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A mineral survey of Louisiana beef cow/calf production systems

Kyle Austin Guidry
Louisiana State University and Agricultural and Mechanical College

A MINERAL SURVEY OF LOUISIANA BEEF COW/CALF PRODUCTION SYSTEMS

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"*If you can, everything is possible to those who have faith*" (Mark 9:23)

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LIST OF ABBREVIATIONS

BRD……...……Bovine Respiratory Disease

Ca…….…….Calcium

CE……..…….Central

Cl...……...Chloride

Co…….……...Cobalt

Cu…….…….....Copper

DM……..…….Dry Matter

FP……...……..Florida parishes

I……...Iodine

Fe…..……..…….Iron

Mg……...……Magnesium

Mn……...…Manganese

Mo……Molybdenum

NE……...……Northeast

NW……...…….Northwest

P……..…Phosphorus

K……Potassium

Se……Selenium

Na……..……Sodium

SC……...……..South central

SE…….……..Southeast

SW……...……..Southwest

S……...…Sulfur

Zn……...Zinc

ABSTRACT

The purpose of this research was to determine the state and regional mineral status of Louisiana forages and beef cattle. Louisiana beef cattle operations (n = 25) were sampled and divided into seven geographical regions, including the northwest (NW), northeast (NE), central (CE), southwest (SW), south central (SC), Florida parishes (FP) and southeast (SE) regions. Over a two year period, water and soil samples were collected from each operation annually, forage samples were collected quarterly in Aug to Sep, Nov to Dec, Feb to Mar and May to June and bovine serum samples were collected twice annually in the fall and spring seasons. The highest ($P < 0.05$) average regional water K and S concentrations were observed in the SE region and water Ca and Mg concentrations were the highest ($P < 0.05$) in the NE, CE and SE regions. However, all water mineral concentrations, with exception of Na, were lower than the reported upper desired levels considered safe for livestock consumption (Socha et al., 2003). Similar to water, soil Ca, Mg and K concentrations in our study, were higher ($P < 0.05$) in the SE compared to all other regions. Soil Cu concentrations were below critical levels in the CE region and all soil Zn concentrations, except the SE region, were lower than reported critical levels indicating soil deficiency. The average forage concentration for each mineral were: Ca (0.42%), P (0.28%), Mg (0.21%), K (1.83%), Na (0.10%), S (0.32%), Cu (8.12 ppm), Fe (323.46 ppm), Mn (254.85 ppm) and Zn (41.29 ppm). In addition, only mean forage Cu concentrations were lower than minimum requirements and regional forage K (NW region), Mg (FP region), Na (CE region) and S (NW and SE regions) concentrations were higher ($P < 0.05$) than other regions. The average regional serum K concentration in the NE region was higher ($P < 0.05$) than all other regions. Average bovine serum mineral concentrations in Louisiana were: Ca (9.02 mg/100 ml), P (13.62 mg/100 ml), Mg (1.92 mg/100 ml), K (21.66 mg/100 ml), Na (303.30 mg/100 ml), S (103.31

mg/100 ml), Cu (0.63 µg/ml), Fe (7.44 µg/ml), Zn (1.28 µg/ml), Mn (8.08 ng/ml) and Se (64.48 ng/ml). Furthermore, of these minerals, serum Mg, Na, Cu and Mn concentrations were lower than critical levels, indicative of deficiency.

CHAPTER I

INTRODUCTION

Forage production is an essential factor in relation to beef cattle nutrition for cow/calf operations. Beef cattle typically derive 85% of their diet from some type of forage, leaving 15% to be derived from supplements and (or) concentrate diets (Greene, 2000). However, commonly grazed forages can be deficient in several essential minerals required by ruminants to maintain adequate health (Kappel et al., 1985; Greene, 1997). Therefore, surveys are conducted to assess the mineral status of forages, cattle, soil and water in order to determine the presence of a mineral deficiency or toxicity.

Mineral surveys have been conducted both internationally and in the United States to determine differences in mineral status, and have shown differences between states and differences for regions within states. A majority of forage and cattle mineral surveys have reported P and Zn (Gizachew et al., 2002; Ndebele et al., 2005; Almaraz et al., 2007; Salih et al., 1983 and Greene, 1997), Cu (Greene, 1997) and Na (Kiatoko et al., 1982) deficiencies. Mathis and Sawyer (2004) reported multiple deficient mineral concentrations in forages in a survey conducted in New Mexico. This survey reported the percent of forage samples that contain mineral concentrations lower than the requirements presented by the NRC (2000) for gestating and lactating cattle. Forage P (100%), Mg (97%) and Na (93%) samples were reported deficient for lactating cows and forage S (92%) and Zn (77%) samples were reported deficient for all beef cattle. An Arkansas survey examined the percentage forage samples that were deficient in minerals (Davis et al., 2002). Forage Se, Cu and Zn concentrations were deficient representing 62, 52, and 41% of samples, respectively. Similarly, Na was the most deficient with less than 10% of samples considered as adequate (Davis et al., 2002). In addition, Salih et al. (1983)

reported deficient P, Zn, and Se concentrations in 40, 46.7, and 100% of serum samples from various herds located in four regions of Florida.

Louisiana was excluded from the most recent comprehensive forage analysis from cow/calf herds in 18 states in the United States (Corah and Dargatz, 1996). Likewise, Dargatz and Ross (1996) conducted a survey of blood Se concentrations in cattle on 253 cow-calf operations in 18 states excluding Louisiana. However, in Louisiana Brown et al. (1988) surveyed forage samples collected from dairy operations. Unfortunately, results in this study were skewed as most samples were collected from cattle operations in close proximity to the research station. Therefore the mineral status of Louisiana cattle and their forages are largely unknown. Thus, the objective of this research was to assess the mineral status of Louisiana beef cattle and forages. Obtaining useful data will allow Louisiana beef cattle producers to more effectively design mineral supplementation programs using derived information.

CHAPTER II

LITERATURE REVIEW

Minerals in Nutrition

The importance of mineral nutrition in the health and well-being of animals and humans has been known for centuries, though individual elements involved were generally unknown (Ammerman et al., 1983). Research has indicated that macro-minerals such as Ca, P, K, Na, Cl, Mg and S are essential in animal diets in large concentrations. Minerals known as micro or trace minerals are also required in the diet, however in smaller concentrations; these include Fe, I, Cu, Co, Se, Zn and Mn (Ammerman et al., 1983). Indentifying cattle mineral status and meeting the NRC (2000) gestation and lactation beef cattle requirements are vital to maintaining health and at optimum concentrations can improve fertility, immunity and overall performance (Gaylean et al., 1999). Individual minerals are responsible for multiple functions in the body and interact with one another to perform various actions. Often, increased concentrations of certain minerals have negative impacts on other minerals by binding into indigestible compounds and decreasing availability. For example, increased concentrations of Mo, S, and Fe increase the requirements of other minerals such as Cu (Greene, 1997; Underwood and Suttle, 2001). Potassium is another antagonist mineral which causes increased Mg requirements (Greene et al., 1997). Therefore, dietary mineral concentrations must be at satisfactory levels in order to achieve maximum utilization in the body.

Calcium is the most abundant mineral in the body and primarily functions as a component of the skeletal system. It is also involved in vital functions such as blood clotting, transmission of nerve impulses, muscle contractions and cardiac regulation (NRC, 2000). Judson and McFarlane (1998) reported that some feedstuffs may not provide adequate Ca concentrations

to beef cattle. However, most forages are a good source of Ca, enough to meet the requirements of grazing beef cattle, especially cattle grazing leguminous species (Underwood and Suttle, 2001). Due to the large Ca stores in bone and the body's tight regulation of blood Ca, deficiencies are not common (NRC, 2000). However, an imbalance of major cations and anions in the diet may predispose lactating cattle to hypocalcemia (Judson and McFarlane, 1998). Hypocalcemia also known as milk fever or parturient paresis occurs when circulating serum Ca levels become depleted. This causes the mobilization of Ca from bone to meet lactation requirements in the body following parturition. Symptoms include listlessness, muscle weakness, rumen stasis and loss of consciousness resulting in death (Underwood and Suttle, 2001). Feeding a low Ca diet prior to parturition can increase endocrine activity and prepare the cow for increased Ca demand following parturition. Jorgensen (1973) reported cattle fed pre-parturient diets with Ca concentrations from 100 to125 g/d had a lower occurrence of milk fever than those fed diets at higher Ca levels.

Phosphorus is vital for various functions in the body, including cell growth, differentiation as a component of RNA and DNA and is responsible for the formation of the organic bone matrix (NRC, 2000). However, 80% of P in the body is found in bones and teeth with the remainder in soft tissue. Phosphorus is often mentioned in conjunction with Ca due to their function in bone formation and with hydroxyapatite (Underwood and Suttle, 2001). Additionally, a dietary Ca to P ratio of 1:1 to 2:1 has commonly been viewed as acceptable; however the NRC (2000) reports similar performance with ratios ranging from 1:1 to 7:1. Nonetheless, forage P deficiencies are common, indicated by previous research (Kiatoko et al., 1982, Salih et al., 1983 and Mathis and Sawyer, 2004). However, most P-fertilized grasses will provide adequate P concentrations for gestating and lactating beef cattle (Greene, 1997).

Magnesium is known to activate more than 300 enzymes in the body (Wacker, 1980). When Mg is severely deficient, grass tetany, a common problem in early lactating cattle grazing lush pastures may occur (Judson and McFarlane, 1998). When advanced, grass tetany causes paralysis, severe convulsions and unconsciousness resulting in death (Underwood and Suttle, 2001). High dietary Ca, P and K levels have been shown to adversely affect Mg absorption by forming insoluble salts (P and K) or competing for the same absorption sites (Ca) in the small intestine (McDowell, 2003). Potassium is most commonly associated with reduced Mg absorption. Therefore, feeds high in K increase Mg requirement, increasing the probability of cows developing grass tetany (unless Mg is supplemented). On the other hand, K plays an important role in acid-base and water balance, osmotic pressure and muscle contractions. Severe K deficiency is unlikely in ruminants because forages contain more than adequate concentrations of K, usually ranging from 1 to 4% of DM in the diet (NRC, 2000).

In extracellular fluid, Na is the major cation and Cl is the major anion, and both are most known for maintaining osmotic pressure, and regulating water and acid-base balance (Underwood and Suttle, 2001). Ruminants have a natural craving for common salt (Na and Cl) and have been shown going to great lengths to consume salt even if it is not offered (McDowell, 2003). Forages vary considerably in Na while cereal grains and oilseed meals are usually inadequate for beef cattle (NRC, 2000). Though Na concentration in feedstuffs is variable, the mineral is readily available and inexpensive to supplement.

In ruminants, S is an important component of amino acids such as methionine, cysteine and cystine as well as two B-vitamins, thiamin and biotin (NRC, 2000). Sulfur concentrations vary widely for forages as well as crops and feedstuffs (Underwood and Suttle, 2001). However, with the exception of low S forages, feedstuffs containing considerable amounts of protein are

normally sufficient in meeting the S requirement of rumen microbes and does need to be supplemented (McDowell, 2003). Though S requirements are often met, negative impacts can occur with increased S levels. Toxic levels of S, especially in drinking water (> 4,000 mg/L) and supplements (> 0.40% of DM) may induce Cu deficiency (Underwood and Suttle, 2001) as well as retard growth rate and considerably reduce feed intake (Kandylis, 1984).

Copper is essential in the body as an enzyme component such as lysyl oxidase and superoxide dismutase (SOD), though it is required in small amounts in the body (McDowell, 2003). Copper concentrations in some forage do not meet ruminants' dietary requirements and also vary within plant species and can be affected by various factors. For example, Dennis et al. (1998) reported tall fescue infected with endophyte fungus (*Neotyphodium coenophialum*) had lower Cu concentrations than endophyte free tall fescue (2.8 vs.3.4 ppm). Increased Mo, S, and Fe concentrations have the potential to decrease Cu availability and therefore increase the mineral's requirement and (or) occurrence of deficiency (Underwood and Suttle, 2001). An ideal Cu:Mo ratio without causing negative effects on Cu requirement is 3:1. Molybdenosis or Mo toxicity may also be a concern with increased Mo levels (5 to10 ppm) in pastures and can cause reduced growth rate, scours, weight loss and infertility (Judson and McFarlane, 1998). According to McDowell (2003), grazing ruminants are more likely to suffer from Cu deficiency or excess Mo than monogastrics. Copper toxicity is more likely to occur in young calves than adults who are more tolerant and may also be influenced by Mo, Fe and S levels (NRC, 2000). Copper toxicity occurs primarily in dairy calves prior to weaning when given Cu-rich milk substitutes (Underwood and Suttle, 2001).

Iron is most known as an essential component of hemoglobin and myoglobin proteins involved in oxygen transport and utilization (NRC, 2000). Most plant species grazed by

livestock contain large amounts of Fe, however forage concentrations can be variable (Underwood and Suttle, 2001). Dietary Fe requirements can increase due to high levels of Ca, P, Mn, Cu or Zn levels and the presence of gossypols, phytins or tannins (McDowell, 2003). Iron deficiencies are not commonly a problem with grazing livestock, but toxicity and its antagonistic effects on Cu may be more of a concern (Greene, 2000).

Most forage available to beef cattle contains adequate Mn concentrations, but may also depend on plant species, soil pH and soil drainage (NRC, 2000). Therefore, in most cases, adequate Mn is available for prothrombin formation, blood clotting and as a component of pyruvate carboxylase in glucose metabolism (Hurley and Keen, 1987). One vital function of Mn is its relationship with MnSOD, which protect cells from damaging oxygen radicals. Similarly, Mn deficiency lowers MnSOD activity in organs such as the heart, increasing the chances of damage (Underwood and Suttle, 2001).

The most important function of Zn in the body is its involvement in the immune system. In a review by Galyean et al. (1999), researchers indicated Zn supplementation may be needed for high stress calves with a propensity to succumb to Bovine Respiratory Disease (BRD). Additionally, studies have reported that Zn is one of the most commonly deficient minerals in forages grazed by beef cattle (Greene, 1997). Therefore, mineral supplementation of Zn may be essential to maintain proper immune function and in prevention against disease.

Determination of Mineral Status

Mineral Requirements in the Diet

The beef cattle industry relies heavily on forage-based diets as the primary source of livestock nutrients. However, various forages grazed by cattle are inadequate in essential minerals (Greene, 1997). Mineral requirements vary considerably for beef cattle due to stages of

development and production, such as growth, finishing, gestation and lactation as well as differences between genders. The variation in mineral requirements often reflects the individual minerals' functions in the body. Mineral requirements and maximum tolerable concentrations for beef cattle are shown in Table 2.1.

Table 2.1 Mineral Requirements and Maximum Tolerance Concentrations in Beef Cattle[a]

Mineral[b]	**Cows Gestation**	**Early Lactating**	**Max Tolerance**
%			
Calcium	0.20	0.37	
Phosphorus	0.13	0.25	
Potassium	0.60	0.70	3.00
Magnesium	0.12	0.20	0.40
Sodium	0.06-0.08	0.10	
Sulfur	0.15	0.15	0.40
ppm			
Copper	10.00	10.00	100.00
Iron	50.00	50.00	1,000.00
Manganese	40.00	40.00	1,000.00
Molybdenum			5.00
Zinc	30.00	30.00	500.00

[a]NRC, 2000.
[b]Units are described as (% or ppm) of DM in the diet

Beef cattle dietary requirements for Ca, P, K, Mg and Na increase in stages of production such as from gestation to lactation (NRC, 2000). Requirements of trace minerals such as Cu, Fe, Mn and Zn remain constant during gestation and lactation. Unlike the other macro minerals,

dietary Cl requirement has not been well established for beef cattle. However, Leibholz et al. (1980) reported that a diet containing 6.5% salt decreased growth and organic matter intake of calves. Similar to Cl, the Mo requirement in beef cattle is not well established. However, the estimated Mo maximum tolerable concentration is 5 ppm, though concentrations can reach up to 10 ppm. Additionally, the negative affect of Mo in the cow may not all be attributed to its antagonistic affect on Cu absorption. Gengelbach et al. (1994) fed supplemental Cu, Mo and Fe to calves to determine the effect on calf performance. Calves supplemented with only Mo decreased in weight gain, indicating that Mo may have a deleterious effect on cows independent of its ability to increase Cu deficiency.

Forage Mineral Status

Factors such as fertilization practices, weather conditions, soil characteristics and stage of growth can alter forage mineral composition (Greene, 1997). Kappel et al. (1983) examined seasonal variations on mineral concentration of southern warm and cool season forages. Forage samples were collected between 1977 and 1979 from bermudagrass (*Cynodon dactylon*) and bahiagrass (*Paspalum notatum*) as well as from oats (*Avena sativa*) and ryegrass (*Lolium multiflorum*) from dairy herd operations. Forage P and Mg concentrations met the NRC (2000) requirements and were not different between warm and cool season grasses. Bermudagrass and bahiagrass samples had significantly lower concentrations of Ca and K compared to oats and ryegrass mixtures; however all forages were above the NRC (2000) requirements. Manganese requirement was met by all forages. Additionally, the 30 ppm Zn requirement was met by bermudagrass and bahiagrass, but not by oats and ryegrass mixtures (23 ppm). Copper bermudagrass, bahiagrass, oats and ryegrass were 8.0, 8.5, 5.8 ppm, respectively, and below the NRC (2000) Cu requirement for gestating and lactating beef cattle.

Greene (1997) reviewed previous studies that analyzed mineral concentrations of southern grown forages. Similar to the previous study (Kappel et al., 1983), mineral requirements were met for Ca, K and Mn, and no forage met the Cu requirement. Additionally, forage Fe and S concentrations were also analyzed and met NRC (2000) beef cattle mineral requirements. However, differences existed in concentrations of Zn and P compared to the results reported by Kappel et al. (1985). Furthermore, Zn concentrations were inadequate in bahiagrass (29.6 ppm) and bermudagrass (24.3 ppm). The NRC (2000) lactating cattle P requirement (0.25%) was met for bahiagrass (0.48%) but not by bermudagrass (0.21%). Ryegrass (24.9 ppm) was also deficient in Zn, but no data were reported for P. Unlike Kappel et al. (1985), Mg (0.20%) was inadequate in bermudagrass (0.17%), though requirements were met by bahiagrass and ryegrass. Greene (1997) indicated that the most commonly deficient minerals in the review were P, Cu and Zn and in contrast, the minerals considered to be the most excessive included S, Mn and Fe. Though previous studies have described trends for mineral concentrations of commonly grazed forages in the south, no consideration was given to specific geological locations.

Serum Determination of Mineral Status

Mineral determination in blood components of animals is commonly used to assess mineral status. However there are limitations and results must be interpreted with care (Herdt et al., 2000). Blood mineral composition or its functional form in circulation may not always be reliable due to large or rapid changes in dietary intake (Judson and McFarlane, 1998). However, blood collection is the easiest and least time consuming method for collection, especially when handling cattle in the field. Critical levels of serum are used to determine mineral status and if concentrations fall below critical levels, cattle are considered to be deficient (Table 2.2).

According to Herdt et al. (2000), blood Ca is not a good indicator of Ca status due to the sensitive homeostatic mechanism of Ca and the large reserves in bone. Though not a good indicator of deficiency, Salih et al. (1983) reported average bovine serum samples of 10.4 mg/100ml, which is well above the critical level of 8 mg/100 ml. In contrast to Ca, serum P is a reliable indicator of mineral status; however samples must be separated from the red blood cells within 2 to 3 hrs of collection due the release of P in red blood cells (Herdt et al., 2000). Additionally, McDowell (2003) reported that P levels constantly below 4.50 mg/100 ml are indicative of P deficiency. Serum Mg is another relatively reliable indicator of mineral status and cattle with a serum Mg concentration lower than 2.00 mg/100 ml have been considered deficient (Herdt et al., 2000). Though K deficiency may be difficult to determine using serum K, critical levels have been reported at 9.75 mg/100 ml. Sodium and Cl serum critical levels as described by Underwood and Suttle (2001) are 285.06 and 248.17 mg/100 ml, respectively. However, plasma Na only falls during terminal stages of Na deficiency, and Cl deficiency is not a common occurrence, therefore serum concentrations may be of little diagnostic use in the determination of mineral status (Underwood and Suttle, 2001). Sulfur deficiency has been estimated at serum levels lower than 1 mg/100 ml. However, S concentrations in ruminal fluid lower than 1.0 to 3.8 µg S/l may be the best indicator of deficiency, due to S interactions in ruminal microflora (McDowell, 2003).

The critical serum Cu level has been set at 0.60 µg/ml. However, when circulating Cu is depressed, liver Cu is released into the bloodstream and only in extreme deficiencies does serum Cu become depleted (Herdt et al., 2000). In ruminants, serum ferritin is an early indicator of Fe deficiency and serum levels can decline to 1.1 µg/ml without showing signs of deficiency (McDowell, 2003). In addition, serum Mn levels lower than 5 ng/ml are indicative of Mn

deficiency. However, according to McDowell (2003), analysis of liver (< 6ppm) and diet (< 40 ppm) may give better indication of Mn deficiency. Zinc deficiency in severe instances is more evident by clinical signs, but early stages of deficiency can be assessed by determining plasma or serum (0.60 µg/ml) critical levels and forage mineral concentrations (McDowell, 2003).

Table 2.2 Lower Critical Levels of Serum Mineral Concentrations in Beef Cattle[a]

Mineral	Critical Level
Calcium (mg/100 ml)	8.00
Phosphorus (mg/100 ml)	4.50
Magnesium (mg/100 ml)	2.00
Potassium (mg/100 ml)	9.75
Sodium (mg/100 ml)	285.06
Chloride (mg/100 ml)	248.17
Sulfur (mg/100 ml)	1.00
Copper (µg/ml)	0.60
Iron (µg/ml)	1.10
Manganese (ng/ml)	5.00
Zinc (µg/ml)	0.60

[a]McDowell, 2003; Underwood and Suttle, 200l.

Influence of Soil on Forage and Cattle Mineral Status

Soil characteristics such as type, mineral concentrations and pH have important effects on forage mineral concentrations and subsequent cattle mineral status. Soil types like heavy clay soils, can hold greater concentrations of minerals closer to the surface while sandy soils allow minerals to leach more easily away from the topsoil (Greene, 1997). Venuto et al. (2002) conducted a study on seven soils (types of sandy, silt loam and clay soils) and chemical

compositions in Louisiana to determine nutritional content of ryegrass for cattle. The average ryegrass Ca (0.44%), K (1.66%), Mg (0.24%), Mn (99.1 ppm), Fe (170.1 ppm) and Zn (47.9 ppm) concentrations from all 7 soil types were higher than the NRC (2000) requirements for lactating beef cattle. Additionally, the average forage Cu concentration of 3.2 ppm was the only mineral lower than beef cattle lactation requirements (NRC, 2000). The researchers indicated in this study that the 7 different soils varied in mineral concentrations. Soil Cu concentrations ranged from 0.21 to 2.13 ppm in 4 of the 7 soils analyzed, and were at concentrations lower than 1.00 ppm, the critical level that may indicate forage deficiency in Cu (Salih et al., 1983).

Table 2.3 Lower Critical Levels of Soil Mineral Concentration with Regards to Forage[a]

Mineral	**Critical Level, ppm**
Calcium	71.00
Phosphorus	5.00
Potassium	30.00
Magnesium	9.10
Copper	1.00
Iron	4.50
Manganese	5.00
Zinc	6.00

[a]Review by Salih et al., 1983.

Soil can also be a direct source of mineral to cattle due to soil ingestion caused by higher grazing intensities or when pasture availability is low (Underwood and Suttle, 2001). Cattle with P and Na deficiencies may also have significant instances of voluntary soil ingestion (Judson and

McFarlane, 1998). Furthermore, deficient soil mineral concentrations induce forage mineral deficiencies, which can lead to problems with the cattle (Table 2.3).

Influence of Drinking Water on Mineral Status

Mineral supplies in drinking water may contribute to mineral status, but is not always a source of minerals for cattle. However, when water is sourced from underground, the quality can be variable and considerable quantities of Na, Ca and Mg salts may be consumed (Judson and McFarlane, 1998). Sulfur may also influence water consumption as mentioned by Grout et al. (2006), who reported sulfate levels above 4,000 mg/L decreased water intake. Water does not significantly contribute to daily mineral intake, although at average concentrations, it provides 1 to 3% of the P daily requirement (McDowell, 2003). The authors also indicate that livestock species receive less than 2% of the daily requirement for K, Fe, Zn, Cu and Se in water and from 3 to 12% for Mn. Additionally, S from deep aquifers may reach 600 mg/l, potentially creating S induced Cu deficiency (Smart et al., 1986).

Mineral Surveys

International Surveys

In order to determine mineral status of forage and cattle, surveys are instituted to gain greater understanding of beef cattle mineral status and dietary requirements. Mineral surveys are utilized globally to determine cattle mineral status. Response variables included tissue, blood, feedstuffs, soil and water. Surveys have been conducted to determine forage and cattle mineral status in countries such as Ethiopia (Gizachew et al., 2002; Khalili et al., 1993), Zimbabwe (Ndebele et al., 2005) and Mexico (Almaraz et al., 2007). Khalili et al. (1993) conducted a survey to determine the status of soils, feeds and cattle in the Selale Ethiopian Highlands. Differences between rainy and dry seasons during a 2 yr period were reported. Soil results for the

study indicated that Ca was higher than critical levels and year did not have a significant effect. However, Na was lower in the yr 1 (41.4 ppm) compared to yr 2 (99.9 ppm). Soil Mg was also lower in the 2nd yr (716 ppm) compared to the 1st (768 ppm). Farm soil P was low containing 10.6 and 7.8 ppm for 1st and 2nd yrs, respectively. Soil pH averaged 5.3 in yr 1 and 5.4 in yr 2. All feeds were low in both yrs for Na (0.01 and 0.01% in yrs 1 and 2, respectively); although most other beef cattle mineral requirements were met. Mean blood plasma for Ca and Mg were lower during the rainy season (10.94 and 2.17 mg/100 ml) compared to the dry season (10.38 and 2.48 mg/100 ml). On the other hand, plasma P concentrations were lower in the dry season (8.07 mg/100 ml) compared to the rainy season (8.64 mg/100 ml). Additionally, no relationships between plasma and soil minerals or plasma and forage mineral concentrations were established (Khalili et al., 1993).

Gizachew et al. (2002) monitored cattle status in Western Ethiopia by sampling serum, soil and native pastures. Regions were divided between upland and bottomland grazing sites and similar to Khalili et al. (1993), pH ranged from 5.3 to 5.5. Soil mineral concentrations in bottomland regions were adequate for all minerals except P and Zn in both seasons. Season had no effect on soil mineral concentrations in the upland regions (Gizachew et al., 2002). Upland forage mineral concentrations met NRC (2000) beef cattle requirements for Ca, K, Fe and Mn in both seasons. However, forage mineral concentrations varied for Mg (0.19 vs. 0.12%), P (0.32 vs. 0.09%), Cu (19.44 vs. 8.18 ppm) and Zn (24.74 vs. 19.28 ppm) between wet and dry seasons, respectively. Similar trends for bottomland forage were observed for Ca, K, Fe and Mn as well as P (0.35 vs. 0.08%), Cu (20.10 vs. 6.18 ppm) and Zn (25.70 vs. 21.39 ppm) in wet and dry seasons, respectively. Forage P, Zn and Mg concentrations were deficient in both seasons and Cu concentrations were deficient in the dry season. Serum mineral concentration for Ca, K, Mg, Fe,

Mn, Cu and Zn were all well above critical levels. In most cases, mineral concentrations were lower in the dry season compared to the wet season and there were no correlations between soil or native pasture and serum minerals.

A survey was conducted in Zimbabwe, by comparing 5 districts within one region of the country (Ndebele et al., 2005). Soil Ca, P, Na, Cu and Zn concentrations were higher than reported lower critical levels, indicative of deficiency, for both rainy and dry seasons. Soil Ca concentrations were higher in dry season compared to the rainy season for all regions except one. Alternatively, soil Cu concentrations in all districts were higher in the rainy season compared to the dry season. Unlike Ca and Cu, soil concentrations of Na, P and Zn were not different between seasons. Furthermore, the differences in soil Ca and Na concentrations were attributed to the deep-sandy soils located in the region. Forages were deficient in P and Na at levels less than 0.25 and 0.08 % in both wet and dry seasons, respectively. Additionally, forage Ca, Cu and Zn concentrations in the rainy season were lower than the NRC (2000) requirements for lactating beef cattle. Forage Ca and Zn concentrations were low in all regions during the wet season and all forage samples analyzed for P and Zn were deficient. Plasma Zn and Na were analyzed and results indicated no seasonal differences, although concentrations were well above critical levels. Significant correlations were observed between soil and forage Ca ($r = 0.42$), Na ($r = 0.50$) and Cu ($r = 0.73$) concentrations, forage and animal tissue Ca ($r = 0.33$), P ($r = 0.36$), Zn ($r = 0.67$) and Cu ($r = 0.38$) concentrations, and soil and animal tissue Ca ($r = 0.32$), P ($r = -0.27$) and Cu ($r = 0.44$) concentrations.

Almaraz et al. (2007) conducted a survey in Mexico that analyzed forage and serum minerals from four sampling sites. All forage Ca, P, Zn and Se concentrations collected throughout Mexico were either marginal or deficient and Fe concentrations were observed at

excessive levels. Mean forage Cu (9.86 ppm) and Mg (0.17 ppm) concentrations were deficient in only 1 of the 4 sampled regions. Potassium (1.30%) and Na (0.35%) were the only minerals to meet minimum NRC (2000) requirements in all four regions. Unlike P and Na, Mn forage concentrations varied greatly between regions. Average serum Ca, Na, Mg and Se concentrations were reported higher than critical levels despite showing deficient concentrations in various regions. Serum Cu and Zn (0.007 µg/ml for both minerals) concentrations were deficient, which was attributed to low forage Cu or high Fe causing Cu requirements to increase. Serum P (6.77 mg/100 ml), K (25.81 mg/100 ml) and Fe (1.96 µg/ml) concentrations were considered normal.

United States Surveys

Other mineral surveys have been conducted around the United States, especially in Florida. Florida cattle mineral status was studied by Salih et al. (1983). Average soil concentrations were well above lower soil critical levels, with the exception of Cu (0.63 ppm), Mn (3.3 ppm) and Zn (1.4 ppm). Soil Cu, Mn and Zn concentrations were deficient, but forage Cu and Mn concentrations were higher than the NRC (2000) requirement for lactating beef cattle. Similar to international studies, forage P (0.22%) and Zn (18.7 ppm) concentrations were at deficient levels. However, P soil concentrations were above the critical limit of 5 ppm. The average serum Ca, P, Mg, Cu and Zn concentrations were 10.4 mg/100 ml, 5.2 mg/100 ml, 2.4 mg/100 ml, 0.90 µg/ml and 0.84 µg/ml, respectively and considered normal.

In another Florida survey, Kiatoko et al. (1982) reported forage Mg and K concentrations of 0.22 and 1.05% higher during the wet season (Sept to Oct) compared to 0.14 and 0.25% in the dry season (Feb to Mar), respectively. Additionally, Mg and K concentrations in the dry season were lower than the NRC (2000) requirements for lactating cattle. Similarly, forage P concentrations of 0.16 and 0.10% were lower than in the wet and dry seasons, respectively, and

were also lower than the NRC (2000) requirements for lactating cattle. Additionally, forage Mg (0.14%) and K (0.46%) concentrations were lower than lactating cattle requirements in the dry season, but were adequate in forage Mg (0.22%) and K (1.05%) concentrations in the wet season. Forage Ca concentrations of 0.30 and 0.32% were reported in the wet and dry seasons, respectively, and were considered adequate for mature cows in gestation, but not lactation. Mean wet-season forage Na concentrations were 0.18% in the southeast and higher than the southwest (0.08%), central (0.07%) and northwest (0.07%) regions, which were considered deficient. Wet-season soil concentrations were considered adequate for all minerals except K in the southwest region (27.2 ppm). Additionally, P soil concentrations were higher in the southeast (54.1 ppm) and central (78.8 ppm) regions compared to the southwest (14.9 ppm). Bovine plasma mineral concentrations were adequate and were not different by season or region.

McDowell et al. (1982) reported forage Cu, Fe, Mn and Zn concentrations considerably higher than those presented by Salih et al. (1983) in Florida. Mean forage concentrations of Cu (51.5 vs. 22.3 ppm), Fe (130.6 vs. 127.2 ppm) and Mn (70.7 vs. 84.7 ppm) were reported in wet and dry seasons, respectively. However, forage Zn (19.8 vs. 23.6 ppm) concentrations during the wet and dry seasons were lower than the NRC (2000) requirement for lactating beef cattle. Additionally, forage Mo concentrations of 0.36 and 0.65 ppm were lower than 5 ppm, which would negatively affect the Cu requirement (McDowell et al., 1982). Soil Cu concentrations were adequate across regions and Mn was deficient in all regions except the northwest; however this region was not different from the other three regions. Additionally, soil Zn concentrations in the southwest (1.2 ppm), central (1.3 ppm) and northwest (0.8 ppm) regions of Florida were lower than the southeast region (6.0 ppm) and the critical level of 6 ppm (Salih et al., 1983). Furthermore, plasma Cu (1 vs. 0.8 ppm) and Zn (1 vs. 0.9 ppm) concentrations in the wet and

dry seasons were higher than the critical level of 0.6 ppm (Salih et al., 1983) and were not different between region or season.

In a national study, Corah and Dargatz (1996) reported forage analysis from cow/calf operations in 18 states and various grasses were analyzed for trace mineral status. States included were Alabama, Arkansas, California, Colorado, Florida, Georgia, Iowa, Kansas, Kentucky, Mississippi, Missouri, Nebraska, New Mexico, Oklahoma, Tennessee, Texas, Virginia and Wyoming. Most samples in the survey were adequate for Mn (80%) and deficient for Zn (63.3%). Bermudagrass Zn concentrations were marginal or deficient in 50% of the samples and Zn was the most commonly deficient mineral analyzed (Corah and Dargatz, 1996). When compared to all forages, bermudagrass Cu (55.6%) and Mn (91.7%) concentrations were most likely to be adequate. On the other hand, native grass Cu concentrations were marginally deficient in 50% of samples.

Dargatz and Ross (1996) determined Se status in beef cattle in the same 18 states surveyed by Corah and Dargatz (1996). Cattle were sampled from each state with at least five cattle per herd and each herd was classified into a specific Se concentration range (severely deficient, marginal deficient, adequate or highly adequate). Regional differences were compared and results from the study indicated that the southeast had the highest percentage of severely deficient (14.3%) and marginally deficient (22.9%) cattle.

Louisiana Survey

Brown et al. (1988) reported forage mineral concentrations of various grains and forages from Louisiana dairy cattle operations. However, the data was skewed heavily towards Washington, Iberia and Tangipahoa parishes. Although no cattle mineral status indicators were measured, mineral concentrations of bahiagrass, bermudagrass, and ryegrass pastures were

reported. Similar to the two southern forage surveys, Cu deficiency as well as Fe and Mn excesses were observed. Bahiagrass, bermudagrass and ryegrass were reportedly deficient in Cu concentrations containing 5.90, 4.60 and 6.80 ppm, respectively. Results showed a mean bermudagrass Mn concentration of 52.20 ppm, and bahiagrass and ryegrass mean concentrations of Fe at 216.8 and 193.2 ppm and Mn at 292.1 and 93.5 ppm, respectively were considerably higher than the NRC (2000) requirements for lactating beef cattle. All grasses contained adequate concentrations of Mg, K, and S. Similarly, Ca concentrations met beef cattle lactation requirements in bermudagrass (0.48%) and ryegrass (0.52%), but only the gestation requirement in bahiagrass (0.34%). In addition, the bahiagrass Zn concentration of 30.10 ppm was adequate, but was inadequate at 29.00 and 24.90 ppm for bermudagrass and ryegrass, respectively. Given that forage deficiencies were reported in this limited survey, more research is warranted to better understand the Louisana beef cattle and forage mineral status.

CHAPTER III

A MINERAL SURVEY OF LOUISIANA BEEF COW/CALF PRODUCTION SYSTEMS

Introduction

Considerable research has been conducted both internationally and domestically with regards to the mineral status of beef cattle and forage. However, Louisiana was excluded from the most recent comprehensive forage analyses, and forage surveys within the state have provided limited information. To our knowledge, no survey has been conducted to assess the mineral status of beef cattle within Louisiana. Therefore, this work was conducted to gain inference on Louisiana beef cattle mineral status using serum, forage, soil and drinking water mineral concentrations surveyed throughout the state.

Materials and Methods

Experimental Design

The LSU Agricultural Center Animal Care and Use Committee approved all animal procedures. The survey was conducted over a 2 yr period starting in the fall of 2007 and ending in the spring of 2009. Louisiana was divided into 7 regions, including the northwest (NW), northeast (NE), central (CE), southwest (SW), south central (SC), Florida parishes (FP) and southeast (SE) regions (Figure 3.1). With the assistance of county agents, producers were identified to participate in the survey. Survey participants included five producers in the NW, region, four producers in the CE, SC and SE regions, three producers in the NE and SW regions, and two producers in the FP region (n = 25). Bovine serum, forage, soil and water were collected from beef cattle operations for mineral analysis. Two producers who participated in the study, one in the NE region and one in the SE region, collected forage, soil and water, but not serum throughout the duration of the study.

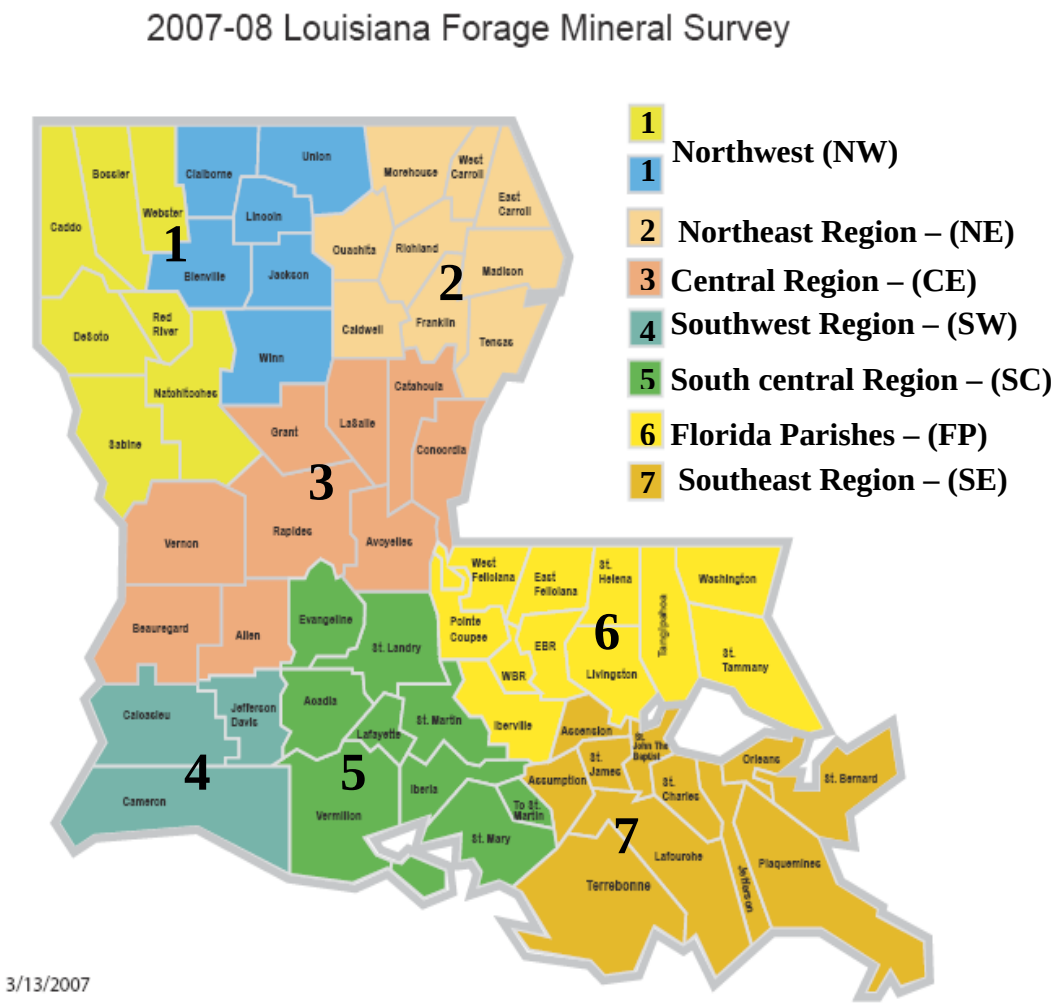

Figure 3.1 Geographical Distribution of Mineral Survey Participants

Serum Collection and Analysis

Five cows per operation were randomly selected and were bled to determine mineral status. The same five cattle from each producer were bled twice annually for 2 consecutive years, totaling 4 collection periods. The sampling periods included the fall/winter (Aug-Dec) of 2007-2008 and spring/summer (Jan-June) of 2008-2009. In the event cattle were sold or died during the study they were not replaced and only the remaining cattle were bled, leaving the final number of cattle sampled ranging from 4-5 head per operation. Throughout the trial, a total of 3 cows were removed, including one in the each of the NW, CE and SW regions.

Blood was harvested via coccygeal venipuncture using 10 ml serum collection tubes (BD Vacutainer, Franklin Lakes, NJ) and samples were kept on ice anywhere from 3 hrs to 5 d, until centrifugation at 0° C for 20 min. Samples were then stored at -18° C in 5 ml polystyrene tubes (BD, Bedford, MA) until analysis. Serum samples were sent to the Michigan State University Soil Testing Laboratory (East Lansing, MI) and analyzed via inductively coupled spectrophotometry (ICP-OES), (Spectro, Germany) for Ca, P, K, S, Na, Mg, Cu, Fe, Mn, Zn and Se concentrations.

Forage Collection and Analysis

Forage was collected quarterly. One sample was collected from each farm every two months during the two-year survey. Months collected were August to September, November to December, February to March and May to June. Forage samples were collected from cattle operations for all four time periods during yr 1 and three times in yr 2, with May to June not collected in yr 2. Hand-plucked samples were collected in 5 to 6 locations within pasture and roots and soil were removed before being placed into collection bags. Forages were takes from pastures in which cattle were grazing at the time of collection and included grasses such as bermudagrass, bahiagrass, and ryegrass individually or some combination of the three, along with other vegetation (legumes and (or) weeds) growing in the pasture. Hay samples were collected from cattle operations, primarily during winter months when no grass was available. However, during particular sampling periods, producers fed both grass and hay to supplement cattle. It was determined that mineral concentrations of grass and hay samples from the same operation were not different within these sampling periods. Therefore, grass and hay mineral concentrations were combined to obtain one sample mineral concentration per farm within these sampling periods.

Forage samples were stored at -18° C until drying. Samples were dried in a constant-air flow oven (Precision Scientific, Chicago, IL) at 60° C for 48 h to a constant weight. Samples were ground and stored at -18° C until digestion. For digestion, 0.50 g forage samples were weighed into plastic 50 ml plastic tubes (SCP Science, Champlain, NY) and digested in an automatic dispensing block digester (Thomas Cain, Omaha, NE) using 5 ml nitric acid and 3 ml hydrogen peroxide. Following digestion, samples were brought up to 20 ml with distilled water, filtered using two-sided twist on filters (SCP Science, Champlain, NY) and were capped and stored in sterile plastic tubes (SCP Science, Champlain, NY). Samples were then analyzed at the Soil Testing and Plant Analysis Laboratory at Louisiana State University, Baton Rouge, LA. An inductively coupled spectrophotometer (ICP-OES), (Spectro, Germany) was used to determine forage Ca, P, K, S, Na, Mg, Cu, Fe, Mn, Mo and Zn concentrations.

Soil and Water Collection and Analysis

Soil and water samples were collected once annually in 2007 and 2008 from August to May. Soil samples were collected similar to forage, in 5-6 locations in the pasture in which the cattle were grazing at time of collection and were taken at a depth of 8 to 12 cm. Water samples were collected using clean plastic bottles or plastic collection tubes and sampled from water troughs in cattle pastures. A minimum of 50 ml of water was collected from each farm. Soil and water were stored at 5° C until analysis. Samples were analyzed at the Soil Testing and Plant Analysis Laboratory at Louisiana State University, Baton Rouge, LA. Soil and water samples were both analyzed by using an inductively coupled spectrophotometer (ICP-OES), (Spectro, Germany) for Ca, Mg, K, Na and S, with P, Cu and Zn also analyzed in soil and Cl analyzed in water.

Missing Samples

Due to complications in receiving samples, blood and forage samples were not collected from various producers, for specific periods during the survey (Table 3.1). Louisiana and its coastline were greatly impacted on September 1, 2008 and September 11-12, 2008 during hurricanes Gustav and Ike, respectively. A majority of missing serum samples were from the fall/winter 2008 collection period and August to September 2008 collection period for forage. Missing serum samples in the fall/winter 2008 were not collected from one producer in the CE, SW and SC regions and two producers in the NW and SE regions.

Table 3.1 Number of Samples Collected in the Trial

		Year							
		1				2			
Region	Producers	Serum	Forage	Soil	Water	Serum	Forage	Soil	Water
1	5	48	20	5	5	37	15	5	5
2	3	20	12	3	3	15	8	3	3
3	4	27	16	4	4	28	10	4	4
4	3	28	12	3	3	24	7	3	2
5	4	40	16	4	4	30	11	4	4
6	2	20	8	2	2	20	6	2	2
7	4	29	15	4	4	19	8	4	4

A total of seven farms were not sampled for serum in the fall/winter of 2008. Additionally, serum samples were not collected from one producer in the NE and CE regions in the spring 2009. Missing forage samples, included one in the SE region in Feb-Mar 2008, two samples in the CE region in Aug-Sep 2008, one in the NE and CE regions for the Nov-Dec 2009

sampling period and one in the CE and SC regions in Feb-Mar 2009. Additionally, one water sample was not collected in the fall 2008 from the SW region due to the hurricanes.

Statistical Analysis

Response variables of interest were soil, water, forage and bovine serum concentrations sampled from individual farms. All variables were classified and averaged by region. Farm was considered the experimental unit for all analyses and sampling units were the individual animal for bovine serum concentrations and pasture for forage, soil and water concentrations. All dependent variable means were analyzed using the Proc Mixed of SAS (SAS Institute, Cary, NC).

Mineral concentrations in water and soil were analyzed in the same model, as were forage and bovine serum values. For water and soil values and forage and bovine serum values, the model included region as a fixed effect, and year and farm within region as a random effects. All soil, water and forage (except Mg and K) mineral values were analyzed as the natural log base. Similarly, only Mn, Fe, Zn and Se bovine serum values were analyzed as the natural log base. Values were analyzed using the natural log base because samples were heavily skewed. Mean values were analyzed on the natural log due to the increased occurrence of skewed values. The Tukey-Kramer adjustment was applied to all means to compare region, sampling period, and sampling period by region values. Additionally, water Cl, and forage and serum P and Zn concentrations were not different regionally; despite displaying a *P*-value lower than the significance level. Mineral correlations coefficients for forage and serum mineral values were analyzed using Proc Corr of SAS. Significance was declared at $P \leq 0.05$, and a trend was reported if $0.05 < P \leq 0.10$.

Results and Discussion

Soil Mineral Concentrations

Overall, regional soil Ca, Mg and K concentrations were significantly different and soil Na concentrations tended to differ. However, despite displaying great variation for individual samples and between regions, soil P, S, Cu and Zn concentrations did not differ (Table 3.2). Soil pH in our study ranged from 5.0 to 7.5 throughout the state. The greatest regional variation was in soil Ca concentrations, ranging from 3,439 ppm in SE region to 518 and 781 ppm in NW and FP regions, respectively. Additionally, at a concentration of 2,066 ppm, the SC region was also higher than the NW region. All regional soil Ca concentrations were higher than the reported critical level of 71 ppm (Salih et al., 1983). Soil Ca concentrations were four times greater than those reported by Salih et al. (1983), who reported an average soil Ca concentration of 403 ppm. In addition, Kiatoko et al. (1982) reported no regional difference between the southeast, southwest, central and northwest regions of Florida, displaying variable soil Ca concentrations of 1,700, 1,200, 400 and 400 ppm, respectively. Results in our study were more reflective of Ca concentrations reported in Ethiopia with soil Ca concentrations of 4,100 and 3,900 ppm (Khalili et al., 1993). Similarly, Gizachew et al. (2002) reported Ethiopian soil Ca concentrations 32 times higher than the critical level at concentrations of 2,298 and 2,332 ppm in the wet and dry seasons, respectively. Soil Ca concentrations in our study would be expected to be at increased levels throughout the state, as 75% of producers throughout all regions applied lime to pastures. Dolomitic lime provides both Ca and Mg to the soil, as it contains Ca and Mg carbonate (Ball et al., 2002).

The highest average soil Mg concentration of 980.1 ppm was observed in the SE region and was higher than all other regional concentrations, including the lowest Mg concentration of

130.7 ppm in the NW region. In addition, all average regional soil Mg concentrations were considerably higher than the critical level of 9.10 ppm (Salih et al., 1983). Adequate soil Mg concentrations were reported in Florida by Salih et al. (1983) with a mean concentration of 70.5 ppm. Kiatoko et al. (1982) also reported soil Mg concentrations lower than those in our study, but above critical levels in the southeast, southwest, central and northwest regions of Florida at concentrations of 29.6, 116.9, 32.3 and 57.0 ppm, respectively. However, Khalili et al. (1993) reported considerably higher soil Mg concentrations of 768 and 716 ppm in yr 1 and 2 of the study, respectively. Similar to Ca, soil Mg concentrations in our study were higher than concentrations in previous studies because of the increased application of lime.

The highest average soil K concentration of 479.7 ppm was observed in the SE region and was significantly higher than all regions, while the lowest was in the SW region at 103.53 ppm. Despite displaying regional differences, all average regional soil K concentrations were higher than the reported critical level of 30 ppm (Salih et al., 1983). Furthermore, Kiatoko et al. (1982) reported soil K concentrations considerably lower than those in our study, at soil K concentrations of 54.1, 27.2, 32.1 and 64.3 ppm in the southeast, southwest, central and northwest regions of Florida, respectively. Similarly, a mean soil K concentration of 76.3 ppm was reported in Florida by Salih et al. (1983). However, higher K concentrations were reported by Gizachew et al. (2002) with soil K concentrations of 293.25 and 289.34 ppm in upland sites and 324.53 and 320.62 ppm in bottomland sites for the wet and dry seasons, respectively.

Average regional soil P concentrations ranged from the greatest concentration of 72.25 ppm in the NW region to the the SW and CE regions at 19.90 ppm, but were not different. Though not different, regional averages were variable due to the high variabilitily of samples within regions.

Table 3.2 Regional Soil Mineral Concentrations for Cattle in Louisiana. Values reported are least square means with their 95% confidence interval (Lower, Upper) or SEM[*]

	Region							
ppm	NW	NE	CE	SW	SC	FP	SE	*P*-value
Ca	518[c] (333, 808)	1205[abc] (681, 2136)	1169[abc] (713, 1919)	1592[abc] (899, 2821)	2066[ab] (1259, 3391)	781[bc] (388, 1575)	3439[a] (2096, 5644)	0.01
P	72.25 (34.1, 153.1)	59.63 (22.6, 157.3)	24.35 (10.5, 56.4)	19.90 (7.5, 52.4)	19.90 (8.6, 46.1)	21.48 (6.6, 70.5)	27.31 (11.8, 63.3)	0.16
Na	19.93 (8.4, 47.3)	26.10 (8.6, 79.6)	19.94 (7.6, 52.4)	99.73 (32.7, 304.3)	76.25 (29.0, 200.3)	42.76 (10.9, 167.6)	92.64 (35.3, 243.3)	0.08
S	18.27 (10.4, 32.1)	25.25 (12.3, 52.0)	16.70 (8.9, 31.3)	34.64 (16.8, 71.3)	20.27 (10.8, 38.0)	25.47 (10.6, 61.4)	35.85 (19.1, 67.2)	0.46
Cu	1.35 (0.7, 2.8)	1.48 (0.6, 3.8)	1.33 (0.6, 3.0)	0.98 (0.4, 2.5)	2.52 (1.1, 5.6)	1.43 (0.5, 4.5)	2.88 (1.3, 6.5)	0.51
Zn	4.24 (2.3, 7.9)	3.77 (1.7, 8.4)	2.89 (1.4, 5.8)	1.84 (0.8, 4.1)	2.42 (1.2, 4.9)	3.62 (1.4, 9.6)	7.59 (3.8, 15.2)	0.16
Mg[d]	130.68[b] [9.37]	254.38[b] [117.7]	253.28[b] [103.3]	205.29[b] [117.7]	388.12[b] [103.3]	160.11[b] [142.1]	980.11[a] [103.3]	0.01
K[d]	140.46[b] [42.7]	163.36[b] [54.9]	233.23[b] [47.6]	103.53[b] [54.9]	171.25[b] [47.6]	164.00[b] [67.2]	479.71[a] [47.6]	0.01

[abc]Different superscripts represent significant regional differences of ($P < 0.05$).

[*]The mean variability is presented as 95% confidence interval for variables transformed on a natural log base or as SEM for variables analyzed on the original scale.

Additionally, all observed regional concentrations were considerably higher than the reported critical level of 5.00 ppm (Salih et al., 1983). Results were similar to those reported in Florida by Salih et al. (1983), who reported a mean soil P concentration of 76.2 ppm. However, contrary to our study, Kiatoko et al. (1982) reported greater P concentrations of 53.4 and 78.8 ppm in the southeast and central regions of Florida, which were higher than the P concentration of 14.9 ppm in the southwest regions. Similar to soil Cu concentrations, average regional soil P concentrations in the NW and NE regions did not differ from any other regions, despite the usage of chicken litter in these regions as a fertilizer source for grazing pastures. With such high soil P concentrations, forage P would be expected at much higher concentrations than previous studies reporting P deficiencies.

Soil Na concentrations did not differ regionally, but presented a range of 99.73 to 19.93 ppm. In agreement with our study, Khalili et al. (1993) reported mean Na soil concentrations of 41.4 and 99.9 ppm in yrs 1 and 2 of the Florida study, respectively. Similarly, Kiatoko et al. (1982) reported no regional differences in soil Na concentrations of 16.2, 22.1, 10.2 and 16.4 ppm in the southeast, southwest, central and northwest regions of Florida, respectively. Furthermore, average soil S concentrations did not differ regionally in our study and ranged from the highest concentration of 35.85 ppm to the lowest at 16.70 ppm. Comparing average soil S concentrations in our study to others is difficult, as soil S concentrations are limited in literature and most researchers fail to include S analysis when analyzing soil mineral concentrations.

Similar to Na and S, average regional soil Cu concentrations did not differ, but ranged from a concentration of 2.88 to 0.98 ppm. Additionally, all average soil Cu concentrations were higher than the reported critical level of 1.00 ppm (Salih et al., 1983), with the exception of 0.98 ppm Cu in the SW region. Average Cu soil concentrations in our study were higher than results

in other studies, such as Salih et al. (1983) who reported a mean soil Cu concentration of 0.63 ppm. Similarly, Gizachew et al. (2002) reported soil Cu concentrations of 0.50 and 0.51 ppm in the wet season and 0.88 and 0.64 ppm in the dry seasons for upland and bottomland regions, respectively. However, higher soil Cu concentrations of 1.3, 1.6, 0.6 and 2.1 ppm were reported by McDowell et al. (1982) in the southeast, southwest, central and northwest regions of Florida, respectively. Broiler litter is known to contain large concentrations of Cu and P due to the increased usage of these minerals in poultry diets (McGinley et al., 2004). However, average soil Cu concentrations in the NW and NE regions of our study, were not different regionally, despite the use of chicken litter as fertilizer by 5 of the 8 producers in these regions.

Average regional soil Zn concentrations ranged from 7.59 to 1.84 ppm, but did not differ regionally. Additionally, soil Zn concentrations in all regions, with the exception of the SE region, were at Zn concentrations lower than the critical level of 6.00 ppm (Salih et al., 1983). In agreement with our study, deficient soil Zn concentrations were reported by Salih et al. (1983) with a mean soil Zn concentration of 1.4 ppm, well below the critical level.Similarly in Florida, McDowell et al. (1982) reported deficient concentrations of 6.0, 1.2, 1.3 and 0.8 ppm in the southeast, southwest, central and northwest regions, respectively. Higher soil Zn concentrations in Zimbabwe were reported by Ndebele et al. (2005) and observed mean Zn concentrations of 48.3 to 20.3 ppm in the rainy season and 13.0 to 95.3 ppm in the dry season.

Water Mineral Concentrations

Drinking water may not be a major contributing source of minerals for grazing beef cattle, but at higher concentrations, water may contribute to mineral status (Underwood and Suttle, 2001). One factor with water effecting mineral status is geographical location.

Table 3.3 Regional Water Mineral Concentrations for Cattle in Louisiana. Values reported are least square means with their 95% confidence interval (Lower, Upper)*

	Region							
ppm	NW	NE	CE	SW	SC	FP	SE	*P*-value
Ca	1.95[b] (0.8, 4.9)	38.93[a] (11.7, 129.6)	5.45[ab] (1.9, 15.4)	20.50[ab] (6.0, 70.6)	32.13[a] (11.3, 91.0)	1.32[b] (0.3, 5.8)	32.10[a] (11.3, 90.9)	0.01
Mg	0.72[bc] (0.2, 2.2)	15.63[a] (3.7, 65.5)	1.61[abc] (0.5, 5.6)	4.74[ab] (1.1, 20.4)	11.11[a] (3.2, 38.5)	0.09[c] (0, 0.5)	15.26[a] (4.4, 52.8)	0.01
K	1.73[ab] (0.8, 3.6)	2.19[ab] (0.9, 5.6)	2.21[ab] (1.0, 5.0)	3.31[ab] (1.3, 8.7)	2.58[ab] (1.1, 5.8)	0.55[b] (0.2, 1.7)	5.21[a] (2.3, 11.8)	0.10
Na	19.84 (5.8, 67.6)	97.14 (20.0, 472.9)	12.28 (3.1, 48.3)	59.11 (11.8, 296.3)	59.94 (15.2, 236.1)	67.13 (9.7, 466.5)	40.10 (10.2, 157.9)	0.37
S	1.37[ab] (0.4, 4.2)	1.52[ab] (0.4, 6.6)	0.54[b] (0.2, 1.9)	0.45[b] (0.1, 2.0)	1.05[ab] (0.3, 3.7)	2.91[ab] (0.5, 17.4)	12.92[a] (3.7, 45.7)	0.02
Cl	7.77 (2.2, 27.4)	69.41 (13.7, 352.9)	6.61 (1.6, 27.0)	47.68 (9.0, 252.5)	36.13 (8.8, 147.7)	2.60 (0.4, 19.1)	56.51 (13.8, 231.1)	0.04

[abc] Different superscripts represent significant regional differences of ($P < 0.05$).

*The mean variability is presented as 95% confidence interval for variables transformed on a natural log.

Therefore, water mineral concentrations were assessed to determine mineral status and statewide variation. Average regional water Ca, Mg and S concentrations differed by region; however, water Na and Cl concentrations did not differ regionally (Table 3.3).

Additionally, water K concentrations in our study tended to be different regionally. Average regional water Ca concentrations of 38.93, 32.13 and 32.10 ppm in the NE, SW and SE regions were higher ($P = 0.01$) than Ca concentrations of 1.95 and 1.32 ppm in the NW and FP regions. Additionally, average regional water Ca concentrations in our study were well below the desired upper level (100 ppm) and maximum upper level (150 ppm) concentrations for livestock (Socha et al., 2003). Also, water Ca concentrations were considerably lower than the average water Ca concentration of 65 ppm and maximum observed concentration of 590 ppm sampled from 3,651 U. S. water sources (Socha et al., 2003). Therefore, water is not a reliable source of Ca in the diets of beef cattle.

Increased water S concentrations are known to decrease water and feed intake starting at concentrations of 2,500 to 3,000 ppm (Grout et al., 2006). However, the highest water S concentration of 12.92 ppm was observed in the SE region and was higher than S concentrations of 0.54 and 0.45 ppm in the CE and SW regions, respectively.Additionally, water S concentrations in our study were observed at desirable levels, as all S concentrations were lower than upper desired (50 ppm) and maximum upper (300 ppm) levels for livestock which would may contribute to mineral status. Results in our study were also lower than the average sampled U.S water S concentration of 27 ppm and the maximum observed U.S. S concentration of 1,197 ppm (Socha et al., 2003).

In our study, average water Mg concentrations of 15.63, 11.11 and 15.26 ppm in the NE, SW and SE regions were higher than the Mg concentration of 0.09 ppm in the FP region. Similar to Ca, water Mg concentrations are known to be present at high quantities for livestock species

(NRC, 1974). However, water Mg concentrations in our study were considerably lower than the reported upper level and maximum upper level concentrations of 50 and 100 ppm, respectively (Socha et al., 2003) Additionally, water Mg concentrations were also lower than the average Mg concentration of 24 ppm reported by Socha et al. (2003) from samples around the United States. Furthermore, Grout et al. (2006) reported a significant decrease in overall water consumption from 39.8 to 12.6 L/d, when $MgSO_4$ in water increased to a concentration of 4,500 ppm from 1500 ppm; however water Mg concentrations in our study were considerable lower than 1500 ppm.

Average water Na concentrations in our study did not differ regionally and ranged from a concentration of 97.14 to 12.28 ppm. Furthermore, average water Na concentrations in the NE (97.14 ppm), SW (59.11 ppm), SC (59.94 ppm) and FP (67.13 ppm) regions were higher than the reported upper desired level of 50 ppm for livestock, but were below the maximum upper level of 300 ppm (Socha et al., 2003). In agreement with our study, an average water Na concentration of 46 ppm was reported by Socha et al. (2003) with a maximum observed concentration of 1,556 ppm. Similarly, Grout et al. (2006) also reported no change in water consumption (L/d) at concentrations between 1500 ppm to 4500 ppm of $NaSO_4$ in water.

The highest observed Cl concentration (69.41 ppm) was reported in the NE region and the lowest Cl concentration was in the FP region at 2.61 ppm. Despite no regional differences, the increased amount of variability for samples within regions cause the large amount of variability between regions. All water Cl concentrations in our study were considerably lower than the upper desired level (100 ppm) and maximum upper level (300 ppm) for livestock. Chloride concentrations were also lower than the reported U.S. average and maximum water Cl concentrations of 59 and 727 ppm, (Socha et al., 2003).

Average regional water K concentrations tended to differ and a concentration of 5.21 in the SE region was higher than the FP region at 0.66 ppm. Additionally, average water K concentrations in the regions NW (1.73 ppm), NE (2.19), CE (2.21 ppm), SW (3.31), SC (1.05 ppm) and SE (5.21 ppm) regions were higher than average K concentrations reported by Socha et al. (2003) at 1 ppm, but were lower than the maximum observed concentration of 6 ppm. Furthermore, water K concentrations in our study were lower than both the desired upper level and maximum upper level concentrations for livestock of 20 ppm.

Forage Mineral Concentrations for Cattle

Forage K, Mg, Na and S concentrations differed by region. While regional forage Zn concentrations tended to differ, forage Ca, P, Cu, Fe, and Mn concentrations were not different by region (Table 3.4). A mean forage K concentration of 1.83% was observed, with minimum and maximum K concentrations of 0.24 and 6.00%, respectively (Table 3.5). Forage K concentrations in our study were lower than the NRC (2000) requirements for gestating (0.60%) and lactating (0.70%) cows in only 5 and 7% of forage samples, respectively. Additionally, the highest average regional forage K concentration of 2.20% was observed in the NW region and was higher than the FP region with a concentration of 1.07%. Similarly, all average regional forage K concentrations were considerably higher than the NRC (2000) requirements for gestating and lactating cows. Contrary to our study, Mathis and Sawyer (2004) reported a mean forage K concentration of 0.37% and forage K concentrations lower than gestating and lactating cattle requirements in 83 and 89% of New Mexico forage samples. However, similar to our study, Davis et al. (2002) reported forage K concentrations well above minimum K requirements with concentrations of 1.89, 1.82 and 1.89% in bermudagrass, mixed grass and hay samples, respectively. Similarly, Kappel et al. (1983) and Brown et al. (1988) reported bermudagrass and bahiagrass K concentrations of 1.78 and 1.60% and 1.61 and 1.80%, respectively.

Table 3.4 Regional Forage Mineral Concentrations for Cattle in Louisiana. Values reported are least square means with their 95% confidence interval (Lower, Upper)*

	Region							
%	NW	NE	CE	SW	SC	FP	SE	*P*-value
Ca	0.39 (0.33, 0.46)	0.36 (0.29, 0.44)	0.40 (0.33, 0.48)	0.40 (0.32, 0.49)	0.39 (0.32, 0.47)	0.38 (0.30, 0.48)	0.51 (0.42, 0.61)	0.17
P	0.32 (0.27, 0.39)	0.30 (0.23, 0.39)	0.22 (0.18, 0.27)	0.20 (0.16, 0.26)	0.22 (0.18, 0.27)	0.24 (0.18, 0.33)	0.26 (0.21, 0.32)	0.04
Mg	0.20^{ab} (0.18, 0.23)	0.17^{ab} (0.15, 0.21)	0.21^{ab} (0.18, 0.24)	0.21^{ab} (0.17, 0.24)	0.16^{b} (0.14, 0.18)	0.25^{a} (0.20, 0.30)	0.22^{ab} (0.19, 0.25)	0.02
K	2.20^{a} (1.75, 2.77)	1.86^{ab} (1.38, 2.49)	1.38^{ab} (1.07, 1.79)	1.29^{ab} (0.95, 1.73)	1.36^{ab} (1.05, 1.76)	1.07^{b} (0.75, 1.52)	1.81^{ab} (1.40, 2.34)	0.01
Na	0.02^{c} (0.02, 0.04)	0.04^{bc} (0.03, 0.08)	0.03^{c} (0.02, 0.04)	0.15^{a} (0.09, 0.27)	0.09^{ab} (0.05, 0.14)	0.07^{abc} (0.04, 0.14)	0.06^{abc} (0.04, 0.09)	0.01
S	0.36^{a} (0.30, 0.43)	0.31^{ab} (0.24, 0.40)	0.23^{b} (0.18, 0.28)	0.32^{ab} (0.25, 0.40)	0.28^{ab} (0.23, 0.35)	0.24^{ab} (0.18, 0.32)	0.36^{a} (0.29, 0.45)	0.03
ppm								
Cu	8.94 (7.54, 10.61)	7.38 (5.92, 9.20)	7.13 (5.90, 8.61)	6.73 (5.42, 8.35)	6.55 (5.42, 7.90)	7.81 (6.05, 10.08)	8.45 (7.01, 10.19)	0.13
Fe	167.27 (106, 265)	146.04 (84, 255)	189.88 (115, 314)	287.32 (164, 504)	260.32 (158, 429)	155.34 (80, 301)	299.53 (182, 493)	0.19
Mn	225.16 (126, 401)	137.47 (65, 289)	167.15 (88, 319)	226.20 (107, 478)	184.53 (99, 352)	343.61 (138, 854)	147.84 (77, 282)	0.65
Zn	51.37 (40, 66)	38.21 (28, 52)	30.18 (23, 40)	39.35 (29, 54)	28.92 (22, 38)	33.62 (23, 50)	42.84 (33, 56)	0.05

[abc] Different superscripts represent significant regional differences of ($P < 0.05$).

[*]The mean variability is presented as 95% confidence interval for variables transformed on a natural log.

Brown et al. (1988) also reported a higher ryegrass K concentration at 3.56% in Louisiana. Similarly, 13% of samples in our study were higher than the toxic concentrations of 3.00% known to induce grass tetany (NRC, 2000). However, average state and regional forage K concentrations in our study were well above NRC (2000) requirements for beef cattle, but still lower than toxic concentrations.

A mean forage Mg concentration of 0.21% was observed for forage, with maximum and minimum Mg concentrations of 0.43 and 0.09%, respectively. Additionally, no Mg concentrations were below the minimum requirement of 0.12% for gestating cows, but 40% of samples were lower than the required dietary Mg concentration for lactating cows at 0.20% (NRC, 2000). The highest average regional forage Mg concentration of 0.25% was observed in the FP region and was higher than the SC region with a concentration of 0.16%. Additionally, all regional forage Mg concentrations were higher than the NRC (2000) gestation requirements, but the NE (0.174%) and SC (0.158%) regions were below lactation requirements. Unlike our study, Mathis and Sawyer (2004) reported 77% and 97% deficiency in New Mexico forage samples for gestating and lactating requirements, respectively.

Additionally, a mean forage Mg concentration of 0.09% was reported in New Mexico, with a range of 0.03 to 0.36%. Our results were similar to Brown et al. (1988) who reported Louisiana bermudagrass, bahiagrass and ryegrass samples, which contained Mg concentrations of 0.27, 0.28 and 0.23%, respectively. Similarly, Davis et al. (2002) reported Arkansas bermudagrass and mixed grass forage Mg concentrations of 0.22 and 0.26%, respectively. Results reported in Florida were also in agreement with our study, as Salih et al. (1983) reported a mean forage Mg concentration of 0.22% and Kiatoko et al. (1982), despite displaying no regional differences, reported mean Mg concentrations of 0.22 and 0.14% in the wet and dry

seasons, respectively. Despite the increased application of lime by producers in our study, forage Mg concentrations did not respond to liming as those reported by Hillard et al. (1992). Forage Mg concentrations increased with lime applications at a rate of 0, 672, or 3,808 kg ha^{-1}.

Table 3.5 Maximum, Minimum and Mean Mineral Concentrations and Percent Deficiency for Forage Samples in Louisiana

				% Deficient	
%	Low	High	Mean	Gestating[a]	Lactating[a]
Ca	0.20	1.05	0.42	0	40
P	0.06	0.92	0.28	9	45
Mg	0.09	0.43	0.21	4	45
K	0.24	6.00	1.83	5	7
Na	0.01	1.37	0.10	57	70
S	0.08	0.73	0.32	5	5
ppm					
Cu	2.89	24.11	8.12	75	75
Fe	39.29	2246.28	323.46	2	2
Mn	17.78	1014.21	254.85	3	3
Zn	14.22	183.12	41.29	26	26

[a]In accordance with NRC (2000) dietary requirements for gestating and lactating beef cattle

Forage Na concentrations in 57 and 70% of samples collected were below the NRC (2000) requirements of 0.06 to 0.08 and 0.10% for gestating and lactating cows, respectively. Additionally, a mean forage Na concentration of 0.10% was observed in Louisiana, with minimum and maximum concentrations of 0.01 and 1.37%. However, unlike the average forage Na concentration for the state, the average regional concentration of 0.15% in the CE region was the only regional Na concentration above the minimum requirements for lactating cows. In addition, average regional forage Na concentrations of 0.09, 0.07 and 0.06% in the SW, CE and FP regions were above minimum NRC (2000) requirements for gestating cows, but not for

lactating cows. Similarly, the forage Na concentration in the SW region was higher than concentrations of 0.02 and 0.03% in the NW and CE regions, respectively. Mathis and Sawyer (2004) reported 91 and 93% of New Mexico forage samples below gestating and lactating cattle requirements, with a mean forage Na concentration of 0.05% and a range from 0.01 to 0.57%. Additionally, Davis et al. (2002) reported Arkansas bermudagrass, mixed grass and hay Na concentrations of 0.04, 0.03 and 0.04%, respectively. In agreement with our study, Kiatoko et al. (1982) reported a forage Na concentration of 0.18% in the southeast region of Florida, which was higher than forage Na concentrations of 0.07, 0.08 and 0.07% in southwest, central and northwest regions, respectively. Though most sampled regions were considered deficient in forage Na, the contribution of dietary Na in drinking water should not be overlooked (Mathis and Sawyer, 2004). Four of the seven sampled regions in our study had water Na concentrations greater than the upper desired level for livestock at 50 ppm (Socha et al., 2003). Additionally, supplementary Na is regularly supplied to Louisiana cattle in practical conditions because of its relatively low cost, palatability and ready availability.

Mean forage S concentration was 0.32%, with minimum and maximum S concentrations of 0.08 and 0.73%. Similarly, only 5% of forage S concentrations from samples in our study were lower than the NRC (2000) requirements of 0.15% for gestating and lactating cows. In addition, average regional forage S concentration of 0.36% in the NW and SE regions were higher than the lowest S concentration of 0.23% in the CE region. Mathis and Sawyer (2004) reported 92% of New Mexico forage samples lower than minimum S beef cattle requirements, as well as a deficient mean forage S concentration of 0.10% with a concentration range of 0.03 to 0.29%. Similarly, Brown et al. (1988) reported bahiagrass, ryegrass and bermudagrass forage S concentrations lower than those in our study, with concentrations of 0.15, 0.18 and 0.30%,

respectively. Davis et al. (2002) also reported lower forage S concentrations in bermudagrass, mixed grass and hay samples at 0.26, 0.21 and 0.23%, respectively. Additionally, Kiatoko et al. (1982) reported no regional differences in Florida and forage S concentrations of 0.22 and 0.18% in the wet and dry seasons, respectively. Though average state and regional forage S concentrations in our study were below the toxic concentration of 0.40%, 17% of forage samples in our study were at S concentrations higher than this level (NRC, 2000). Forage S concentrations above toxic levels can decrease Cu absorption, increasing requirements (NRC, 2000); however, the percentage of high forage S concentrations in our study was low and would not drastically alter Cu status.

Mean state forage Zn concentration of 41.29 ppm was observed in Louisiana, with minimum and maximum Zn concentrations of 14.22 and 183.12 ppm. Additionally, average forage Zn concentrations in the study tended to differ regionally; however no regional differences were observed after the Tukey-Kramer adjustment. Nonetheless, average regional forage Zn concentrations ranged from 51.37 ppm to a concentration of 28.92 ppm in the SC region, which was the only region with a forage Zn concentration below requirements. Forage Zn concentrations in 26% of our forage samples were lower than the NRC (2000) requirement of 30 ppm for gestating and lactating cows. Contrary to our study, Mathis and Sawyer (2004) reported forage Zn concentrations below cattle requirements in 77% of samples in New Mexico, as well as a mean forage Zn concentration of 23.7 ppm and range from 5.1 to 75.0 ppm. Brown et al. (1988) reported concentrations of Zn in bahiagrass of 30.10 ppm, but deficient Zn concentrations of 29.00 and 24.90 ppm were observed in bermudagrass and ryegrass samples, respectively. Similarly, Kappel et al. (1983) reported forage Zn concentrations of 35.00, 29.40 and 23.00 ppm in bermudagrass, bahiagrass and ryegrass, respectively. Deficient forage Zn concentrations were

also reported in Florida by Salih et al. (1983) (18.7 ppm) and McDowell et al. (1982) (19.8 and 23.6 ppm in wet and dry seasons, respectively). In agreement with our study, Davis et al. (2004) reported adequate mean Zn concentrations of 34.3, 38.3 and 35.3 in bermudagrass, mixed grass and hay samples, respectively.

Mean state forage Ca concentration was 0.42%, with minimum and maximum Ca concentrations of 0.20 and 1.05%. Additionally, no forage samples were lower than the NRC (2000) requirements of 0.20% for gestating cows, but 40% were below the lactation requirement of 0.37%. Average regional forage Ca concentrations were not different, but ranged from 0.51% in the SE region to 0.36% in the NE region, which was the only region lower than the NRC (2000) lactation requirement. Compared to our study, Mathis and Sawyer (2004) reported forage Ca concentrations below gestation and lactation requirements in 23 and 34% of forage samples. In agreement with our study, a mean forage Ca concentration of 0.46% with a range of 0.13-1.59% was also reported in New Mexico. Additionally, Davis et al. (2004) reported that mixed grass, bermudagrass and hay samples at forage Ca concentrations of 0.58, 0.51 and 0.58%, respectively. Forage Ca concentrations were also reported by Brown et al. (1988) and Kappel et al. (1983) for bermudagrass, bahiagrass and ryegrass samples at concentrations of 0.48, 0.34 and 0.52% and 0.38, 0.40 and 0.53%, respectively. However, forage Ca concentrations in Florida were reported below beef cattle lactation requirements by Salih et al. (1983) at concentrations of 0.30 % and by Kiatoko et al. (1982) at 0.30 and 0.32% in the wet and dry seasons, respectively. The increased application of lime in pastures may have increased forage Ca concentrations in our study. Hillard et al. (1992) reported average forage Ca concentrations over 3 years of 0.26, 0.32 and 0.52% of DM with the increased application of limestone at 0, 672, or 3,808 kg ha^{-1}, respectively.

The mean forage P concentration was 0.28%, with minimum and maximum concentrations of 0.06 and 0.92%. Additionally, average regional forage P concentrations did not differ. Statewide forage P concentrations were lower than the NRC (2000) requirements for gestating (0.13%) and lactating (0.25%) cows in 9 and 45% of forages samples, respectively. Despite no regional forage P concentrations below gestating cow requirements, the CE, SW, SC and FP regions had concentrations of 0.22, 0.20, 0.22 and 0.24%, lower than the NRC (2000) P requirement for lactating cows. Results in our study were not in agreement with Mathis and Sawyer (2004), who reported all collected New Mexico forage samples below gestation and lactation P requirements, with a mean forage P concentration of 0.07% and range of 0.01 to 0.18%. Similarly in Florida, Salih et al. (1983) reported a mean forage P concentration of 0.22%, lower than the P requirement for lactating cows. Additionally, Kiatoko et al. (1982) also reported deficient mean forage P concentrations of 0.16 and 0.10% in the wet and dry seasons, respectively. In agreement with our study, Kappel et al. (1983) and Davis et al. (2002) reported adequate P concentrations in bermudagrass and bahiagrass (0.45 and 0.48%) and bermudagrass and mixed grass (0.28 and 0.30%), respectively.

State forage Cu concentrations were lower than the requirement of 10 ppm for gestating and lactating cows in 75% of collected forage samples NRC (2000). The state mean forage Cu concentration was 8.12 ppm, with minimum and maximum Cu concentrations of 2.89 and 24.11 ppm, respectively. Average regional forage Cu concentrations were not different, but were all lower than the beef cattle dietary requirement. Unlike our study, Mathis and Sawyer (2004) reported only 40% of forage samples below the beef cattle Cu requirements, as well as a mean forage Cu concentration of 12.6 ppm and a range from 2.0 to 52.0 ppm. However, in agreement with our study, deficient forage Cu concentrations were reported by Brown et al. (1988) and

Kappel et al. (1983) for bahiagrass, bermudagrass and ryegrass concentrations of 5.90, 4.60 and 6.80 ppm and 8.50, 8.00 and 5.80 ppm, respectively. Adequate forage Cu concentrations were reported in Florida by Salih et al. (1983) with a mean forage Cu concentration of 15.1 ppm and by McDowell et al. (1982) at Cu concentrations of 51.5 and 22.3 ppm in the wet and dry seasons, respectively. Additionally, increased forage S and Fe concentrations may cause the cattle Cu requirement to increase, even though concentrations are at adequate levels (Underwood and Suttle, 2001). Thirteen and 6% of the forage samples in our study were higher than S (0.40%) and Fe (1,000 ppm) toxic levels, respectively.

Mean statewide forage Fe concentrations were 323.46 ppm, with minimum and maximum Fe concentrations of 39.29 and 2,246.28 ppm, respectively. Additionally, only 2% of forage Fe concentrations were lower than the NRC (2000) requirement of 50 ppm for gestating and lactating cows. Similarly, average regional forage Fe concentrations surpassed Fe requirements for beef cattle and ranged from 146.0 to 299.5 ppm. Mathis and Sawyer (2004) reported all forage samples above Fe requirements for cattle, with a mean forage Fe concentration of 876 ppm and a range of 113 to 7,450 ppm, considerably higher than Fe concentrations in our study. In agreement with our study, Brown et al. (1988) reported bahiagrass and ryegrass Fe concentrations of 216.8 and 193.2 ppm and Davis et al. (2002) reported bermudagrass, mixed grass and hay concentrations of 212.0, 244.0 and 220.0 ppm, respectively. However, contrary to all studies, Salih et al. (1983) reported a deficient mean forage Fe concentration of 29.2 ppm in Florida. Despite displaying 6% of forage Fe concentrations above the maximum tolerable level of 1,000 ppm for beef cattle, average state and regional concentrations remained lower than the toxic Fe concentration in forage (NRC, 2000).

Mean statewide forage Mn concentration was 254.85 ppm, with minimum and maximum Mn concentrations of 17.78 and 1,014.21 ppm. In addition, only 3% of forage samples were lower than the NRC (2000) Mn requirement of 40 ppm for gestating and lactating beef cattle. Only one forage sample had a Mn concentration greater than the maximum tolerable level of 1,000 ppm for beef cattle (NRC, 2000). Furthermore, average regional forage Mn concentrations were well above minimum Mn requirements, but were not different. Contrary to our study, Mathis and Sawyer reported 16% of forage Mn concentrations in New Mexico lower than Mn requirements for beef cattle. Additionally, the mean forage Mn concentration of 75.5 ppm was reported with a range of 14.2 to 222.0 ppm. Studies conducted by Kappel et al. (1983) and Brown et al. (1988) in Louisiana reported lower Mn concentrations of 111.1, 139.9 and 84.0 ppm and 52.2, 292.1 and 193.0 ppm for bermudagrass, bahiagrass and ryegrass samples, respectively. Forage Mn concentrations lower than those in our study were reported in Florida. Salih et al. (1983) reported a mean Mn concentration of 66.3 ppm and McDowell et al. (1982) reported mean forage Mn concentrations of 70.7 and 84.7 ppm in the wet and dry seasons, respectively.

Serum Mineral Concentrations in Cattle

Average bovine serum mineral concentrations for Ca, P, K, S, Fe, Zn and Se were above the respective critical levels in all regions. Average regional concentrations for serum Ca, Mg, Na, S, Cu, Mn, Fe and Se did not differ, but serum K concentrations were different regionally (Tables 3.6, 3.7). In addition, the average serum K concentration in Louisiana was 21.66 mg/100 ml with maximum and minimum concentrations of 49.29 and 13.07 mg/100 ml, respectively (Table 3.8). Additionally, the greatest regional average for serum K concentrations was in the NE region at 29.12 mg/100 ml and was greater than the CE, SC, FP and SE regions with concentrations of 19.91, 19.45, 19.32 and 19.24 mg/100 ml, respectively.

Table 3.6 Regional Serum Mineral Concentrations for Cattle in Louisiana. Values reported are least square means (mg/100 ml) with their SEM*

	Region							
mg/100 ml	NW	NE	CE	SW	SC	FP	SE	*P*-value
Ca	9.12 [0.24]	9.12 [0.30]	8.88 [0.25]	9.22 [0.27]	9.12 [0.25]	9.38 [0.30]	8.73 [0.27]	0.40
P	13.82 [0.36]	14.26 [0.54]	12.89 [0.40]	14.64 [0.45]	12.96 [0.39]	14.61 [0.52]	12.81 [0.46]	0.02
Mg	1.80 [0.24]	1.94 [0.25]	1.92 [0.24]	2.07 [0.24]	2.03 [0.24]	2.00 [0.25]	1.99 [0.24]	0.18
K	22.37^{ab} [1.56]	29.12^{a} [2.15]	19.91^{b} [1.67]	24.15^{ab} [1.85]	19.45^{b} [1.67]	19.32^{b} [2.12]	19.24^{b} [1.85]	0.01
Na	307.25 [6.32]	298.71 [6.73]	303.59 [6.40]	300.80 [6.50]	302.19 [6.38]	306.21 [6.63]	308.99 [6.54]	0.11
S	100.94 [1.87]	108.41 [2.89]	104.13 [2.08]	101.94 [2.38]	105.32 [2.06]	99.83 [2.83]	103.43 [2.41]	0.30

^{abc} Different superscripts represent significant differences of ($P < 0.05$).

* SEM for variables analyzed on the original scale.

Table 3.7 Regional Serum Mineral Concentrations for Cattle in Louisiana. Values reported are least square means with their 95% confidence interval (Lower, Upper) or SEM[d]

	Region							
µg/ml	NW	NE	CE	SW	SC	FP	SE	*P*-value
Cu[d]	0.69 [0.06]	0.57 [0.09]	0.67 [0.07]	0.60 [0.07]	0.56 [0.07]	0.73 [0.09]	0.47 [0.07]	0.19
Fe	1.99 (1.78, 2.24)	1.77 (1.49, 2.12)	1.96 (1.73, 2.23)	1.82 (1.57, 2.10)	1.75 (1.54, 1.99)	2.08 (1.75, 2.48)	1.60 (1.38, 1.85)	0.14
Zn	1.36 (1.15, 1.61)	1.19 (0.92, 1.55)	0.96 (0.79, 1.15)	1.42 (1.15, 1.76)	1.01 (0.84, 1.21)	0.96 (0.74, 1.24)	1.10 (0.89, 1.37)	0.05
ng/ml								
Mn	3.47 (2.31, 5.22)	2.82 (1.48, 5.37)	2.45 (1.55, 3.86)	5.17 (3.05, 8.75)	2.86 (1.81, 4.51)	5.09 (2.70, 9.62)	2.94 (1.73, 5.01)	0.37
Se	52.57 (38.4, 72.0)	70.12 (42.7, 115.2)	49.88 (35.1, 71.0)	59.83 (40.0, 90.0)	60.02 (42.2, 85.3)	63.71 (38.8, 104.6)	72.20 (48.1, 108.4)	0.81

[abc] Different superscripts represent significant differences of ($P < 0.05$).

[*]The mean variability is presented as 95% confidence interval for variables transformed on a natural log base or as SEM for variables analyzed on the original scale.

However, all concentrations were above the reported K critical level of 9.75 mg/100 ml, which indicates deficiency in beef cattle (Underwood and Suttle, 2001). Relative to other studies, serum K concentrations were higher in our study than those reported by Khalili et al. (1993) in Ethiopia. Average plasma K concentrations were 14.35 and 15.69 mg/100 ml in yr 1 and at 15.69 and 15.33 mg/100 ml in yr 2, for wet and dry seasons, respectively (Khalili et al., 1993).

Table 3.8 Maximum, Minimum and Mean Mineral Concentrations and Percent Deficiency of Bovine Serum Samples in Louisiana

mg/100 ml	Low	High	Mean	% Deficient
Ca	3.15	11.54	9.02	8
P	6.70	19.85	13.62	0
Mg	0.63	3.19	1.92	57
K	13.07	49.29	21.66	0
Na	236.00	348.90	303.30	13
S	69.86	130.30	103.31	0
µg/ml				
Cu	0.04	1.26	0.63	40
Fe	0.99	90.75	7.44	0
Zn	0.47	12.83	1.28	0
ng/ml				
Mn	0.51	531.10	8.08	76
Se	17.85	238.40	64.48	6

Average bovine serum K concentrations of 24.88 and 13.95 mg/100 ml were reported by Gizachew et al. (2002) in the wet and dry seasons, respectively. Despite reporting all bovine serum K concentrations above critical levels, K deficiency in cattle can be caused by various factors other than the lack of K, such as malnutrition, negative N balance and endocrine malfunction (McDowell, 2003). However, one possible explanation for the increased bovine

serum K concentrations in our study is that 13% of collected forage samples were reported at concentrations higher than the K toxic levels for cattle at 3.00% (NRC, 2000).

Phosphorus concentrations are typically analyzed in serum. However, a major concern in the measurement of serum P concentration is the increased exposure of serum to blood cells, which may cause serum P to increase 1 mg/100 ml within 12 hrs of clot exposure (Herdt et al., 2000). Statewide, average bovine serum P concentration was 13.62 mg/100 ml with minimum and maximum serum P concentrations of 6.70 and 19.85 mg/100 ml. No bovine serum P concentrations were lower than the reported critical level of 4.50 mg/100 ml (McDowell, 2003). Average regional serum P concentrations were also higher than critical levels and ranged from 14.64 to 12.81 mg/100 ml, though regions were not different. Results in our study were not reflective of those in Florida, as Salih et al. (1983) reported a mean serum P concentration of 5.2 mg/100 ml and Kiatoko et al. (1982) reported mean plasma P concentrations of 6.1 and 5.2 mg/100 ml in the wet and dry seasons, respectively. Almaraz et al. (2007) reported a mean bovine serum P concentration of 6.77 mg/100 ml and Khalili et al. (1993) reported serum P concentrations in Ethiopian cattle were 11.36 and 6.99 mg/100 ml in yr 1 and 5.06 and 5.79 in yr 2 for the rainy and dry seasons, respectively. Due to the extended period of time (3 to 5d for some samples) needed to receive serum samples in our study; hemolysis may have occurred prior to centrifugation and thus could have contributed to increased bovine serum P concentrations.

Bovine serum Fe concentration is commonly used to determine Fe status in cattle and is considered deficient if serum Fe concentrations fall below 1.10 µg/ml (McDowell, 2003). Only 1 bovine serum Fe concentration was reported below this critical level. Furthermore, state serum Fe concentrations were variable and overall minimum and maximum concentrations were 0.99 and 90.75 µg/ml, with an average serum Fe concentration of 7.44 µg/ml, well above the critical

level. Additionally, all regional serum Fe concentration averages were above the critical level and ranged from 1.60 to 2.08 µg/ml. In agreement with our study, Almaraz et al. (2007) reported differences in bovine serum Fe concentrations above critical levels. However, reported concentrations were lower than those observed in our study, as the mean serum Fe concentration was 1.96 µg/ml.

Similar to Ca, blood never becomes a transport pool for Zn excretion in cases of Zn intake excess and this makes blood concentrations of Zn less sensitive to dietary intake, compared to minerals such as Se and Mg. Although 80 to 90% of Zn in blood is in depletion resistant erythrocytes, Zn serum and plasma concentrations are more dynamic, therefore making them the evaluation of choice to determine Zn status in blood (Herdt et al., 2000). Despite Zn deficiency in 26% of the forage samples, no bovine serum Zn concentrations fell below the critical level of 0.60 µg/ml Zn (McDowell, 2003). Statewide, the mean serum Zn concentration was 1.28 µg/ml, with minimum and maximum Zn concentrations of 0.47 and 12.83 µg/ml, respectively. Despite no differences, average regional serum Zn concentrations ranged from 0.96 to 1.42 µg/ml. Results in our study were similar to Gizachew et al. (2002) who reported bovine serum Zn concentrations of 1.45 and 0.91 µg/ml in the wet and dry seasons, respectively. Additionally, Salih et al. (1983) reported a mean serum Zn concentration of 0.84 µg/ml, lower than the serum Zn concentration in our study. However, McDowell (1982) showed mean serum Zn concentrations for Florida cattle in agreement with those in our study, with Zn concentrations of 1.00 and 0.90 µg/ml in the wet and dry seasons, respectively.

Despite observing deficient forage Na concentrations in all regions except the SW and SC regions, bovine serum Na concentrations were lower than the reported lower critical level of 285.06 mg/100 ml, in 13% of serum samples collected (Underwood and Suttle, 2001). The state

mean for bovine serum was 303.30 mg/100 ml and all regional average serum Na concentrations were above the critical level and minimum and maximum serum Na concentrations were observed at 236.00 and 348.90 mg/100 ml, respectively. The highest average regional serum Na concentration was 308.99 mg/100 ml and observed in the SE region, but did not differ from any regions including the lowest Na concentration of 298.71 mg/100 ml in the NE region. Though bovine serum Na concentrations are rarely measured, Ndebele et al. (2005) reported similar plasma Na concentrations in Zimbabwe cattle similar to those in our study. Average serum Na concentrations from the 5 districts were 321 and 327 mg/100 ml in the rainy and dry seasons, respectively.

Bovine serum Ca concentrations were lower than the reported critical level of 8.00 mg/100 ml in only 8% of collected serum samples (McDowell, 2003). The average state serum Ca concentration was 9.02 mg/100 ml with minimum and maximum concentrations of 3.15 and 11.54 mg/100 ml, respectively. Results indicate that Louisiana cattle maintained a mean serum Ca concentration close to 10 mg/100 ml, which according to McDowell (2003), is the serum Ca concentration typically maintained by beef cattle. However, there were no differences among average regional serum Ca concentrations. In agreement with our study, Kiatoko et al. (1982) reported no regional differences for serum Ca in Florida cattle. Furthermore, in the same study, plasma Ca concentrations were higher than the lower critical level (8.00 mg/100 ml) at 9.60 and 8.80 mg/100 ml in wet and dry seasons, respectively. Salih et al. (1983) also reported an adequate mean serum Ca concentration for cattle in Florida at 10.4 mg/100 ml. However, considerably higher serum Ca concentrations were reported by Gizachew et al. (2002) at 33.75 and 15.33 mg/100 ml in the wet and dry seasons, respectively. Increased serum Ca concentrations in cattle were also reported by Almaraz et al. (2007), with a mean bovine serum

concentration of 16.17 mg/100 ml. It is important to know, serum Ca analysis may not be accurate for the determination of mineral status because of the large stores of Ca in bone and the homeostatic mechanism that regulates blood Ca concentration (Herdt et al., 2000). Therefore, although serum Ca concentrations of cattle in our study were adequate, this may not accurately reflect the actual Ca status of these animals.

Unlike serum Ca, which may be either absorbed from the gut or mobilized from mineralized bone, serum Mg concentration is a direct reflection of Mg absorption from the gut, making serum Mg a good indicator of cattle nutritional status (Herdt et al., 2000). Bovine serum Mg concentrations were lower than the reported critical level of 2.00 mg/100 ml (Underwood and Suttle, 200l) in 57% of samples collected. Furthermore, the average state bovine serum Mg concentration of 1.92 mg/100 ml was lower than critical level, with minimum and maximum Mg concentrations of 0.63 and 3.19 mg/100 ml. Similarly, average regional serum Mg concentrations were not different and ranged from 2.07 to 1.80 mg/100 ml. Average serum Mg concentrations were also reported below serum Mg critical level in the NW, NE, CE and SE regions at 1.80, 1.94, 1.92 and 1.99 mg/100ml, respectively. Results from our study were lower than Mg concentrations reported by Salih et al. (1983) at 2.40 mg/100 ml in Florida cattle. Similarly, plasma Mg concentrations reported by Kiatoko et al. (1982) were above critical levels at 2.60 and 2.10 mg/100 ml in wet and dry seasons, respectively. Adequate serum Mg concentrations were also reported in Mexico by Almaraz et al. (2007), with a mean concentration of 3.25 mg/100 ml. One explanation for the increased number of cattle deficient in Mg may be the high number of Mg deficient forage samples (45%) collected during the trial. However, 80% of producers in our study used mineral supplementation. Nonetheless, Herdt et al. (2000) reported

that Mg is one of two nutritionally important minerals for which blood concentrations are best associated with dietary adequacy.

Serum Cu concentrations may not accurately reflect mineral status in cattle. Though low Cu concentrations indicate deficiency, adequate serum Cu levels do not necessarily indicate adequate Cu status because the liver accumulates Cu and releases it to meet physiological demands when intake is insufficient (Herdt et al., 2000). Nonetheless, bovine serum Cu concentrations collected in our study were below the lower critical level of 0.60 µg/ml indicative of Cu deficiency, in 40% of samples analyzed (McDowell, 2003). In addition, a mean bovine serum Cu concentration of 0.63 µg/ml was observed, as well as minimum and maximum concentrations of 0.04 and 1.26 µg/ml. Despite no regional difference for serum Cu concentrations, averages in the NE (0.57 µg/ml), SC (0.56 µg/ml) and SE (0.47 µg/ml) regions were lower than the reported critical level. However, adequate serum Cu concentrations higher than those observed in our study, were reported in Florida (Salih et al., 1983) with a mean serum Cu concentration of 0.90 µg/ml. McDowell et al. (1982) reported bovine serum Cu concentrations of 1.0 and 0.8 µg/ml in wet and dry seasons, respectively. Results from Salih et al. (1983) were reflective of Gizachew et al. (2002) who reported a greater serum Cu concentration in the wet season than in the dry season (0.66 µg/ml and 1.38 µg/ml, respectively). Serum Cu concentrations would be expected to be deficient, as 75% of forage Cu concentrations in our study did not meet the minimum Cu requirements for both gestating and lactating cattle.

Though variable, statewide mean bovine serum Mn concentration was 8.08 ng/ml and variable minimum and maximum Mn concentrations were 0.51 and 531.10 ng/ml, respectively. Although forage Mn concentrations were below cattle requirements in only 3% of the forage samples, 76% of the bovine serum Mn concentrations collected in our study were below the

critical level of 5 ng/ml (Underwood and Suttle, 2001). Additionally, average regional serum Mn concentrations were below the critical level in the NW (3.47 ng/ml), NE (2.82 ng/ml), CE (2.45 ng/ml), SC (2.86 ng/ml) and SE (2.94 ng/ml) regions. However, according to Hansen et al. (2006), blood Mn concentrations are variable and Mn does not have a well established liver or plasma level where the animal can be classified deficient. Manganese liver concentration is commonly analyzed because it is rich in Mn, but heart and lung tissues have been shown more reflective of status, though difficult to collect (McDowell and Suttle, 2001). Subsequently, limited literature is available for serum Mn concentrations in cattle and most researchers utilize a combination of liver (<6 ppm) and diet (<40 ppm) analysis to determine a more accurate representation of Mn status in cattle (McDowell, 2003).

Bovine serum S concentrations are questionable as indicators for S deficiency because serum sulfate may be of endogenous origin. Typically, ruminal fluid is the best indicator of S deficiency by determining whether or not samples contain sufficient sulfide for unrestricted microbial protein synthesis (McDowell, 2003). Nonetheless, McDowell (2003) suggested that serum S concentrations lower than 1 mg/100 ml may be an indicator of S deficiency. Statewide mean concentration was 103.31 mg/100 ml, with minimum and maximum S concentrations of 69.86 and 130.30 mg/100 ml, well above levels indicating deficiency. Similarly, average regional serum S concentrations did not differ and were above lower critical levels indicative of deficiency, ranging from 108.41 to 99.83 mg/100 ml. In addition, no serum S concentrations in our study were observed at deficient levels. However, similar to serum Mn, research is limited and other methods of determining S status are frequently utilized. Although, serum S and Fe concentrations were considerably greater than their respective critical levels, increased Cu

deficiency would not be a concern, as only 6 and 17% of forage samples displayed Fe and S concentrations above toxic levels.

Selenium, similar to Mg, appears to be directly absorbed from the gut based on its dietary availability with little homeostatic regulation at the level of absorption (Herdt et al., 2000). Therefore, Se serum content is a valuable means of determining Se nutritional status because serum Se concentration directly reflects its intake. Mean statewide bovine serum Se concentration was 64.48 ng/ml while minimum and maximum concentrations were 17.85 and 238.40 mg/ml, respectively. Additionally, Se concentrations in only 6% of serum samples were observed at concentrations below the lower critical level of 30 ng/ml (Salih et al., 1983). Similarly, average regional serum Se concentrations were above critical levels and ranged from 72.20 to 49.88 ng/ml. Bovine serum Se concentrations in our study were not similar to those reported by Salih et al. (1983) with a mean concentration of 6 ng/ml, but McDowell (1982) reported concentrations of 46 and 41 ng/ml, in agreement with those in our study. Dargatz and Ross (1996) reported deficient bovine serum Se concentrations in 4.8, 3.6 and 7.8% of samples for west, central and southeast regions, respectively. Furthermore, bovine serum Se concentrations in our study displayed a low percentage of deficient cattle. When comparing the number of deficient cattle in Louisiana to neighboring states in the southeast region of the Dargatz and Ross (1996) study, the number of Se adequate cattle in our study was considerably higher.

Relationship between Forage and Bovine Serum Mineral Concentrations

Overall, most forage mineral concentrations did not reflect bovine serum. Although, significant relationships were observed between forage and serum concentrations of K ($r = 0.06$), Mn ($r = 0.14$) and Zn ($r = 0.07$). However, correlation values for these minerals were extremely

low indicating a weak relationship. Values in our study, were not reflective of those reported by Ndebele et al. (2005) who showed higher herbage to animal tissue correlations of Ca (r = 0.33), P (r = 0.42), Na (r = 0.50) and Cu (r = 0.73). Correlations were also examined by Gizachew et al. (2002) and results were similar to those in our study, as the relationships of native pasture to serum minerals were not significant.

Conclusions

The research objective was to determine the state and regional mineral status of soil, water, forage and bovine serum concentrations. Overall, regional mineral concentrations were observed, although limited and displayed no significant trends in any of the variables analyzed. The SE region did display the highest soil Ca, Mg and K concentrations and water Ca, Mg, K and S concentrations, but mineral concentrations for forage and bovine serum samples in this region did not correspond with soil and water samples. With the exception of serum K concentrations in the NE region, statewide cattle mineral status did not differ regionally. Additionally, a high percentage of deficient forage concentrations in Ca (40%), P (45%), Mg (45%), Na (70%), Cu (75%) and Zn (26%) were present. Bovine serum mineral concentrations were also lower than critical levels in 57, 13, 40 and 76% of samples for Mg, Na, Cu and Mn, respectively, but displayed limited correlations with forage.

Although a high number of deficient forage samples were observed, in general, results indicated that Louisiana cattle maintained adequate mineral status using bovine serum as an indicator. Due to the fact that over 80% of producers in our study utilize mineral supplementation programs, indicates how effectively these programs are working for beef cattle producers throughout Louisiana.

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VITA

Kyle Austin Guidry was the first born child of Dennis Patrick and Catherine Brown Guidry of Estherwood, Louisiana. Kyle has one younger sibling, Todd Patrick who is currently attending University of Louisiana at Lafayette. Kyle was raised in Estherwood, Louisiana and attended Notre Dame High School in Crowley, Louisiana.

After graduating high school in May 2003, Kyle attended Louisiana State University at Eunice in Eunice, Louisiana, until May 2005. In August 2005, Kyle attended Louisiana State University, where he obtained a Bachelor of Science degree in animal, dairy and poultry sciences in May 2007. In the spring of 2006, Kyle participated in a two year undergraduate research project under the supervision of Dr. Jason E. Rowntree at the Louisiana State University Agricultural Center, Central Research Station, Beef Unit in Baton Rouge, Louisiana.

Kyle entered graduate school in June 2007 under the direction of Dr. Jason E. Rowntree. He is now a candidate for the degree of Master of Science in the School of Animal Sciences at Louisiana State University in Baton Rouge, Louisiana.