynomial contrast for NRC P < 0.05
6Effect of polynomial contrast for Zn level P < 0.05
7Basal vs. 50 ppm Fe P < 0.05
LITERATURE CITED


Mahan, D. C., T. R. Cline, and B Richert. 1999 Effects of dietary levels of selenium-enriched yeast and sodium selenite as selenium sources fed to growing-finishing pigs on performance, tissue selenium, serum glutathione peroxidase activity, carcass characteristics, and loin quality. J. Anim. Sci. 77:2172-2179


