THE EFFECT OF SOIL AND PLANT SEASONAL MINERAL VARIATIONS ON GOAT PLASMA MINERAL STATUS IN SIAVONGA DISTRICT OF SOUTHERN PROVINCE OF ZAMBIA

By

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DECLARATION

I **Tapiwa Lundu** do hereby declare that this dissertation represents my own work and has not been previously submitted for the award of a degree or any other qualification at this or another University.

Signature: ---------- **Date: ----------**

CERTIFICATE OF APPROVAL

This thesis by **Tapiwa Lundu** has been approved as fulfilling the requirements for the award of the degree of Master of Science in Anatomy and Physiology by the University of Zambia.

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ABSTRACT

The status of selected minerals in soil, plants and goat plasma in Siavonga district of Zambia was evaluated in the rainy, cold dry and the hot dry seasons between November 2009 and June 2010. Samples were collected in November 2009 (late hot dry season), February 2010 (rainy season) and June 2010 (cold dry season) and analysed for content of Phosphorus, Calcium, Potassium, Magnesium, Copper, Iron and Molybdenum. In addition to the minerals, soil was also analysed for pH. Thirteen plant species consumed by free ranging goats: *Balanites aegyptiaca*, *Eleusine coracana*, *Azadirachta indica*, *Amaranthus spinosum*, *Lonchocarpus capassa*, *Acacia jelad*, *Xanthocersis zambesiaca*, *Berchemia discolour*, *Tamarindus indica*, *Paspalum dilatum*, *Acacia atothiris, Maesopsis eminii*, *Colophospermum mopane* were collected and analysed for their comparative seasonal mineral content. Molybdenum could not be detected in all the three sample types at a detection limit of 0.02mg/L. In the soil samples, all the six minerals were significantly higher ($p<0.05$) in the hot dry season than in the cold dry and the wet seasons. Soil pH showed no significant seasonal variation. Pooled results show that plant Phosphorus and Potassium concentrations were significantly higher ($p<0.05$) in the hot dry season than in the wet and cold dry seasons. Concentrations of Calcium and Copper were significantly higher ($p<0.05$) in the cold dry season than in the hot dry and wet seasons. Magnesium and Iron concentrations were significantly higher ($p<0.05$) in the wet season than in the hot dry and the cold dry seasons. Mean plasma Phosphorus and Magnesium were significantly higher ($p<0.05$) in the hot dry season than in the cold dry and the wet seasons. Calcium concentrations were significantly higher ($p<0.05$) in the cold dry season than in the hot dry and the wet seasons. Potassium concentrations were significantly different in all the seasons ($p<0.05$), being highest in the hot dry season and lowest in the cold dry season. Plasma Copper was significantly higher ($p<0.05$) in the wet season than in the cold dry and hot dry seasons. Iron concentrations were significantly different in all the seasons ($p<0.05$), the highest was observed in the cold dry season and the lowest in the hot dry season. Therefore, season has been shown to affect concentrations of Phosphorus, Calcium, Magnesium, Potassium, Copper and Iron in soil, plant material and goat plasma. This

work will provide baseline information to farmers and animal nutritionists on the seasonality of minerals in soil, plant material and goat plasma, which is essential for formulating supplements to improve productivity of goats.

DEDICATION

This thesis is dedicated to:

My husband Kondwani,

For your love, support and understanding

My brother and sisters,

For believing in me

My daughter Muwemi,

For making everything worthwhile

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LIST OF SYMBOLS AND ABBREVIATIONS

%	Percentage
<	Less than
°C	Degrees Celsius
-	Negative
/	Per
µg	Microgram
mg	Milligram
g	Gram
kg	kilogram
ppm	Parts per million
mm	Millimeters
rpm	Revolutions per minute
cm	Centimeter
No.	Number
nm	Nanometer
dm^3	Cubic decimetre
dm^{-3}	Per cubic decimetre
SEM	Standard error of the mean
DM	Dry Matter
SS	Sum of Squares

MS	Mean Squares
df	Degrees of freedom
dL	Decilitre
L	Litre
M	Molar
hr	Hour
mmol	Millimole
meq	Milliequivalent
p	Probability
DTPA	Diethylenetriaminepenta-acetic acid pentasodium salt
TEA	Triethanolamine

CHAPTER ONE

1.0 INTRODUCTION

Livestock are a source of essential food products, employment and income for both rural and urban populations. Animal draft power contributes directly to increased agricultural production in general and food security in particular. Livestock production has in general been affected by poor animal nutrition, animal diseases and increased costs of veterinary inputs. The drought which occurred in Zambia between 1991 and 1992 led to an increase in health and nutritional problems of livestock especially in the traditional sector, resulting in large livestock losses. Sporadic outbreaks of Corridor disease, African Swine Fever, Black Quarter, Newcastle disease, Contagious Bovine Pleuro Pneumonia and Trypanosomiasis have had a negative impact on livestock production in the country. The above factors have resulted in high mortalities among farm animals. Goats have demonstrated resistance to most of the cattle diseases and a remarkable ability to survive extended periods of drought. They have acted as life savers, especially for the resource-poor rural farmers (Lungu, 1998).

Africa's goat population increased by 75% between 1980 and 2005 and constitutes 30% of the world goat population (Simela and Merkel, 2008). Although Africa produces about 20% of the world's chevon, its share of world chevon market has been declining. Exports from Africa represent less than 5% of the total world trade. This is because most goats in Africa are raised by smallholder farmers for subsistence and trading in informal markets. Until recently, cattle production has been the principal concern of government livestock policies in Zambia, mainly because of the greater individual value of cattle and their contribution to the national economy (MACO, 2003).Goat production is increasingly playing an important role in most households in Zambia. It is mainly at the subsistence level, which involves the production of a few goats to meet household needs mainly for meat and as a source of income for the family.

Some of the constraints to goat production in Zambia are insufficient feed, inadequate disease control and prevention measures and unsanitary conditions, (Ahmadu and Lovelace, 2002). Insufficient nutrition due to restricted feeding increases disease susceptibility (Maiga, 1992). Kids are the most vulnerable group of the flock and any attempt made to ensure their survival is bound to increase productivity and economic returns to the farmer.

Ruminants obtain most of their nutrients from natural grasslands. Consequently, ruminant production systems become susceptible to seasonal changes in the availability and nutrient value of the natural grasslands. Studies done in Zimbabwe (Hatendi, 1991) showed that for several months of the year during the dry season, ruminants may be unable to eat enough herbage to supply their nutrient requirements, which may result in impaired productivity. The fact that goats can survive in environments where sheep and cattle cannot survive has led to erroneous assumptions about their nutritional requirements. Some people believe that goats can survive on almost anything including paper and plastics. Yet what they do not understand is that selection of browse is the most important factor in survival under harsh conditions. Goats are able to utilize a broad range of forage species and to select forage material with high nutrient concentration (Lovelace *et al*., 1993; Narjisse 1991).

Browse leaves and pods form a natural part of the diet of goats, which meets over 60% of the forage requirements (Aganga *et al.*, 2000). Despite the fact that most of the mineral requirements of goats can be supplied by the browse plants, their mineral content is also affected by season and soil type. Supplementation is therefore recommended in many areas especially during the dry season (Aganga and Mesho, 2008; McDowell, 1997). The concentration of individual minerals in forages varies greatly depending on soil, plant and management factors (Haenlein, 1991).

For most minerals, determination of total dietary mineral concentration provides a useful overall indicator of the adequacy of mineral nutrition available to the goat. Dietary analysis also forms the basis for understanding the seasonal nature of mineral deficiencies in grazing goats. Measurement of minerals in blood and animal tissues

potentially offer the best indicator of mineral nutrition in the goat, as they account for dietary selection and the variable uptake and availability of minerals.

This study involved goats owned by villagers in Siavonga district in the Zambezi Valley of the Southern Province, which is one of the districts with the largest number of goats in Zambia. The goats were followed seasonally to observe effects of season on mineral levels in plasma. Plants that are commonly browsed by these goats, as well as soil were also collected for similar analyses.

1.1 Study justification

Mineral deficiencies, imbalances and toxicities have been reported to inhibit tropical ruminant production systems (Pastrana *et al.*, 1991). Previous studies on Zambian Goats have shown that these goats have a high production potential, which is yet to be fully exploited by goat keepers in the country. Ahmadu and Lovelace, (2002) reported in one of their studies that poor nutrition contributed to low growth rates and mortalities of goats in Zambia.

There is, however a lack of knowledge on the status of mineral nutrition in goats in Zambia. Thus, it is necessary to obtain information on the mineral status of goats to establish baseline data that is essential for formulating ways of supplementing minerals to improve goat production, enhance income generation and to assess whether the consumer of goat meat obtains the essential elements from the meat. This work will provide baseline information to farmers and animal nutritionists on the seasonality of minerals in goat plasma, plant material and soil, which is essential for formulating supplements to improve productivity. It will provide a description of phosphorus, calcium, magnesium, potassium, copper, molybdenum and iron levels in goats for diagnosing deficiencies and toxicities in order to institute corrective or preventive measures.

1.2 Study objectives

1.2.1 General objective

The general objective of the study was to determine the status of selected essential minerals in soil, plant material and goat plasma in Siavonga District of Southern Province of Zambia.

1.2.2 Specific objectives

The specific objectives of this study were as follows:

1. To determine the pH and status of phosphorus, calcium, magnesium, potassium, copper, molybdenum and iron in soil in the hot dry, cold dry and wet season.
2. To determine the status of phosphorus, calcium, magnesium, potassium, copper, molybdenum and iron in plant material in the hot dry, cold dry and wet season.
3. To determine the status of phosphorus, calcium, magnesium, potassium, copper, molybdenum and iron in goat plasma in the hot dry, cold dry and wet season.
4. To compare seasonally, the levels of these minerals in soil, plant material and goat plasma.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Distribution of Zambian goats

Goats, which are important in the marginal areas of Zambia are widely distributed throughout the country, but over 60% are in river valley areas and semi-arid regions (CSO, 1997), which are characterized by poor crop production and cannot support cattle production because of trypanasomiasis and feed scarcity (Ahmadu *et al.*, 2000; DAPH, 1993). The adaptability of goats, their prolificacy and modest nutrient requirements make them well adapted to poor marginal lands (Ahmadu *et al.*, 2000).

A 2003 estimate showed the population of goats in Zambia to be at about 2 million with 95 percent of these being owned by traditional farmers (DVLD, 2003). More recent reports on goat populations in Zambia have shown a marked reduction in the population. Currently there are about seven hundred and fifty nine thousand goats in the national flock with Southern Province contributing the highest number (DVLD, 2009). The reasons for this decrease in goat population are not very clear at this stage but these are the figures reported by DVLD.

Goats have a number of beneficial characteristics which make them a useful asset to small scale farmers. They generally use feed not being used elsewhere in the household; they are prolific and are a convenient protein source. There is need to carry out research on these small ruminants in order to come up with ways of improving productivity and hence improve food security and income for households.

Siavonga district in Southern Province was selected to be our study area. The district was chosen because it is one of the highest goat producing districts in the province.

2.2 Types of Goats found in Zambia

Zambian goats are believed to originate from the present day Zimbabwe (the Matebele and Shona Kingdoms). There are many indigenous types (Mwenya, 2001) which are further described by the locality within which they are found. In the Southern half of the country three different types have been identified:

i. **The South East African Dwarf Goat or Gwembe Valley goat:** This is a small sized goat found predominantly in the Gwembe valley in Southern Province. The goat has adapted to hot and dry climatic conditions with low rainfall patterns. There are variations in coat colour ranging from completely black, brown, black and white, grey to white and brown. The horns are of medium size and curved backwards (MACO, 2003; Chisanga and Mwenya, 1998).

ii. **The Plateau Goat:** a medium sized breed found on the plateau areas and appears to be widely distributed in the country. Colours vary from black, brown and roan with or without white markings. The goats are short with fine and glossy coats (Chisanga and Mwenya, 1998);

iii. **The Valley Goat:** it is a larger breed found in most of the southern half of the country and the northern parts of the Zambezi escarpment and Luangwa valley The breed has several colours white, black, brown and grey as the main colours and a combination of these colours is rare (MACO, 2003; Chisanga and Mwenya, 1998);

Recently, some exotic breeds of goats have been introduced into the country by Non Governmental Organisations (NGOs), private individuals and farmers. These breeds have high performance traits with respect to meat and milk yield. These are namely;

i. **The Boer goat;** an exotic meat breed from South Africa. The Boer goat project in Zambia was introduced in 1999 with the objectives of: exploring ways and means of increasing the rate of multiplication of the Boer goat herd; and, enhancing productivity of local goat breeds through the provision of bucks with higher productive potential (GART, 2007).

ii. **The Saanen goat;** This is a dairy breed that is being promoted among the small-scale farmer groups in Zambia. It was imported from East Africa (Kenya, and Tanzania) into Zambia. (MACO, 2003).

2.3 Importance of goats

Goats are used for diverse purposes in different parts of the world. These include meat, milk, mohair fibre production, cheese production, and skins for leather making. Meat production is the major use of goats worldwide, particularly in Asia, Africa, the Middle East, and Latin America (Smith and Sherman, 1994). In Zambia, goats are mainly used as a source of meat protein; they serve as gifts at funerals, weddings and as dowry. They also serve as barter objects and are kept as assets that can easily be liquidated (MACO, 2003).

2.4 Nutrient Requirements for Goats

Nutrients are substances that aid in the support of life for animals. Meat goats require nutrients for body maintenance, growth, reproduction and production of products such as meat, milk and hair. The groups of nutrients that are essential in goat nutrition are energy, protein, minerals and vitamins (Mcdowell, 2003; Suttle, 2010; Luginbuhl and Poore, 1998). Weaners, followed by does during the last month of gestation and high lactating does, and yearlings, require a higher quality diet than average lactating does, adult bucks and dry does. In order to feed them adequately, goats should be grouped

according to their nutritional needs. Therefore, does during the last month of gestation, high lactating does and yearlings should be grouped and fed separately from the rest of the herd having lower nutritional needs. In a grazing situation, goats having the highest nutritional requirements should have access to lush, leafy forage or high quality browse. In a barn feeding situation such as during some winter months, these same goats should be offered the highest quality hay available. Whether grazed or barn fed, goats should be supplemented with a concentrate feed when either the forage that they are grazing or the hay that they are fed do not contain the necessary nutrients to cover their nutritional requirements.

2.5 Minerals in goat nutrition

Inorganic nutrients are called minerals. Minerals are subdivided into macro and micro minerals. Macro minerals are those required in concentrations greater than 100 ppm (parts per million) and often as a percentage of the diet (or g per kg) per day (McDowell, 2003). Micro minerals are required in smaller quantities of less than 100 ppm and are expressed as ppm and sometimes as ppb (parts per million). Macro minerals include Calcium (Ca), Phosphorus (P), Sodium (Na), Potassium (K), Chloride (Cl^-), Sulfur (S) and Magnesium (Mg). Micro minerals include Iron (Fe), Copper (Cu), Cobalt (Co), Manganese (Mn), Zinc (Zn), Iodine (I), Selenium (Se), Molybdenum (Mo), Fluoride (F^-) and Chromium (Cr), (Suttle, 2010). Goats require many minerals for basic body function and optimum production. The mineral requirements for goats are not as well known as they are for other livestock species and have often been extrapolated from sheep or cattle requirements due to lack of studies in goats. As such, mineral recommendations for goats often have a wide range because of lack of accurate goat-specific information.

Calcium, Phosphorus, Magnesium and Potassium were the macro minerals that were investigated in this study. The micro minerals studied were Iron, Copper and Molybdenum. Selection of these minerals was based on their importance in the diet of

goats. These minerals are also known to interact with one another in various ways, for example, the synergy between Calcium and Phosphorus can be achieved when they are present in the diet at a ratio of 2 to 1.

Calcium and Phosphorus are major structural components of bones and teeth. Calcium is also necessary for muscle contraction, nerve conduction and blood clotting. Most forage are high in Calcium, so Calcium is low only if high grain diets are fed, which would be unusual for goats. The main deficiency symptoms are seen in the skeletal system. Bones can become soft and weak and may be deformed, resulting in lameness. This condition is called rickets in young animals, and osteomalacia in adult animals (Hart, 2008). Milk is relatively high in Calcium, and lactating goats need adequate levels of calcium for milk production. Does can get hypocalcemia or milk fever, while lactating. This condition is caused by a metabolic disorder that leads to a shortage of Calcium in the blood due to Calcium being used for milk production. Urinary calculi are a condition brought about in part by an imbalance in the Calcium to Phosphorus ratio in the diet. The condition is caused by feeding goats a high phosphorus diet. The disease occurs when calculi (stones), usually comprised of phosphate salts, lodge in the urinary tract and prevent urination. Normally, phosphorus is recycled through saliva and excreted via feces in ruminants. High grain, low roughage diets decrease the formation of saliva and therefore increase the amount of phosphorus excreted in the urine. Lack of water and water sources that are high in minerals are also contributing factors.Generally, twice as much Calcium as Phosphorus should be in the diet of ruminant animals. An excess of calcium can cause abnormal bone growth (Hart, 2008; Mcdowell, 2003; Suttle, 2010).

Phosphorus is essential in energy metabolism and acid-base balance and is a constituent of enzymes and genetic material (Hart, 2008). Low quality, weathered forages will be deficient in phosphorus, especially for high and average lactating does. The major symptoms of phosphorus deficiency include reduced growth, listlessness, unkempt appearance, depressed fertility, pica (depraved appetite, eating wood, rocks and bones) and decreased serum phosphorus (Hart, 2008; Mcdowell, 2003; Suttle, 2010). Phosphorus deficiency is the most widespread and economically important mineral

deficiency of grazing livestock. This is attributed to the fact that most Zambian soils are reported to be deficient in Phosphorus (Yerokun, 2008).

Magnesium is required for normal skeletal development, nervous and muscular system functions and for enzyme systems. It is also closely associated with metabolism of Calcium and Phosphorus (Hart, 2008). Grass tetany can occur when goats in early lactation are grazing lush, leafy small grain, annual ryegrass of grass/legume pastures. Under those conditions, it is advisable to provide a mineral mix that contains 5 to 10 percent magnesium (Luginbuhl and Poore, 1998).

Potassium functions as an electrolyte in the body alongside Sodium and Chloride. They are also essential in transmission of nerve impulses (Hart, 2008). These minerals are highly water soluble and are easily lost with diarrhea. A deficiency of Potassium could occur on high concentrate diets, with symptoms including poor appetite, urinary calculi, body stiffness progressing from front to rear and pica. Certain minerals are significant because they interfere with the use of other nutrients and not because they are deficient in forage. For example, high intake of Potassium can lead to a decrease in the absorption of Magnesium; similarly, high intake of Molybdenum and Iron can reduce the availability of dietary copper and thus may induce a deficiency syndrome for copper (Grace and Lee, 1990).

Copper is essential in formation of red blood cells, hair pigmentation, connective tissue and enzymes (Hart, 2008). It is also important in normal immune system function and nerve conduction. Deficiency symptoms include anemia, bleached looking and rough hair coat, diarrhea and weight loss. High dietary molybdenum can depress absorption of copper and cause a deficiency. There should be at least four times as much copper as molybdenum in the diet (Hart, 2008; Kessler, 1991).

Molybdenum is a vital part of three important enzyme systems, *xanthine oxidase, aldehyde oxidase,* and *sulfite oxidase.* It has a vital role in uric acid formation and iron utilization, in carbohydrate metabolism, and sulfite detoxification. Molybdenum deficiencies are very rare. Toxicity occurs above 3 ppm due to reduced copper

absorption, resulting in a copper deficiency. High dietary levels of molybdenum are usually related to soil content (Hart, 2008).

Iron is essential for the formation of the red blood cell pigment, hemoglobin, required for oxygen transport. It is also a component of certain enzymes such as cytochrome oxidase and catalase (Smith and Sherman, 1994). Grazing animals rarely develop iron deficiency except in association with continual blood loss. The major iron deficiency symptom is anemia. Milk is very low in iron; therefore, kids raised for a long time on milk alone will develop anemia. Soil contamination on forages can provide significant levels of dietary iron (Hart, 2008).

2.6 The Pasture Resource

2.6.1 Natural Grassland

Natural pastures form the basis of ruminant production. Most pastures in Zambia are savanna-type grasslands and over half of the country is covered by trees, varying from more open conditions in the south to the tall, dense woodlands in the north and northwest. True grasslands are those areas which are naturally without trees and are found in places with a permanently high water table. Grasslands in Zambia cover 27% of the total land mass; they range from pure grasslands to those with scattered trees (Aregheore, 2006). In seasonal rainfall areas, the quality of perennial grasses rapidly decreases in the early part of the wet season before reaching the flowering stage.

At the beginning of the rainy season young grass has a high concentration of nutrients. As the season advances, there is a drastic reduction in the content of proteins and other nutrients and a rapid increase in fiber. With the onset of the dry season growth stops, the herbage dries and its palatability decreases. Levels of vitamins and minerals, which are high at the beginning of the rainy season, are almost nonexistent towards the end of the dry season. Natural grassland is dominated by *Hyparrhenia* species especially *Hyparrhenia filipendula* which is frequently burnt during the dry season (Aregheore, 2006).

2.6.2 Browse plants and fodder trees

Browse leaves and pods form a natural part of the diet of goats, which meets over 60% of the forage requirements and have been used by traditional farmers as sources of forage in Botswana (Aganga *et al.,* 2000). Tree fodders are important sources of high quality feed for grazing ruminants and as supplements to improve the productivity of herbivores fed low quality feeds. In the savanna, the availability of palatable species varies in accordance with the season. During the dry season, grass is dry, unpalatable, of poor feed value and the quantity is inadequate. On the other hand, browse plants provide fresh green forage with new shoots, flowers and fruit.

Fodder tree/shrub legumes have the potential for alleviating some of the feed shortages and nutritional deficiencies experienced in the dry season on smallholder farms in Zambia. Fodder trees are very important in the valley where grass grows for a short period only due to scarcity of rain. Zambia has a wide range of naturally occurring tree/shrub species that can be used as fodder for ruminants (Mulofwa *et al.,* 1994). Over the years a number of trees have been selected for their agronomic qualities and are currently being used in arable farming systems to promote soil fertility and control erosion. Some of the important tree species that have been suggested by Mulofwa *et al.* (1994) for use as fodder in Zambia's southern province are listed below with their corresponding local (Tonga) names:

Botanical name	**Local name**
• *Faidherbia albida*	Musangu
• *Parinari curatellifolia*	Mubula
• *Piliostigma thonningii*	Musekese
• *Ficus* species	Mukuyu
• *Dicrostachys cinerea*	Katenge
• *Ziziphus mauritiana*	Musau
• *Tamarindus indica*	Musiika
• *Diospyros kirkii*	Muchenjelekete

- *Leucaena leucocephala* Lukina

Because of their high content of protein, minerals and vitamins and availability in the dry season, fodder tree/shrub legumes have the capacity to complement the feeding of crop-residues and natural pastures. Tree/shrub legumes also have other advantages in that they are available on-farm and can also be used as a source of feed, timber and medicines at village level. However, the presence of anti-nutrients, in particular tannins can limit animal performance; particularly foliage if fed in large quantities (Simbaya, 2002; D'mello, 1992). A number of technologies including, wilting, sun-drying, treatment with chemicals and ammoniation have been developed and available to increase the use of foliage from trees and shrubs (Simbaya, 2002). However, towards the end of the dry season there is usually a substantial amount of green fodder from exotic planted and naturally occurring trees.

2.7 Mineral status of soils

Soils of the tropics are variable in their chemistry and fertility, ranging from the most fertile to the most infertile in the world (Sanchez and Logan 1992). Mineral deficiencies and imbalances in soils and forages often inhibit livestock production in tropical and sub tropical parts of the world (McDowell, 1985). This is because mineral content of a plant depends to some extent on the mineral content of the soil (Mtimuni, 1982). Deficiencies of minerals in soils of the tropics have been reported. In Zambia however, information on the mineral status of soil is scanty. This may be because little work has been done or data has not been published. The availability of phosphorus in Zambian Alfisols, Ultisols and Oxisols, the dominant agricultural soils in the country, is relatively low (Yerokun, 2008). This finding is supported by results of a Food and Agricultural Organisation (FAO) funded study done to assess the deficiencies of macro and micro minerals in soils of Choma, Monze and Kalomo towns in the Southern Province of Zambia (FAO, 2010). The study showed that about 83 percent of the 124 soils tested had low levels or were deficient in P, while only 8.9 percent had high levels of P and 5.6

percent had intermediate levels of P (FAO, 2010). These results clearly showed that the majority of the cultivated soils tested had a problem of limited supply of P for crop production. Copper and Phosphorus deficiencies were also reported in Zambia by Rees in 1978. In Ethiopia, Phosphorus was low in soils as reported by Khalili et al, (1993). Investigations on macro-mineral status of soil in Pakistan suggested that Calcium, Phosphorus and Potassium were deficient but Magnesium was slightly higher (Pasha *et al.,* 2009).

According to FAO (2010) only about 27 percent of the soils sampled had low levels of K or could be considered to be deficient in K. The majority had sufficient reserves of K to meet the requirements of most plants. About 43 percent had high levels of K. Of the three districts that were sampled, there was widespread deficiency of K in the soils from Kalomo, where 75 percent of the soil sampled were deficient in K. Soils from Monze, on the other hand appeared to have very few cases of K deficiency while Choma had a few cases, about 9 or 22.5 percent of K deficiency. The occurrence of magnesium deficiency was low in the soils from the three districts with a frequency of about 5.7 percent. Magnesium was therefore not a likely limiting macronutrient in most soils from these three districts (FAO, 2010). Calcium deficiencies are not common in soils that are not highly weathered and highly leached. Most soils in the Southern Province of Zambia are not highly weathered and highly leached though many are acidic. None of the soil samples that were tested indicated having low levels of calcium or deficiencies of calcium (FAO, 2010). Iron deficiency is usually associated with leached sandy soils, alkaline soils and soils high in Phosphorus (Jones, 1998). FAO (2010) reported that approximately 83 percent of the soils tested contained adequate levels of Fe to meet the requirements of most crops. None of the soils from Choma had deficiencies of Fe, while 9.4 percent of soils from Kalomo and about 9.6 percent of the soils from Monze indicated deficiencies of iron. Iron therefore was not a major limiting micronutrient to crop production in most soils of the three districts investigated. The status of copper was also assessed by FAO in 2010. A majority of the soils tested, approximately 98 percent had adequate amounts of copper for the requirements of most crops, and only 2 percent were deficient in copper. From these results it was evident that copper deficiencies in the soils were very uncommon and that copper was unlikely to be a limiting

micronutrient to crop production in most of the soils in Kalomo, Choma and Monze Districts.

Many other factors affect soil mineral content, availability of minerals to plants and availability of minerals in forages grazed by animals. It is therefore difficult to single out one or two factors that explain most of the variation in mineral content of animal tissues, plants and soils. Thus, site specific analyses and management of soil will be increasingly necessary as demands grow on soils of the tropics for animal production (Sanchez and Logan 1992).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

The study was carried out in Lusitu and Simamba areas of Siavonga district, situated approximately 152.4 km south of Lusaka, Zambia. These are rural areas with subsistence farming being the major activity. Animal husbandry is dominated by goat production based on free range management. Siavonga is one of the districts with the largest population of goats in Zambia. The goat population was estimated to be about 45,272 (DVLD, 2008). A few farmers keep sheep and cattle. This is because the population of these animals has been reduced by the effects of tick borne diseases and droughts.

The study area has a mountainous landscape, lying about 950 meters above sea level. The climate is characterized by high temperatures of above 29°C and annual rainfall of less than 800 mm. The vegetation is predominantly Mopane woodlands and baobab trees.

Figure 1 Map of Zambia showing study area in Siavonga, Southern Province

3.2 Study animals

The breed of goats reared in the study area is the South East African Dwarf Goat or Gwembe Valley Goat. This breed of goat is found predominantly in the Gwembe valley in Southern Province. The goat has adapted to hot and dry climatic conditions with low rainfall patterns. It has a small body size and a coat colour ranging from completely black, brown, black and white, grey to white and brown. The horns are of medium size and curved backwards (MACO, 2003; Chisanga and Mwenya, 1998). The study goats were not supplemented; they depended on naturally occurring browse plants and grass for their nutritional requirements.

3.3 Study design

A multistage sampling method was used. The primary sampling units were households with night shelter for goats and the secondary sampling units being adult female goats aged between 2 and 3 years.

3.3.1 Sampling period

Sampling was done in the wet season (February), cold dry season (June) and the hot dry season (November). For the purpose of this study wet season includes the months from December to April, cold dry season is from May to August and hot dry season is from September to November. Each area was visited once in each season. At each visit, soil, plant and blood samples were collected.

3.3.2 Sample size calculation

The sample size for the goats used in this study was calculated using the equation for a study comparing two means (Eng, 2003) as shown below

$$N=4\sigma^2 (Z_{crit} + Z_{pwr}) \square D^2$$

Where;

- N is the total sample size (the sum of the sizes of both comparison groups)
- σ is the assumed standard deviation (assumed to be equal for both groups)
- Z_{crit} value is the desired significance criterion
- Z_{pwr} is the desired statistical power
- D is the minimum expected difference between the two means

σ was assumed to be 0.51 which is approximately the average of the standard deviation found between the northern and southern regions of Malawi in a study done on Cattle (Mtimuni, 1982).

Based on the same study, D was assumed to be 0.2. This was the difference in the mean Cu concentration between the two regions of Malawi.

The significance criterion was set at $p < 0.05$, the corresponding Z_{crit} was therefore 1.96.

The statistical power was set at 0.80 with a Z_{pwr} value of 0.842.

The calculated sample size was:

$$N=4*0.51^2(1.96+0.842)/0.2^2$$

$$N=72$$

A total of 72 goats were recruited in the study. Thirty six of these goats were from Lusitu and the other 36 were from Simamba. To achieve this sample size, 7 households were recruited in each of the two areas. Five goats were sampled per household in each season. One extra goat was sampled from one household in each area to bring the total number of goats to 72. Therefore, the total number of samples for the three seasons was expected to be; 72 goats * 3 seasons = 216 goats.

3.3.3 Goat identification

The selected goats were identified using numbered ear tags. This was done in order that the same goats would be sampled at each subsequent visit.

3.4 Sample collection and preparation for analysis

3.4.1 Soil sampling and preparation for analysis

Soil was collected from ten randomly selected sites at each of the sites where the plants were sampled from. The soil was then mixed to come up with one composite sample for each village. Soil samples were collected using a stainless steel sampling Auger, at a depth of approximately 20 cm.

At the laboratory, the soil was dried at 60°C for 48 hrs and stored in plastic bags prior to analysis.

In the dry season, an extra soil sample was collected from one more village which later became inaccessible during the wet season. The number of samples collected from each area in the three seasons was as follows:

Lusitu: hot dry season, 4 samples; Cold dry season, 3 samples; Wet season, 3 samples.

Simamba: hot dry season, 2 samples; Cold dry season, 2 samples; Wet season, 2 samples. This therefore implies that a total of sixteen soil samples were collected in the three seasons.

3.4.2 Plant sampling and preparation for analysis

Plant samples were collected from plants commonly browsed by the goats. This was based on information provided by the goat herders. In Lusitu, plant samples were collected from three sites as households were sharing the pastures. In Simamba, samples were obtained from two sites. The samples were collected by cutting grass close to the ground and leaves from browse plants. The plant samples were dried in an oven for 48 hrs at 60°C. The dried plant samples were then ground to pass through a 1 mm screen mesh and stored in labelled paper bags.

3.4.3 Blood sampling and preparation for analysis

Blood samples were collected in heparinised vacutainer tubes through jugular venipuncture. The blood was kept on ice in a cool box and plasma was harvested by centrifugation at 1500 rpm for 10 minutes. The plasma was transported to the laboratory in a cool box. At the laboratory, plasma was kept frozen at -20°c prior to analysis.

3.5 Sample analysis

3.5.1 Soil sample analysis

3.5.1.1 pH determination

Twenty five milliliters of calcium chloride ($CaCl_2$) were added to 10 g of soil. The mixture was shaken for 10 minutes on a mechanical shaker. The mixture was then allowed to stand for a further 30 minutes before reading the pH on a pH meter.

3.5.1.2 Extraction and determination of macro minerals

Two methods were employed as follows:

i. Extraction and determination of available Phosphorus

The Bray 1 method was used (Bray and Kurtz, 1945). Three grams of dried soil (passed through a 2mm sieve) were weighed into a 15ml centrifuge tube and 21 ml of the extracting solution (see appendix A1) was added. The mixture was shaken for 1 minute on a mechanical shaker after which it was filtered through a No. 42 Whitman filter paper. Five millilitres of the filtrate were pipetted into a 25ml volumetric flask. Approximately 10ml of distilled water was then added. Four millilitres of reagent B (see appendix A3) was added and the volume was made up to the mark with distilled water.

The colour was allowed to develop for 15 minutes and P-content in the solution was determined on a spectrophotometer at 882 nm.

ii. Extraction and determination of the exchangeable cations (Ca^{2+}, $Mg^{2+}$and K^{+})

Ten grams of air dried soil was weighed, passed through a 2mm sieve and put into a 250 ml Erlenmeyer flask. Fifty millilitres of ammonium acetate (CH_3COONH_4), pH 7.0 was added to the soil. The mixture was shaken for 30 minutes on a mechanical shaker. The suspension was filtered using No. 42 Whitman filter paper. Potassium ion, Ca^{2+} and Mg^{2+} were measured in the filtrate after diluting samples with $SrCl_2.6H_2O$ by atomic absorption spectroscopy.

3.5.1.3 Extraction and determination of micro minerals (Cu, Fe and Mo)

Twenty grams air-dry soil was mixed with 40ml of the DTPA-TEA extracting solution. The mixture was shaken mechanically for 2 hrs. The suspension was filtered through a No. 42 Whitman filter paper. The individual elements were read on an atomic absorption spectrophotometer.

3.5.2 Plant sample analysis

Samples were analysed for concentrations of Ca, P, Mg, K, Cu, Fe and Mo. Plant samples were processed by wet digestion using nitric acid (HNO_3) and perchloric acid ($HClO_4$). One gram of sample was accurately weighed into a 250 ml volumetric flask. Twenty five millilitres of concentrated nitric acid was added and the plant material was digested on a hot plate until all organic matter had been digested. The flask was removed from the hot plate and allowed to cool. Ten millilitres of distilled water followed by 10 ml concentrated perchloric acid was added and the flask was put back onto the hot plate until dense white fumes emerged from the digest. The flask was removed from the hot plate and 25 ml distilled water was added after cooling. The

material was brought to boil and was then filtered into a 100 ml volumetric flask after cooling. The filtrate was topped up to the mark with distilled water. Potassium, Ca, and Mg were measured in the filtrate after diluting samples with strontium chloride ($SrCl_2.6H_2O$) while Cu, Fe and Mo were measured directly from the filtrate. The respective elements were read on an atomic absorption spectrophotometer (Perkin-Elmer, Model 2380). Phosphorus was determined on a spectrophotometer at 882nm after development of molybdenum blue colour by reacting ammonium molybdate in acid solution with ascorbic acid.

3.5.3 Plasma sample analysis

Plasma samples were deproteinised by adding 3 ml of 10 % Trichloroacetic acid (TCA) to 3 ml of plasma. Plasma was then wet digested using nitric and Perchloric acids as outlined above.

3.6 Statistical analysis

Data was analysed using excel and Statistical Package for Social Scientists (SPSS) version 16.0. The mean and standard error of the mean of mineral concentrations in goat plasma, plant material and soil were calculated. One way Analysis of Variance (ANOVA) was used to compare differences in mineral concentration among seasons. Benferroni t tests were conducted to test for significant differences between seasons. The student's t test was used to compare differences in mean concentrations between Lusitu and Simamba. Throughout significance was declared at p less than 0.05. Plasma, Plant and soil data was then compared with recommended critical levels.

Plasma minerals were compared with the following critical levels:

Ca: 2.6 mmol/L; P: 1.4 mmol/L; Mg: 1.3 mmol/L; K: 5.1 mmol/L; Fe: 166-222 µg/dL; Cu: 58-160 µg/dL (Kaneko, 1980).

Plant minerals were compared with the following critical levels:

Ca: 1.3-3.3 g/kg DM in the diet; P: 1.6-3.8 g/kg DM; K: 1.8-2.5 g/kg DM; Mg: 0.8-2.5 g/kg DM; Cu: 8-10 mg/kg DM; Fe: 30-40 mg/kg DM (NRC, 1981; Kessler, 1991).

Soil minerals were compared with the following critical levels:

Ca 0.35 meq/100g soil (Breland 1976); P 10 mg/kg (Sanchez, 1976); K 0.15 meq/100g soil (Landon, 1984); Mg 0.07 meq/100g soil (Breland, 1976); Cu 0.75 mg/kg (Landon, 1984) and Fe 19 mg/kg (Conrad et al., 1980).

CHAPTER FOUR

4.0 RESULTS

During the period from November 2009 to June 2010, a total of 16 soil samples, 43 plant and 191 plasma samples were collected and analysed for their mineral content. A total of seven minerals were investigated in each of the samples. The results recorded here are for six minerals only, i.e., Phosphorus (P), Potassium (K), Magnesium (Mg), Calcium (Ca), Copper (Cu) and Iron (Fe) as Molybdenum (Mo) could not be detected in all the three sample types at a detection limit of 0.02 mg/L.

4.1 Soil

For each season, the mean and standard error of the mean for soil minerals in Lusitu and Simamba were calculated. The means and standard error of the mean for soil mineral concentrations are summarized in table 1 below. It is important to note that the units for critical levels for soil minerals were converted from milliequivalent per hundred grams (meq/100g) soil to milligrams per kilogram soil. Results for single factor ANOVA used to compare soil mineral levels among the three seasons in Lusitu and Simamba are shown in appendix table D-1 and appendix table D-2, respectively. Benferroni t tests performed to determine differences between specific pairs of seasons for Lusitu and Simamba are shown in Appendix E-1 and Appendix E-2 respectively.

Table 1 Mean soil mineral concentrations and pH as related to season and location

Element	Critical level	Season	Location		Overall
			Lusitu	Simamba	
			Mean ± SEM	Mean ± SEM	Mean ± SEM
P (mg/kg)	10[*]	Wet	9.42 ± 4.44	18.05 ± 1.87	12.86 ± 3.27
		Hot dry	319.00 ± 91.77	525.25 ± 232.25	387.75±94.10
		Cold dry	12.88 ± 10.42	24.24 ± 0.30	17.42±6.35
K (mg/kg)	59.0[**]	Wet	117.02 ± 15.95	118.13 ± 20.08	117.46±10.80
		Hot dry	6975.00 ± 443.06	6965.00±605.00	6971.70±320.82
		Cold dry	106.07 ± 17.51	119.29 ± 19.82	111.36±11.91
Ca (mg/kg)	70.0[***]	Wet	1145.00 ± 614.46	1366.88±130.02	1233.80±343.41
		Hot dry	19518.13±4850.4	36025.00±5150	25020±4825.80
		Cold dry	513.13 ± 269.45	1823.88±647.37	1037.40±408.38
Mg (mg/kg)	8.5[***]	Wet	6.78 ± 0.14	9.00 ± 0.55	7.67 ± 0.57
		Hot dry	1710.00±986.29	5812.50±462.50	3077.50±1073
		Cold dry	6.88 ± 1.03	9.73 ± 2.57	8.02 ± 1.21
Cu (mg/kg)	0.75[**]	Wet	1.15 ± 0.03	0.93 ± 0.03	1.06 ± 0.05
		Hot dry	20.32 ± 1.31	26.65 ± 0.55	22.43 ± 1.57
		Cold dry	0.83 ± 0.12	0.91 ± 0.08	0.85 ± 0.07
Fe (mg/kg)	19[****]	Wet	14.47 ± 1.10	13.85 ± 1.37	14.22 ± 0.75
		Hot dry	592.75 ± 82.04	661.50 ± 14.50	615.67 ± 61.45
		Cold dry	17.16 ± 3.27	17.39 ± 3.13	17.25 ± 2.05
pH		Wet	6.29 ± 0.65	6.77 ± 0.30	6.48 ± 0.38
		Hot dry	6.01 ± 0.31	6.34 ± 114.50	6.12 ± 0.23
		Cold dry	5.67 ± 0.67	7.01 ± 0.74	6.20 ± 0.54

[*]Sanchez, 1976; [**]Landon, 1984; [***]Breland, 1976; [****] Conrad et al., 1980

4.1.1 Effects of season on soil pH

Season had no significant effect on soil pH in Lusitu and Simamba ($p>0.05$). Locality had a significant effect ($p<0.05$) on soil pH being lower in Lusitu than in Simamba. Lusitu soil had an average pH of 5.99 and Simamba soil had an average pH of 6.71.

4.1.2 Effects of season on soil macro minerals

Figures 2a, 2b, 2c and 2d are graphical presentations of the seasonal and location means for soil minerals.

Soil Calcium: The results indicate that Ca was significantly higher ($p<0.05$) in the hot dry season than in the cold dry and the wet seasons, in both localities (Figure 2a). There was no significant difference ($p>0.05$) in Ca concentrations between the cold dry and the wet season.

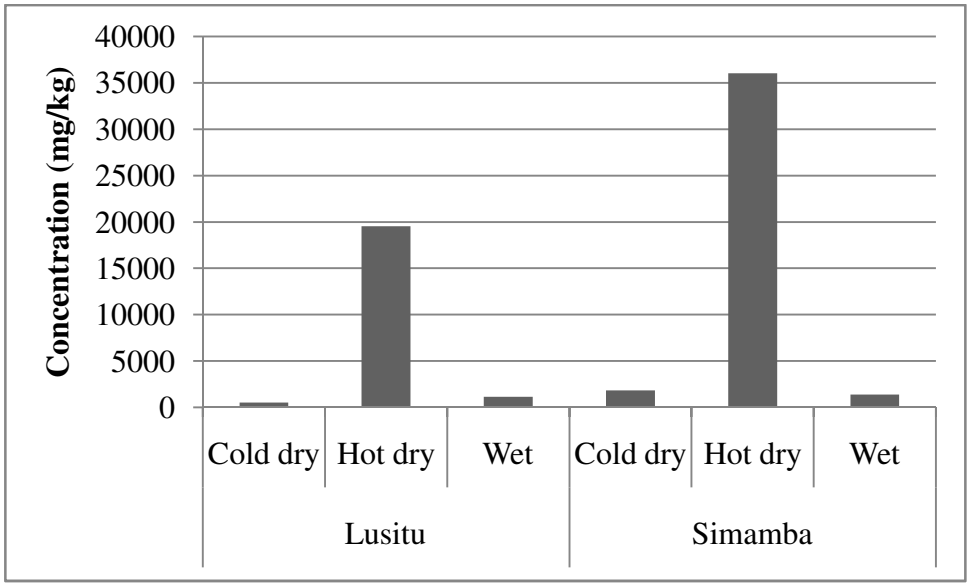

Figure 2a Average seasonal and location differences in soil Calcium

Soil Phosphorus: P was significantly higher ($p<0.05$) in the hot dry season than in the wet and the cold dry seasons, in Lusitu (Figure 2b). There was no significant difference ($p>0.05$) in P concentrations between the cold dry and the wet season. In Simamba, there was no significant seasonal variation (Appendix D-2 and E-2).

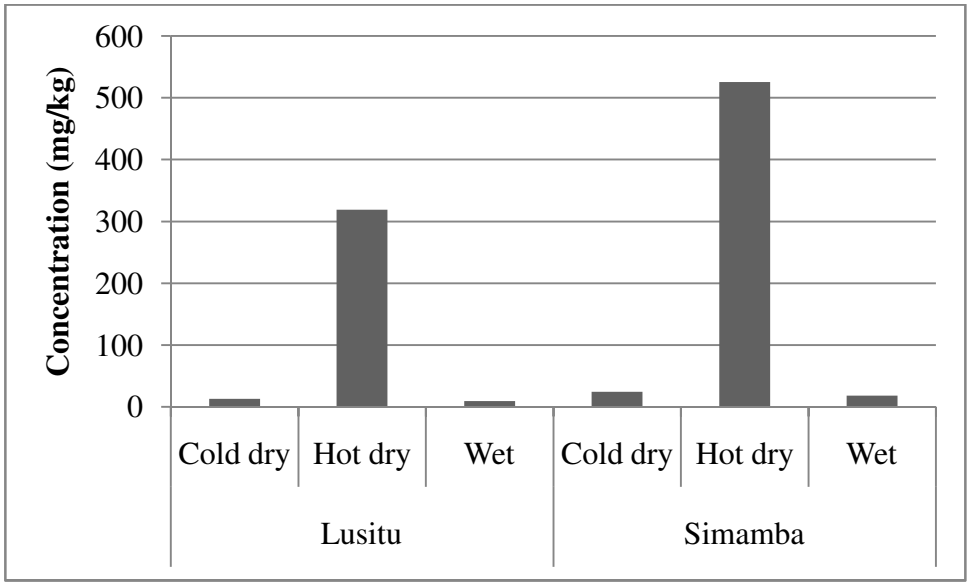

Figure 2b Average seasonal and location differences in soil Phosphorus

Soil Magnesium: In Simamba, Mg concentration was significantly higher ($p<0.05$) in the hot dry season than in the cold dry and wet seasons (Figure 2c). There was no significant difference ($p>0.05$) between the cold dry and the wet season concentrations. In Lusitu, there were no significant ($p>0.05$) seasonal variations in Mg.

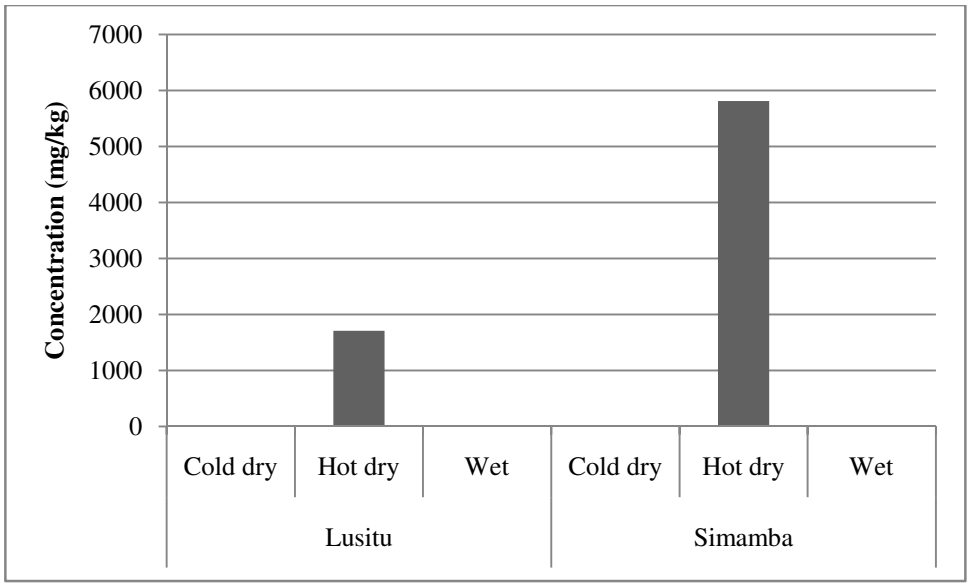

Figure 2c Average seasonal and location differences in soil Magnesium

Soil Potassium: In both locations, K concentration was significantly higher ($p<0.05$) in the hot dry season than in the wet and cold dry seasons (Figure 2d). There was no significant difference ($p>0.05$) between the cold dry and the wet season concentrations.

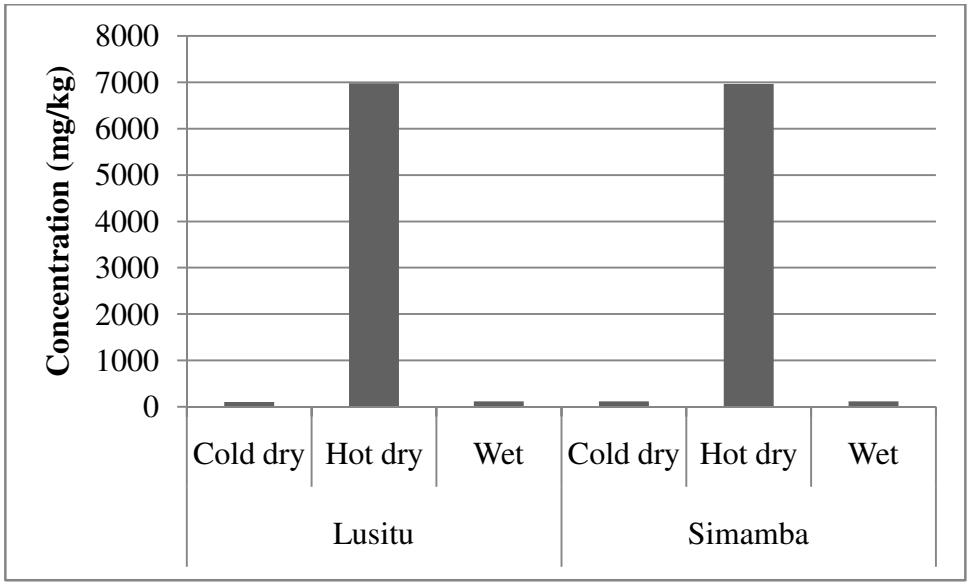

Figure 2d Average seasonal and location differences in soil Potassium

4.1.3 Effects of season on soil micro minerals

Seasonal and location means for soil micro minerals are shown in figures 3a and 3b.

Soil Copper: Concentration of Cu was significantly higher ($p<0.05$) in the hot dry season than in the cold dry and wet seasons in both locations (Figure 3a). There was no significant difference ($p>0.05$) in Cu concentrations between the cold dry and the wet season.

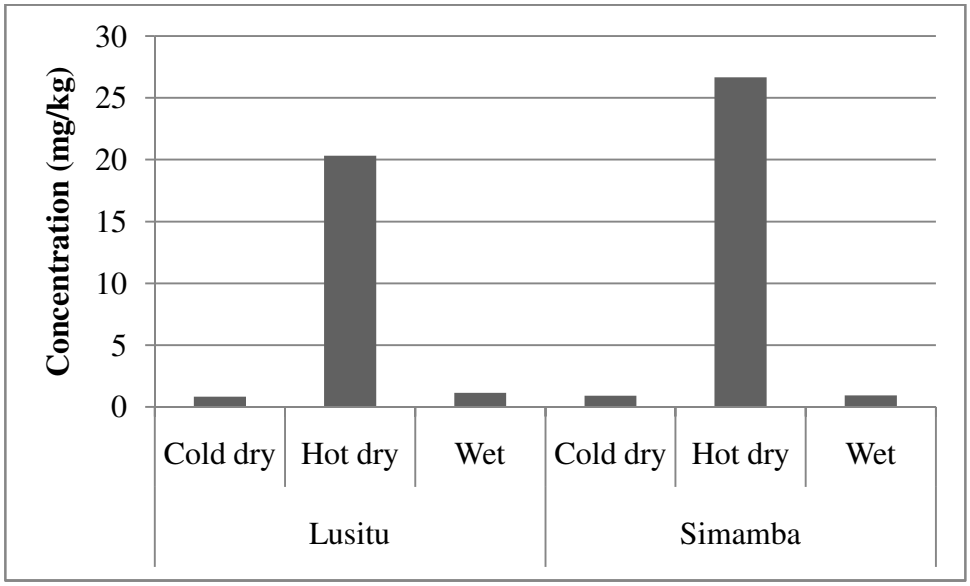

Figure 3a Average seasonal and location differences in soil Copper

Soil Iron: Concentrations of Fe in soil were significantly higher ($p<0.05$) in the hot dry season than in the cold dry and wet seasons in both locations (Figure 3b). There was no significant difference ($p>0.05$) in Fe concentrations between the cold dry and the wet season.

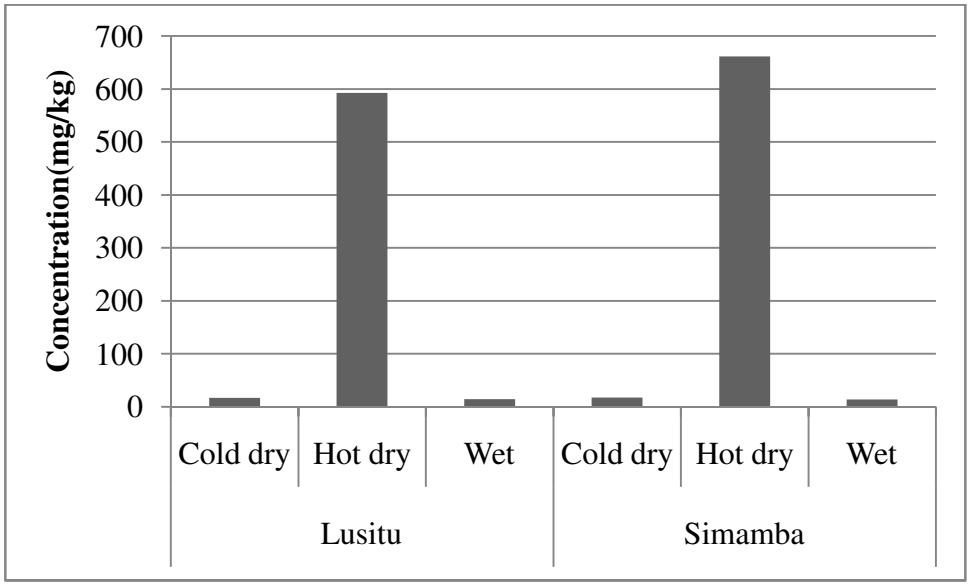

Figure 3b Average seasonal and location differences in soil Iron

4.1.4 Relationships among soil minerals and their relationship to pH

Correlation coefficients which do not explain about 25% of the total variation in mineral content in soil, forage and animal tissue cast doubt on their practical significance (Mtimuni, 1982). The following criterion was used to evaluate correlation coefficients; only values of correlation coefficients greater than or equal to ± 0.5 at the 0.05 significance level were considered. The significant correlation coefficients are highlighted in bold. The asterisk (*) in front of the highlighted figures represent the level of statistical significance.

Cold dry season: Table 2 below shows the relationships among soil minerals and their relationship to soil pH in the cold dry season.

Table 2 Correlation coefficients in soil minerals in the Cold dry season

	P	K	Ca	Mg	Cu	Fe	pH
P	1.000						
K	0.834	1.000					
Ca	0.437	0.612	1.000				
Mg	-0.023	0.320	**0.878***	1.000			
Cu	-0.336	-0.011	0.591	0.802	1.000		
Fe	0.687	0.275	-0.301	-0.699	-0.873	1.000	
pH	0.193	0.439	**0.911***	**0.890***	0.848	-0.548	1.000

*Correlation is significant at the 0.05 level

Calcium positively correlated with Mg with a correlation coefficient of 0.878 at a probability level of 0.05. These elements also correlated positively with pH. There was a positive correlation between pH and soil Ca and Mg with correlation coefficients of 0.911 and 0.890 respectively ($p<0.05$).

Hot dry season: Relationships among soil minerals and their relationship to pH in the hot dry season are shown in Table 3 below.

Table 3 Correlation coefficients in soil minerals in the Hot dry season

	P	**K**	**Ca**	**Mg**	**Cu**	**Fe**	**pH**
P	1.000						
K	0.778	1.000					
Ca	0.473	0.126	1.000				
Mg	0.370	-0.057	0.850	1.000			
Cu	0.615	0.132	**0.887***	**0.949****	1.000		
Fe	-0.501	-0.461	-0.190	-0.195	-0.287	1.000	
pH	**0.889***	0.705	0.597	0.473	0.658	-0.784	1.000

*Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Ca positively correlated with Mg and Cu with correlation coefficients of 0.850 and 0.887 respectively at a probability level of 0.01. Mg also correlated positively with Cu and the correlation coefficient was 0.949 at a probability level of 0.01. P positively correlated with pH and had a correlation coefficient of 0.889 at a probability level of 0.05.

Wet season: Table 4 shows the relationships among soil minerals and their relationship to pH in the wet season.

Table 4 Correlation coefficients in soil minerals in the Wet season

	P	**K**	**Ca**	**Mg**	**Cu**	**Fe**	**pH**
P	1.000						
K	0.176	1.000					
Ca	0.024	0.715	1.000				
Mg	0.590	-0.257	0.053	1.000			
Cu	-0.384	-0.045	-0.368	**-0.899***	1.000		
Fe	-0.823	-0.427	0.61	-0.51	-0.110	1.000	
pH	0.801	0.630	0.477	0.181	-0.148	-0.820	1.000

*Correlation is significant at the 0.05 level

Mg correlated negatively with Cu and the correlation coefficient was -0.899 at a probability level of 0.05. There was no significant correlation ($p>0.05$) between pH and the soil minerals in the wet season.

4.2 Plants

Thirteen plant species were collected and analysed. These are listed below with their corresponding local (Tonga) names. The plants were grouped according to location into Lusitu and Simamba because of variations in the types of plant species collected between the two locations. There were differences in the concentrations of all the six elements between the plants collected in Lusitu and those collected in Simamba. Lusitu had higher levels of plant K, Ca, Mg and Cu. Simamba had higher levels of plant P and Fe. This study was designed to investigate the mineral status of plants commonly browsed by goats and not the mineral status of plants in Lusitu and Simamba per se, so samples were collected in areas commonly browsed by the goats regardless of the need for a balanced sample size. Only one type of grass (*Paspalum dilatum*) was collected and analysed during the wet season. This is because during the dry weather months of the year there is little to no grass growing for goats to graze.

The following is a list of plants collected from Lusitu:

Botanical name	**Local name**
Balanites aegyptiaca	*Mulyanzovu*
Eleusine coracana	*Finger Millet*
Azadirachta indica	*Neem tree*
Amaranthus spinosum	*Bbonko*
Lonchocarpus capassa	*Mukololo*
Acacia geradii	*Munyenyengwe*
Xanthocersis zambesiaca	*Munonge*
Berchemia discolour	*Munji*
Tamarindus indica	*Musiika*

Paspalum dilatum	*Mpunga*
Acacia tortilis	*Mukoka*

The following is a list of plants collected from Simamba:

Botanical name	**Local name**
Paspalum dilatum	*Mpunga*
Maesopsis eminii	*Muchenje*
Acacia tortilis	*Mukoka*
Colophospermum mopane	*Mwaani*

The mineral composition of these plant species are summarised in table 5 for plants collected in Lusitu and table 6 for plants collected in Simamba.

Table 5 Table of mineral composition of plants collected in Lusitu, by season

Season	Plant species	P g/kg	K g/kg	Ca g/kg	Mg g/kg	Cu mg/kg	Fe mg/kg
Wet	*Balanites aegyptiaca*	0.14	25.04	18.00	14.81	1.70	543.00
	Eleusine coracana	0.32	2.11	0.36	5.95	4.30	331.20
	Azadirachta indica	0.14	3.52	16.50	11.67	4.80	389.20
	Amaranthus spinosum	0.32	15.84	16.90	16.80	7.20	654.60
	Lonchocarpus capassa	0.17	2.80	12.00	12.03	8.30	533.60
	Acacia geradii	0.19	2.55	12.60	12.24	3.70	466.10
	Xanthocersis zambesiaca	0.12	1.96	8.90	10.89	4.30	265.90
	Paspalum dilatum	0.21	2.15	7.37	14.21	8.30	1877.00
Cold dry	*Balanites aegyptiaca*	0.16	3.41	2.63	11.23	9.60	603.50
	Berchemia discolor	0.15	2.02	32.30	9.59	9.30	494.80
	Tamarindus indica	0.08	2.65	29.30	14.25	10.80	862.10
	Azadirachta indica	0.16	1.75	22.70	10.66	11.97	1095.87
	Lonchocarpus capassa	0.08	2.91	14.70	11.05	10.30	1020.00
	Acacia geradii	0.07	1.85	11.40	10.86	69.10	562.70
Hot dry	*Balanites aegyptiaca*	2.85	37.14	5.29	5.13	5.70	121.40
	Acacia tortilis	1.90	6.29	15.20	3.61	4.20	120.30
	Berchemia discolor	6.15	6.29	4.20	3.70	5.00	91.20
	Tamarindus indica	3.15	7.35	11.60	3.25	8.80	91.20
	Eleusine corocana	1.75	30.38	0.02	3.69	4.90	58.50
	Azadirachta indica	1.90	9.00	26.60	7.26	7.60	172.80
	Lonchocarpus capassa	5.25	24.47	3.48	3.57	10.60	165.60
	Acacia geradii	1.15	4.63	16.20	5.51	6.90	221.40
	Xanthocersis zambesiaca	4.45	9.31	4.98	5.70	10.00	200.50

Table 6 Table of mineral composition of plants collected in Simamba, by season

Season	Plant species	P g/kg	K g/kg	Ca g/kg	Mg g/kg	Cu mg/kg	Fe mg/kg
Wet	*Acacia tortilis*	0.15	1.79	8.51	4.92	5.85	1227.35
	Colophospermum mopane	0.14	2.42	11.80	10.93	9.70	431.80
	Paspalum dilatum	1.60	1.58	4.61	13.25	8.58	1753.25
	Maesopsis eminii	0.10	1.64	15.80	4.76	6.00	273.10
Cold dry	*Acacia tortilis*	0.16	1.70	19.10	4.53	4.65	784.75
	Colophospermum mopane	0.15	1.83	58.40	1.73	8.00	365.00
	Maesopsis eminii	0.10	2.57	17.00	6.79	8.60	887.30
Hot dry	*Acacia tortilis*	16.35	8.97	9.26	2.94	5.20	243.70
	Colophospermum mopane	14.55	10.67	5.61	4.19	1.30	76.20
	Maesopsis eminii	16.15	9.24	9.26	5.16	0.20	118.80

The seasonal mean mineral concentrations and the standard error of the mean for all the plants shown in the table above in the two localities, were calculated and are shown in Table 7 below. Results for single factor ANOVA used to compare plant mineral levels among the three seasons in Lusitu and Simamba are shown in Appendix Table D-3 and Appendix Table D-4, respectively. Benferroni t tests are shown in Appendix table E-3 for Lusitu and Appendix table E-4 for Simamba data.

Table 7 Mean plant mineral concentrations as related to season and locality

Element	Critical level	Season	Locality		Overall
			Lusitu Mean ± SEM	Simamba Mean ± SEM	Mean ± SEM
P (g/kg)	1.6-3.8*	Cold dry	0.13 ± 0.02	0.14 ± 0.04	0.13 ± 0.02
		Hot dry	3.17 ± 0.58	15.68 ± 0.56	6.3 ± 1.69
		Wet	0.21 ± 0.03	0.87 ± 0.63	0.50 ± 0.28
K (g/kg)	1.8-2.5**	Cold dry	2.26 ± 0.25	1.95 ± 0.31	2.16 ± 0.19
		Hot dry	14.98 ± 4.08	9.63 ± 0.52	13.65 ± 3.10
		Wet	7.53 ± 3.38	1.75 ± 0.22	4.96 ± 1.96
Ca (g/kg)	1.3-3.3*	Cold dry	19.79 ± 4.02	28.37 ± 11.24	22.65 ± 4.45
		Hot dry	9.72 ± 2.79	8.05 ± 1.21	9.30 ± 2.09
		Wet	12.58 ± 1.90	7.88 ± 1.62	10.49 ± 1.36
Mg (g/kg)	0.8-2.5**	Cold dry	11.12 ± 0.88	4.39 ± 1.08	8.88 ± 1.22
		Hot dry	4.60 ± 0.45	4.10 ± 0.64	4.48 ±0.36
		Wet	12.70 ± 1.01	9.81 ± 1.60	11.42 ± 0.94
Cu (mg/kg)	8-10***	Cold dry	18.12 ± 7.30	6.47 ± 1.06	14.24 ± 5.05
		Hot dry	7.07 ± 0.77	2.23 ± 1.51	5.86 ± 0.91
		Wet	5.46 ± 0.69	7.71 ± 0.65	6.46 ± 0.54
Fe (mg/kg)	30-40***	Cold dry	853.84±176.33	705.45 ± 137.13	804.38±123.87
		Hot dry	138.01 ± 18.30	146.23 ± 50.26	140.13±17.28
		Wet	610.44±154.30	1271.60±345.13	904.28±182.48

*NRC, 1981 and Kessler, 1991; **NRC, 1981; ***Kessler, 1991

4.2.1 Effects of season on plant macro minerals

The results for the effects of season on plant macro minerals in Lusitu and Simamba are shown in figure 4a and 4b below. Figure 4a shows the seasonal means for plant P and Ca in the two localities. Figure 4b shows the seasonal means for plant Mg and K in the two localities.

Plant Phosphorus: In the two localities, the hot dry season had significantly higher ($p<0.05$) concentrations of Phosphorus than the cold dry and wet seasons (figure 4a). There was no significant difference ($p>0.05$) in the concentrations of P between the wet and the cold dry seasons.

Plant Calcium: In Lusitu, Ca showed no significant seasonal variation. In Simamba, Ca was significantly higher ($p < 0.05$) in the cold dry season than in the wet and hot dry seasons. There was no significant difference ($p>0.05$) in the levels of Ca (figure 4a) between the wet and the hot dry seasons in Simamba.

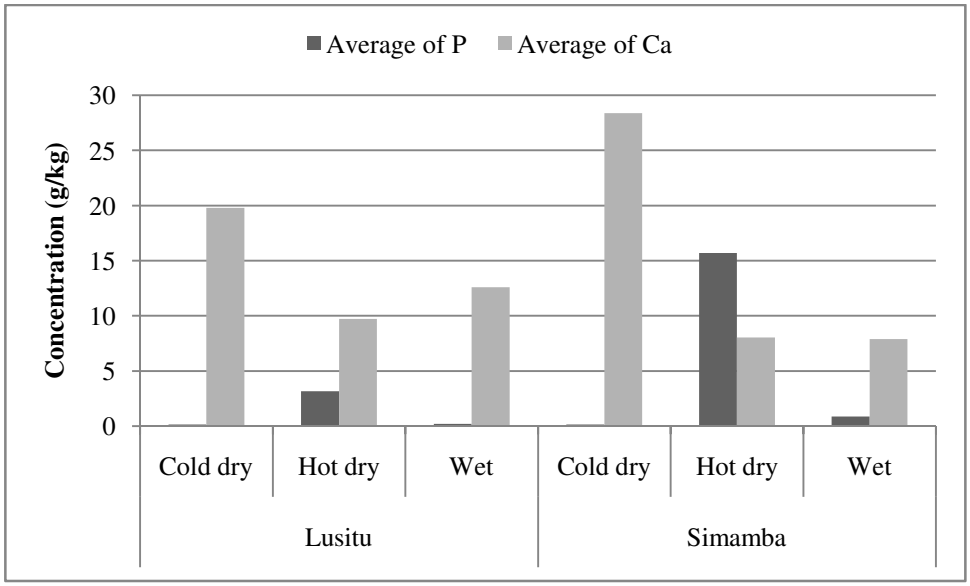

Figure 4a Average seasonal and location differences in plant Phosphorus and Calcium concentrations

Plant Magnesium: in Simamba, there was no significant difference ($p>0.05$) in the concentrations of Mg in the three seasons. In Lusitu, the hot dry season had significantly lower levels ($p<0.05$) of Mg than both the cold dry and the wet seasons (figure 4b).

Plant Potassium: Season significantly affected K concentrations of plants in both Lusitu and Simamba (figure 4b). The hot dry season had significantly higher levels of K than both the cold and the wet seasons ($p<0.05$).

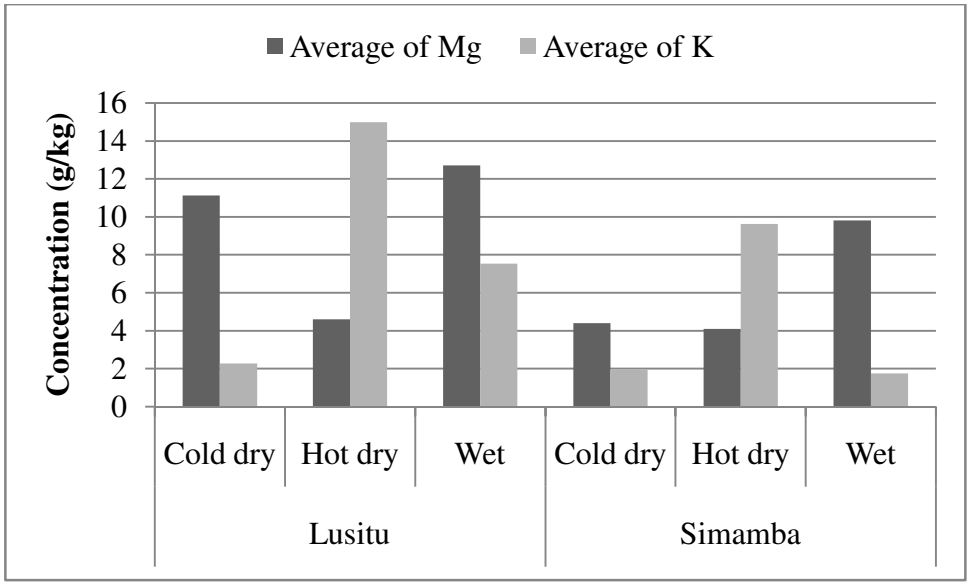

Figure 4b Average seasonal and location differences in plant Magnesium and Potassium concentrations

4.2.2 Effects of season on plant micro minerals

The seasonal and location means for plant micro minerals are shown in figures 5a and 5b. Figure 5a shows the seasonal means for plant Cu in the two localities. Figure 5b shows the seasonal means for plant Fe in the two localities.

Plant Copper: In Lusitu, there were no significant ($p>0.05$) seasonal differences in plant Cu concentrations between the hot dry and wet seasons (Figure 5a). In Simamba, Cu concentrations were significantly higher ($p<0.05$) in the wet season than in the hot dry season.

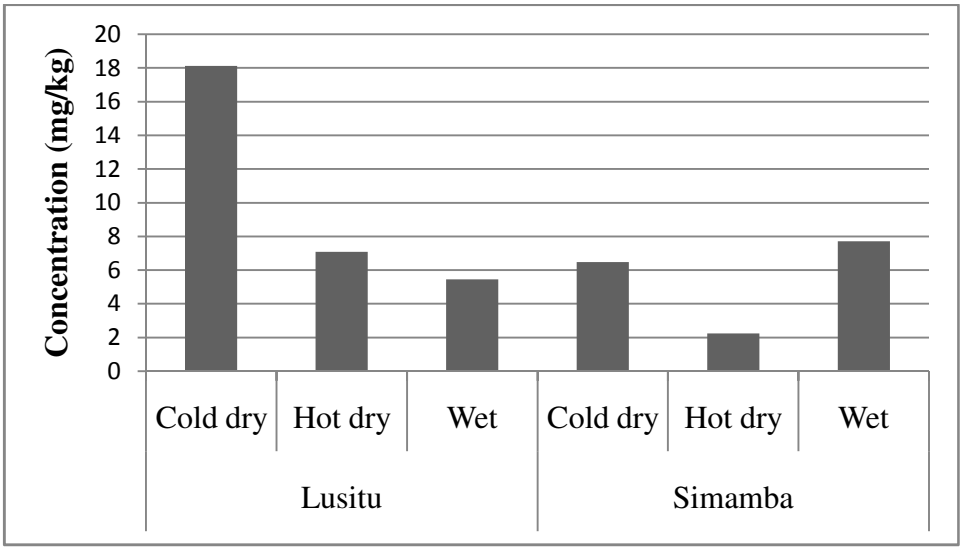

Figure 5a Average seasonal and location differences in plant Copper concentrations

Plant Iron: Fe was significantly higher in the wet season in Simamba than in Lusitu. In Lusitu, Fe was significantly higher ($p<0.05$) in the cold dry season than in the hot dry season (Figure 5b). At a probability level of 0.05, concentrations of plant Fe in the wet season did not differ significantly from the hot dry and the cold dry season concentrations. In Simamba, no significant seasonal variation ($p>0.05$) in plant Fe was observed (Appendix D-4 and E-4).

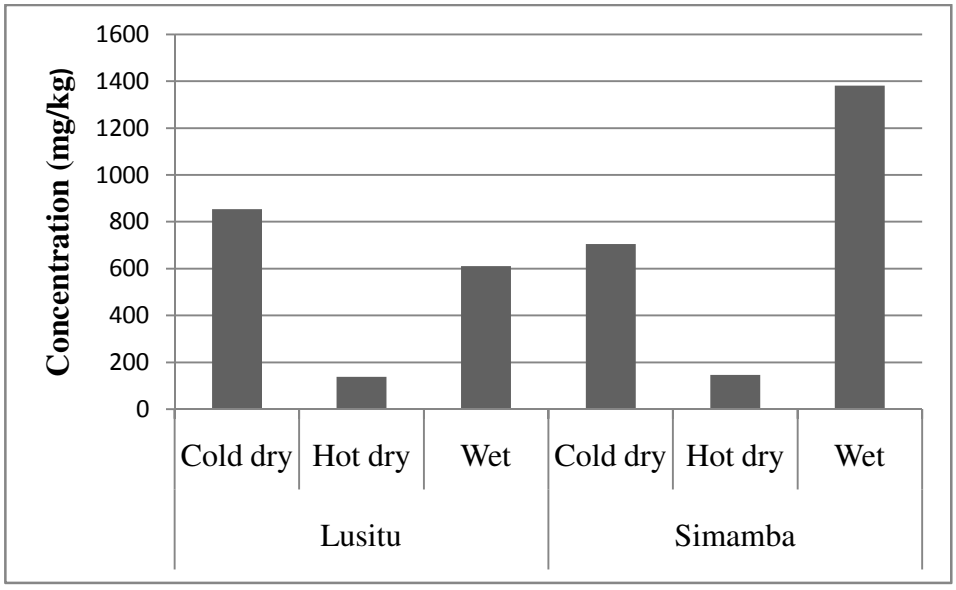

Figure 5b Average seasonal and location differences in plant Iron concentrations

4.2.3 Relationships of plant minerals

Cold dry season: The relationships of minerals in plants in the cold dry season are shown in tables 8.

Table 8 Correlation coefficients in plant minerals in the Cold dry season

	P	K	Ca	Mg	Cu	Fe
P	1.000					
K	0.193	1.000				
Ca	0.374	-0.074	1.000			
Mg	0.197	0.576	-0.149	1.000		
Cu	-0.284	-0.118	-0.239	0.242	1.000	
Fe	0.241	0.057	-0.215	0.382	-0.099	1.000

There were no significant correlations in plant minerals ($p>0.05$). None of the correlation coefficients between plant minerals met the criterion for evaluating correlation coefficients ($r \geq 0.5$) at the 0.05 probability level.

Hot dry season: Table 9 below shows the relationships of plant minerals in the hot dry season.

Table 9 Correlation coefficients in plant minerals in the Hot dry season

	P	K	Ca	Mg	Cu	Fe
P	1.000					
K	-0.224	1.000				
Ca	-0.223	-0.519	1.000			
Mg	-0.253	-0.069	0.558	1.000		
Cu	**-0.601***	0.101	0.077	0.096	1.000	
Fe	0.074	-0.292	0.377	0.282	0.417	1.000

*Correlation is significant at the 0.05 level

P negatively correlated with Cu and gave a correlation coefficient of –0.601 at a probability level of 0.05.

Wet season: Relationships of plant minerals in the wet season are shown in Table 10.

Table 10 Correlation coefficients in plant minerals in the Wet season

	P	K	Ca	Mg	Cu	Fe
P	1.000					
K	-0.036	1.000				
Ca	-0.339	0.339	1.000			
Mg	0.131	0.437	0.278	1.000		
Cu	0.222	-0.296	-0.350	0.185	1.000	
Fe	0.096	-0.096	-0.436	0.182	0.292	1.000

There were no significant correlations in plant minerals ($p>0.05$) (Table 10). None of the correlation coefficients between plant minerals met the criterion for evaluating correlation coefficients ($r \geq \pm 0.5$) at 0.05 probability level.

4.3 Plasma

The sample size varied in the three seasons because some of the farmers that were recruited at the beginning of the study withdrew from the study. During the wet season some areas became inaccessible by road and so some farmers could not be reached. The goats were not replaced since the same goats recruited at the beginning of the study were desired to be re sampled in the subsequent seasons. Therefore the results are based on the following number of samples:

Lusitu: 42 (Hot dry season), 30 (cold dry season) and 15 (wet season).

Simamba: 25 (Hot dry season), 43 (cold dry season), 36 (wet season).

4.3.1 Effects of season on plasma macro minerals

For each season, the mean (mg/L) and standard error of the mean, for the plasma minerals for Lusitu and Simamba were calculated and are tabulated in table 11 below. Figures 6a, 6b, 7a and 7b present the results graphically. Results for single factor ANOVA used to compare mineral levels among the three seasons are shown in Appendix Table D-5 for Lusitu and Appendix Table D-6 for Simamba data. Benferroni t tests performed to determine differences between specific pairs of seasons for Lusitu and Simamba are shown in Appendix table E-5 and Appendix table E-6, respectively.

Table 11 Mean plasma mineral concentrations as related to season and location

Element	Critical level[a]	Season	Location		Overall
			Lusitu[b] Mean ± SEM	Simamba[c] Mean± SEM	Mean ± SEM
P (mg/L)	20.9	Wet	27.5±6.16	18.8±3.13	21.37±2.88
		Cold dry	30.7±8.31[d]	9.74±1.84[e]	18.35±3.75
		Hot dry	82.0±15.0[d]	48.9±8.00[e]	63.45±5.75
K (mg/L)	200	Wet	274±16.3	301±40.3	293±28.7
		Cold dry	132±28.5	84.1±18.5	104±16.1
		Hot dry	891±35.0	834±50.7	871±28.8
Ca (mg/L)	105	Wet	63.7±14.2	147±56.2	122±40.1
		Cold dry	192±22.1	129±17.7	159±7.45
		Hot dry	84.5±8.68[d]	408±270[e]	200±97.3
Mg (mg/L)	31.5	Wet	47.4±6.40	58.9±14.1	55.5±10.1
		Cold dry	49.3±7.13	60.3±12.0	52.8±4.78
		Hot dry	53.0±5.06	61.5±9.42	55.3±3.62
Cu (mg/L)	0.5-1.6	Wet	0.32 ± 0.19	1.44 ± 0.88	1.11 ± 0.62
		Cold dry	0.03 ± 0.00	0.04 ± 0.00	0.04 ± 0.00
		Hot dry	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00
Fe (mg/L)	1.6-2.2	Wet	1.04 ± 0.12	0.86 ± 0.10	0.92 ± 0.08
		Cold dry	1.82 ± 0.13	1.61 ± 0.09	1.69 ± 0.07
		Hot dry	0.67 ± 0.18	0.29 ± 0.09	0.54 ± 0.12

[a] Critical levels were adopted from Kaneko 1980; [b] n =15 (wet season), 30 (cold dry season), 42 (Hot dry season); [c] n =36 (wet season), 43 (cold dry season), 25 (Hot dry season); [d, e] Means in the same row with different superscripts differ ($p<0.05$)

Plasma Phosphorus: In both localities, P was significantly higher ($p<0.05$) in the hot dry season than in the cold dry and wet seasons (figure 6a). There was no significant difference ($p>0.05$) between the cold dry and the wet season.

Plasma Calcium: In both localities, seasonal differences for plasma Ca were found to be significant ($p<0.05$). In Lusitu, concentrations in the cold dry season were higher than in the wet and the hot dry seasons (figure 6a). In Simamba, the concentrations were highest in the hot dry season.

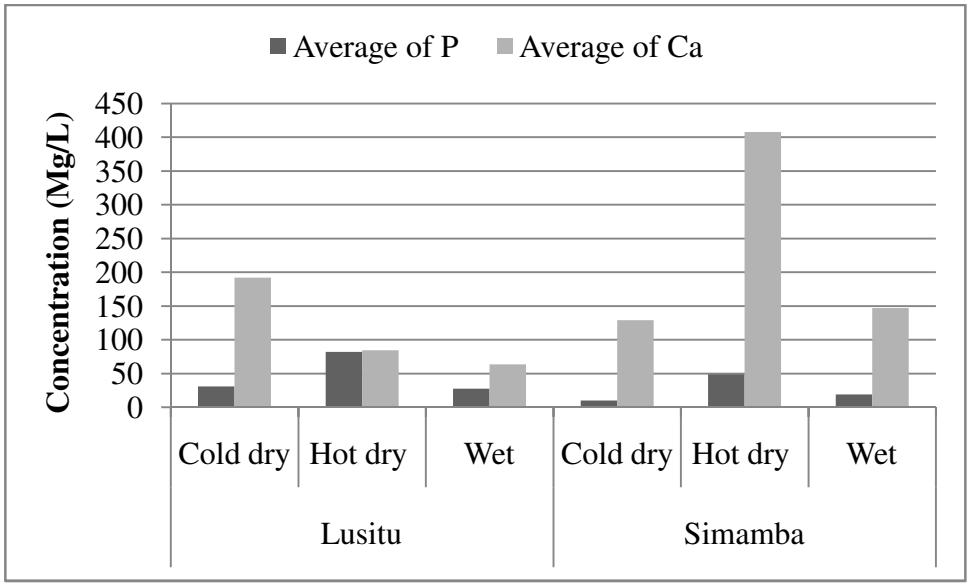

Figure 6a Average seasonal and location differences in plasma Phosphorus and Calcium concentrations

Plasma Magnesium: In both localities, Mg concentrations were significantly higher ($p<0.05$) in the hot dry season than in the cold dry and wet season. There was no significant difference ($p>0.05$) between the cold dry and the wet season.

Plasma Potassium: Plasma K was significantly higher ($p<0.05$) in the hot dry season than in the cold dry and wet seasons, in both localities (figure 6b).

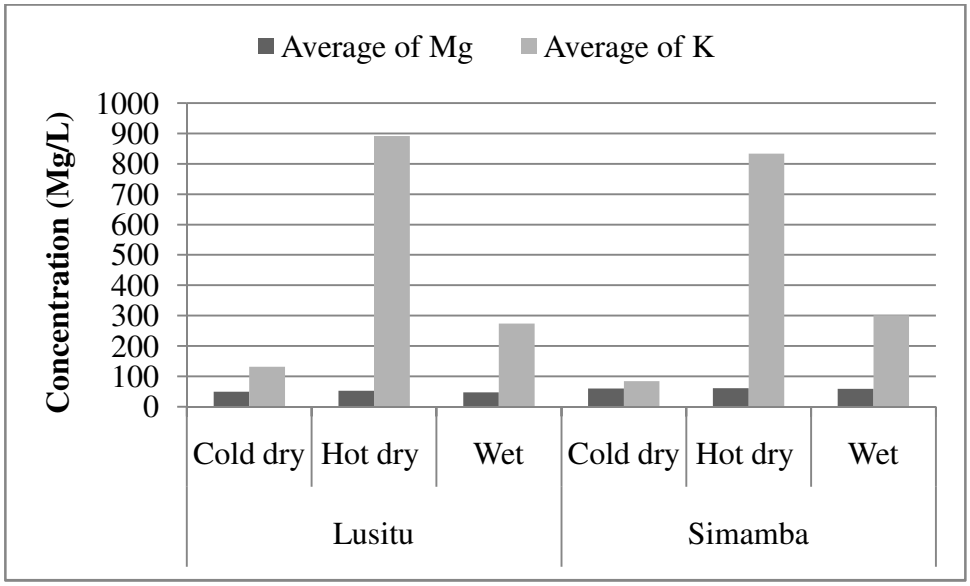

Figure 6b Average seasonal and location differences in plasma Magnesium and Potassium concentrations

4.3.2 Effects of season on plasma micro minerals

Plasma Copper: Cu concentrations were significantly higher ($p<0.05$) in the wet season than in the cold dry and hot dry seasons. There was no significant difference in Cu concentrations between the cold dry and the hot dry season in both localities ($p>0.05$). The goats in Simamba had significantly higher levels of Cu in the wet season than those in Lusitu ($p<0.05$) (Figure 7a).

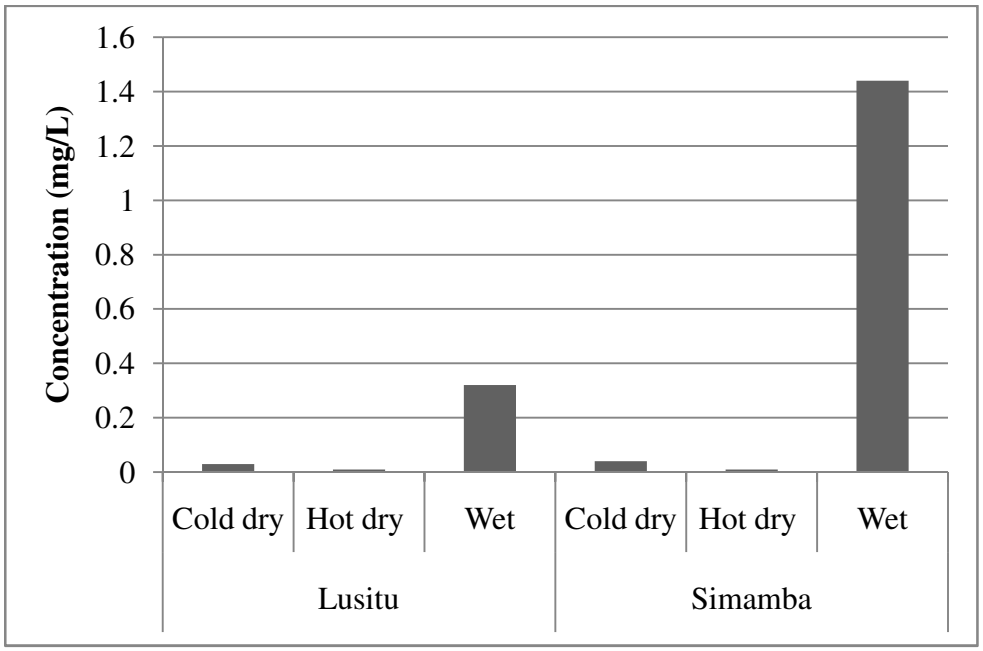

Figure 7a Average seasonal and location differences in plasma Copper concentrations

Plasma Iron: In Lusitu, plasma Fe was significantly higher in the cold dry season than in the wet and hot dry seasons ($p<0.05$). In Simamba, plasma Fe showed variation in all the three seasons, the highest ($p<0.05$) being recorded in the cold dry season and the lowest in the hot dry season (Figure 7b).

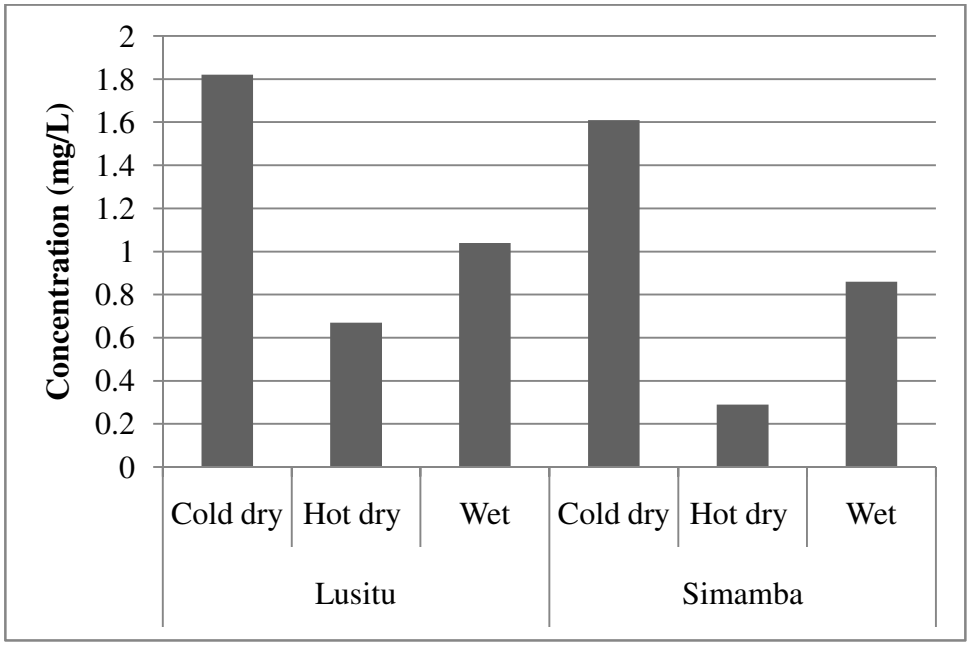

Figure 7b Average seasonal and location differences in plasma Iron concentrations

4.3.3 Relationships of plasma minerals

Cold dry season: Correlation coefficients for plasma minerals in the cold dry season are summarized in Table 12.

Table 12 Correlation coefficients in plasma minerals in the Cold dry season

	P	K	Ca	Mg	Cu	Fe
P	1.000					
K	**0.574****	1.000				
Ca	0.433**	**0.782****	1.000			
Mg	0.291*	**0.683****	**0.658****	1.000		
Cu	0.105	0.218	0.187	0.309**	1.000	
Fe	0.475**	**0.818****	**0.715****	**0.618****	0.223	1.000

*Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Considering only correlation coefficients greater than or equal to ± 0.5 at a probability level of 0.05, the following correlation coefficients are worth noting: There was positive correlation between P and K ($p<0.01$) and the r value was 0.574. K also correlated positively with Ca, Mg and Fe ($p<0.01$) with correlation coefficients of 0.782, 0.683 and 0.818 respectively. In addition to the above correlations of Ca, the element also correlated positively with Mg and Fe ($p<0.01$) and the r values were 0.658 and 0.715 respectively. There was positive correlation between Mg and Fe with an r value of 0.618 ($p<0.01$).

Hot dry season: Relationships of plasma minerals in the hot dry season are shown in Table 13 below.

Table 13 Correlation coefficients in plasma minerals in the Hot dry season

	P	**K**	**Ca**	**Mg**	**Cu**	**Fe**
P	1.000					
K	-0.463**	1.000				
Ca	-0.116	-0.066	1.000			
Mg	**-0.655****	**0.796****	-0.086	1.000		
Cu	-0.249*	0.059	-0.050	0.304*	1.000	
Fe	-0.012	0.084	-0.061	0.003	-0.034	1.000

*Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

P negatively correlated with Mg with a correlation coefficient of -0.655 at a probability of 0.01. K positively correlated with Mg with an r value of 0.796, at a probability level of 0.01.

Wet season: Relationships of plasma minerals in the hot dry season are shown in Table 14 below.

Table 14 Correlation coefficients in plasma minerals in the wet season

	P	**K**	**Ca**	**Mg**	**Cu**	**Fe**
P	1.000					
K	0.218	1.000				
Ca	0.061	**0.777****	1.000			
Mg	-0.135	-0.182	-0.026	1.000		
Cu	0.093	**0.840****	**0.977****	-0.044	1.000	
Fe	**-**0.323*	-0.115	0.158	0.038	0.091	1.000

*Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

At a probability level of 0.01 K positively correlated with Ca and Cu and the r values were 0.777 and 0.840 respectively. At the same probability of 0.01, Ca positively correlated with Cu having an r value of 0.977.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Soil

The results from soil analysis were analysed by comparing with recommended critical levels of soil mineral concentrations. The critical level for soils indicates the element concentration below which normal growth and/ or mineral composition of forage may be adversely affected. The results indicate that all the soil mineral concentrations tended to increase in the hot dry season. This may be due to concentration of minerals as a result of low soil moisture.

During the wet season soil from Lusitu had a mean P concentration of 9.42 ± 4.44 mg/kg that was lower than the critical level of 10 mg/kg (Sanchez, 1976). Phosphorus deficiency is the most widespread and economically important mineral deficiency of grazing livestock. This is attributed to the fact that most Zambian soils are reported to be deficient in Phosphorus (Yerokun, 2008). This is in agreement with the findings of FAO in a study done in three districts of Zambia in Southern Province in 2010. The study reported phosphorus deficiency in 83 percent of the soils that were sampled. The presence of high amounts of oxides and the rate of soil weathering due to high temperatures and moisture in part explain the low availability of P in Zambian soils (Yerokun, 2008).The highest P concentration was recorded in the hot dry season. Low soil moisture is said to reduce P uptake by plants thereby causing an increase in soil P (Jones, 1998). P is also affected by soil pH. At pH values lower than 5.5, phosphate ions combine with iron and aluminium to form compounds which are not readily available to plants (Landon, 1984). At average pH values of 6.71 for soils in Simamba and 5.99 for soils in Lusitu, P is available and its availability increases with increasing pH. The situation changes at pH value greater than 8.0. In the presence of calcium, phosphate tends to be converted to calcium phosphate, and availability of P to plants is reduced.

Aluminum ion is reported to be the dominant cation associated with soil acidity below pH 5.5 (Landon, 1984). Aluminum ions are released from clay lattices at pH values below about 5.5 and become established on the clay complex. In this study the pH in both localities was above 5.5. Ca, Mg and P correlated positively with pH. Ca and Mg may be deficient in acidic soils becoming more available with reducing soil acidity. However, at high pH the minerals become less available in soil. At pH values of 6.71 for soils in Simamba and 5.99 for soils in Lusitu, Ca and Mg become more available in the soil for uptake by plants. In all the three seasons soil Ca was above the required critical level of 70 mg/kg (Breland, 1976). Ca does not seem to be deficient in soils of the Southern Province as observed by this study and FAO (2010). In the present study there was a significant seasonal effect on mean soil Mg concentration ($p<0.05$), so that Mg content in soil was higher in the hot dry season than that in the wet and cold dry seasons. In Lusitu, Mg was below the critical level of 8.5 mg/kg (Breland, 1976) in the cold dry (6.88 ± 1.03 mg/kg) and wet seasons (6.78 ± 0.14 mg/kg). This is contrary to what would be expected at pH values of 5.67 and 6.29 in the cold and hot dry seasons, respectively. There were probably other factors involved that need to be investigated in future studies. The hot dry season concentrations were above the required critical level for plant growth. The soil Mg concentration found in the hot dry season in this study was higher than what was reported earlier in parts of Southern Province (FAO, 2010), Pakistan (Khan *et al.,* 2008) and Malawi (Mtimuni, 1982).

In all the seasons, soil K was above the critical level of 59 mg/kg (Landon, 1984). Soil K becomes more available with increasing pH. This is in agreement with the findings of this study which show that in Lusitu and Simamba, K was above the recommended minimum for plants. At pH values of 6.71 for soils in Simamba and 5.99 for soils in Lusitu, K was readily available for plant uptake.

Micro minerals, in this case, Cu and Fe, become more available with reducing pH; deficiencies are therefore rare below about pH 7 (Landon, 1984). This is in agreement with the findings of this study. The results indicate that Cu was above the recommended critical level of 0.75 mg/kg (Landon, 1984), in the three seasons in both localities.

At pH values greater than 8.0, availability of Cu and Fe reduces. Fe was below the critical level of 19 mg/kg (Conrad et al., 1980) in both localities during the wet and cold

dry seasons. The overall soil Fe values were found to be higher than those reported by Khan et al. (2004).

5.2 Plants

The data for plant minerals was analysed by comparing with recommended critical levels for adult goat nutrition. The critical level indicates the lowest requirement of the element or organic constituent to avoid deficiency symptoms in animals. During the hot dry season all the plants that were analysed had adequate levels of P (critical level 1.6-3.8 g/kg DM; NRC, 1981; Kessler, 1991) that could meet adult goat requirements, with a range of 1.75-6.15 g/kg DM, except for samples of *Acacia geradii* collected from Lusitu that had a P concentration of 1.15 g/kg DM. However in the cold dry season all the plants had P levels below the recommended critical level. A similar pattern was observed during the wet season in the browse plants except for *Paspalum dilatum,* a grass, from Simamba which had adequate P (1.60 g/kg DM). Studies done in Ethiopia have shown that most grasses were marginal to deficient in P (Kabaija and Little, 1988). Despite the seasonal differences in Ca concentrations all browse plants had adequate levels of Ca (range 0.02-58.40 g/kg DM) to meet adult goat requirements (1.3–3.3 g /kg DM in the diet; NRC, 1981; Kessler, 1991) except *Eleusine coracana* which had Ca concentration below the required minimum during the hot dry season (0.02 g/kg DM) and in the wet season (0.36 g/kg DM). Ca is not usually deficient, for optimal livestock performance, in foliage from browse plants that grow in tropical regions (Norton and Poppi, 1995; Ramirez *et al.,* 2001). Like all grain crops, millet was low in calcium. To avoid deficiencies; it is not recommended that millet should form a major part of the diet for goats. It has been recommended by some researchers that diets containing high levels of grain should include a supplemental calcium source, where practical, such as limestone to prevent urinary calculi. Ca and P are both important in the development and maintenance of the body of the animal; the recommended calcium to phosphorus ratio in the diet is a minimum of 2:1 (2 parts calcium to 1 part phosphorus) and a deficiency of either or both in growing animals leads to poorly developed bones.

However, in the present study, this ratio was not achieved in any of the plants. Range forages often contain high levels of Ca in relation to P (Norton, 1994). However, goats are known to be tolerant to high Ca:P ratios (Cohen, 1975).

The findings on plant K with a range of (1.58-37.14 g/kg DM) are similar to those recorded by Ramirez *et al.* (2001) who found higher K concentrations in shrubs grazed by goats during summer than in other seasons. Locality also affected mineral concentrations in the various plant species with deficiencies being observed in some species. During the hot dry season all the plants had adequate levels of K to meet adult goat requirements. The daily adult goat requirements are 1.8–2.5 g /kg DM in their diets (NRC, 1981). With the exception of *Azadirachta indica* (1.75 g/kg DM), all the plants collected from Lusitu had adequate levels of K in the cold dry season. In the same season, *Acacia tortilis* from Simamba had K concentrations of 1.70 g/kg DM which was below the required minimum. During the wet season, deficiencies of K were recorded only in Simamba in *Paspalun dilatum* (1.58 g/kg DM) and *Maesopsis eminii* (1.64 g/kg DM). Variation of K in plants within different seasons may partially be attributed to different stages of plant maturity at the time of plant sampling. With maturity, mineral concentration declines due to a natural dilution process and the translocation of minerals to the root system (Pastrana *et al*., 1991). Plant species such as *Balanites aegyptiaca* (37.14 g/kg DM in the hot dry season) and *Amaranthus spinosum* (15.84 g/kg DM) had K concentrations as much as 10 times the required levels. This may become a problem because of the relationship that exists among K, Mg and Ca. High K concentrations first result in a Mg deficiency; when K is in greater imbalance, they will cause a Ca deficiency (Jones, 1998).

Magnesium requirements for goats are 0.8–2.5 g/kg DM in their diets (NRC, 1981). All tested plants in all seasons had adequate Mg concentrations to meet goat requirements (range 1.73-16.80 g/kg DM). Ramirez et al. (2001) reported that all tested shrubs in all seasons in Mexico had Mg levels that met adult goat requirements. A study on macro mineral status of forages and grazing goats in West Sumatra, Indonesia indicated that mineral concentrations of forages varied widely among species and seasons (Warly *et al*

2006). The study also showed that the average concentration of forage Mg in the dry season was above the critical level, while in the rainy season the Mg concentration was below the critical level. It is worth noting that Mg content in leaves increases with age, the highest concentrations found in older leaves. Therefore feeding goats on mature leaves may be advantageous especially in areas where Mg is known to be deficient in forage. Some plant species have a particular sensitivity to Mg such that they will become Mg deficient under moisture and/or temperature stress even though Mg may be at sufficient availability levels in the rooting media (Jones, 1998).

Copper was below the required minimum for adult goats in most of the plants during the three seasons (critical level 8-10 mg/kg; Kessler, 1991). In Lusitu, during the wet season *Balanites aegyptiaca* (1.70 mg/kg DM), *Eleusine coracana* (4.30 mg/kg DM), *Azadirachta indica* (4.80 mg/kg DM), *Amaranthus spinosum* (7.20 mg/kg DM), *Acacia geradii* (3.70 mg/kg DM) and *Xanthocersis zambesiaca* (4.30 mg/kg DM) had Cu concentrations below the critical level. In the hot dry season *Azadirachta indica* (7.60 mg/kg DM), *Eleusine coracana* (4.90 mg/kg DM), *Balanites aegyptiaca* (5.70 mg/kg DM), *Acacia geradii* (6.90 mg/kg DM), *Acacia tortilis* (4.20 mg/kg DM), *Berchemia discolor* (5.00 mg/kg DM) and *Maesopsis eminii* (6.00 mg/kg DM) had Cu levels below the critical level. In Simamba, during the wet season, *Maesopsis eminii* (6.00 mg/kg DM) had Cu concentrations below the critical level. In the cold dry season *Acacia tortilis* (4.65 mg/kg DM) did not meet the minimum requirement for Cu. Khan et al. (2007) reported significant seasonal fluctuations in forage Cu concentrations in Pakistan. The levels were higher in winter than in summer forage. In winter, the concentration was adequate for goats but found to be borderline to deficient during summer. This is in agreement with the findings of this study which shows that during the cold dry season, all plants except *Acacia tortilis* (4.65 mg/kg DM) had adequate levels of Cu. In Indonesia, Warly et al. (2006) reported that concentrations of micro minerals in forages were significantly affected by species and season. Deficiency of forage Cu was found in both the dry and wet seasons. Cu uptake and subsequent utilisation by plants is influenced by phosphate which reduces the concentration of Cu in roots and leaves of plants. This may be the reason for the significant negative correlation

that was observed between Cu and P ($r = -0.601$, $p<0.05$) during the hot dry season. High levels of Fe and Zn have been found to induce Cu deficiencies (Landon, 1984).

All the plants that were analysed in this study had adequate levels of Fe (range 76.20-1877.00 mg/kg DM) to meet adult goat requirements (critical level 30-40 mg/kg; Kessler, 1991). Concentration of Fe in the three seasons under investigation was higher than the critical level suggested for deficiency of goats. Warly et al. (2006) also reported high Fe concentrations in forage during the dry and wet seasons.

5.3 Plasma

Plasma P was significantly higher ($p<0.05$) in the hot dry season than in the cold dry and wet seasons. A similar pattern was observed in plants and soil. The variation in plasma P could be due to variations in plant P which in turn might have been influenced by soil P status. Blood P was positively correlated with K in the cold dry season and negatively correlated with Mg in the hot dry season. Though this does not suggest a cause and effect type of relationship, it suggests a need for further studies to better our understanding of the interactions among plasma minerals. Blood P has not been recommended by some researchers as a practical criterion for assessing P status in livestock. It is known to be affected by a number of factors; among them is carbohydrate metabolism (Simesen, 1980; Gartner, 1965). During increased carbohydrate utilization blood P level tends to decrease, and during fasting an increase is usually observed. Storage time of plasma and increased temperature also affect blood P levels (Burdin and Howard, 1963). Despite this controversy, plasma P provides a basis for carrying out further investigation. It partly accounts for dietary selection and the variable uptake and availability of Phosphorus in the diet. Bone P is said to be a more reliable estimate of P status than blood P (Cohen, 1973).

In the present study plasma Ca for both localities, was found to be significantly higher ($p<0.05$) in the cold dry season than in the wet and the hot dry seasons. Plant Ca showed

a similar pattern. These findings are supported by Khan *et al.* (2009) who reported high Ca levels in plasma during winter in male goats. Plasma Ca exceeded the critical level of 105 mg/liter (Simesen, 1980) in the three seasons in Simamba. In Lusitu however, Ca was below the recommended critical level during the wet and the hot dry seasons. This was despite having adequate Ca concentrations in plants. This may have been due to increased Ca demand during lactation as some of the goats were lactating. Calcium is one of the more precisely regulated constituents of plasma (Simesen, 1980). Calcium homeostasis is achieved by balancing the absorption of Ca from the alimentary tract with the urinary and endogenous fecal excretions of Ca, as well as fetal and lactation drain of Ca. Hypocalcaemia is one of the main biochemical changes in plasma in a condition known as parturient paresis (milk fever). It is an afebrile condition which is typically associated with parturition and the beginning of lactation. If untreated, the condition may be fatal. It is necessary therefore to maintain plasma Ca levels above the critical levels especially in pregnant and lactating does. Despite the results indicating that the study goats were hypocalcaemic, the goats were not clinically ill.

In both localities, Mg concentrations were higher ($p<0.05$) in the hot dry season than in the cold dry season and wet season as was the case in soil. In plants however, Mg was highest during the wet season. Wet and cold dry season plasma Mg concentrations reported in this study were lower than those reported by Khan *et al.* (2008) in non lactating goats. However in the hot dry season this study shows higher Mg levels than those reported by Khan et al (2008). Plasma Mg concentrations were sufficient to meet adult goat requirements in all the seasons. This may have been due to adequate Mg levels in plants reported in this study. A principal effect of Mg deficiency appears to be disturbance of normal Ca metabolism (Simesen, 1980). Plasma Ca may be low because Mg is required for the release and action of parathyroid hormone (Smith and Sherman, 1994). However, in this study low Ca levels were not accompanied by a reduction in Mg levels.

Plasma K was significantly higher ($p<0.05$) in the hot dry season than in the cold dry and wet seasons, in both localities. The lowest plasma potassium was found in the cold dry season. This is similar to what was observed in plants and in soil. In the three

seasons plasma K concentrations were sufficient for adult goat performance as the concentrations were above the recommended critical level of 200 mg/liter suggested by Kaneko (1980). This is despite K being deficient in some plants during the wet and the cold dry seasons. This may be as a result of different individual preferences for plants as the goats were feeding which may have resulted in goats selecting only those plants that were high in K.

Plasma Cu was significantly higher in the wet season than in the cold dry and hot dry seasons in the two localities. This is not consistent with plant and soil Cu. Goats in Lusitu had Cu concentrations below the critical level (0.5-1.5 mg/L) recommended by Kaneko (1980) in the three seasons, whereas those in Simamba had adequate plasma Cu only in the wet season (1.44 ± 0.88 mg/L). Overall, plasma Cu was only adequate in the wet season (1.11 ± 0.62 mg/L). These concentrations are similar to those reported by Khan *et al*. (2008) with a range of 0.34-1.05 mg/L in non-lactating goats. Low plasma Cu may cause deficiency symptoms such as anaemia, bleached looking and rough hair coat, diarrhoea and weight loss and could be expected by excess intake of Mo, S, Fe, Zn and Ca.

During the wet and hot dry seasons, plasma Fe concentrations were below the critical level of 1.6-2.2 mg/L (Kaneko, 1980) in the two localities. In goats, Fe deficiency is mainly associated with blood sucking strongyles (*Haemonchus*) that cause undetected blood loss in the faeces (Smith and Sherman, 1994). The study goats were free ranging and deworming is rarely done thereby making them susceptible to internal parasites.

These differences in plasma minerals in general, were observed in spite of the animals of same age range and sex. These differences may be related to the effects of season on plants, forage selection and grazing preferences of individual goats. Goats may benefit from supplementation of various minerals year round and particularly during the seasons when their blood plasma shows deficiency.

CHAPTER SIX

6.0 CONCLUSIONS

The status of phosphorus, calcium, magnesium, potassium, copper and iron in soil, plants and goat plasma during the cold dry, hot dry and wet seasons, was determined. The mineral status of soil was such that in the three seasons, phosphorus, potassium, calcium and copper were adequate to meet the requirements for plant growth. Iron and magnesium were deficient for plant growth during the wet and the cold dry seasons. In plants, potassium, calcium, magnesium and iron met the requirements for adult goat nutrition in the three seasons. Copper was deficient during the wet and the hot dry seasons. Deficiency of plant phosphorus occurred during the wet and the cold dry seasons. The mineral status of goat plasma was such that all minerals were deficient except for copper and iron which were adequate in the wet and cold dry seasons, respectively.

This study demonstrated that season had an effect on concentrations of phosphorus, calcium, magnesium, potassium, copper and iron in soil, plant material and goat plasma. Only phosphorus and potassium showed a consistent pattern in the three sample types in which the minerals were highest in the hot dry season. There may be need to supplement phosphorus and copper because most of the plants did not meet the critical levels of these minerals for adult goat requirements. Supplementation of phosphorus may be beneficial especially during the cold dry and the wet seasons when all the evaluated plants failed to meet the minimum requirements for adult goats. Copper may also be considered during the wet and the hot dry seasons as most plants had low Copper concentrations during these two seasons.

6.1 RECOMMENDATIONS

- Since most of the goat keepers in Zambia are resource poor, they may not afford to purchase commercially prepared mineral supplements. Therefore cultivation of plant species that are rich in a specific mineral that is deficient in an area should be encouraged. It is important to note however, that supplementation should be preceded by animal response studies.
- Other measures that could be taken would be to improve the mineral status of those plants that are deficient in a specific mineral. Such measures include fertilizer application in case of Phosphorus, foliar dusting in case of Copper as long as precautions are taken not to deposit excess amounts of these minerals on the vegetation. Effectiveness of such corrective measures under Zambian field conditions needs to be investigated.
- Calcium, potassium, magnesium and iron concentrations in plants occurred in quantities far in excess of adult goat requirements. It is recommended that further research be done to elucidate any deleterious effects to goats that might be associated with such high mineral concentrations. There is also need for further research to elucidate interactions among Copper, Molybdenum and Sulphur; Potassium, Magnesium and Calcium.

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APPENDICES

APPENDIX A: Preparation of reagents for determination of available phosphorus in soil

Appendix A-1: Extracting solution:

- 1M ammonium fluoride (NH_4F) 15 ml
- 0.5M hydrochloric acid (HCl) 25 ml
- Distilled water 460 ml

1M NH_4F: 3.7 g of the NH_4F salt in distilled water diluted to 100 ml and stored in a polyethylene bottle.

0.5M HCl: 20.2 ml of concentrated HCl diluted to 500 ml with distilled water (in a fume hood).

Appendix A-2: Reagent A:

- Dissolved 12g of ammonium molybdate ($(NH_4)_6Mo_7O_{24}$) in 250ml distilled water (1).
- Dissolved 0.2908g of Potassium Antimony Tartrate ($KsbOC_4H_4O_6$) in 100ml of distilled water. (2)
- Prepared 2.5 M sulphuric acid (H_2SO_4) by diluting approximately 148ml concentrated H_2SO_4 to about 1000 ml with distilled water. (3)
- Solution (1), (2) and (3) were mixed in a 2 dm^3 volumetric flask and made up to volume with distilled water.

Appendix A-3: Reagent B:

- Dissolved 1.056g of ascorbic acid to 200ml of reagent A.

Appendix A-4: Phosphorus stock solution

- 100 mg dm^{-3}: Dry Potassium Dihydrogen orthophosphate (KH_2PO_4) at 105°C for 1 hour and cool in a dessicator. Dissolved 0.4393g of oven-dry KH_2PO_4 to 1 dm^3 in a volumetric flask with distilled water.
- Phosphorus solution - 5mg dm^{-3}: Dilute 5 ml of P-stock solution to 100ml with distilled water**.**

APPENDIX B: Preparation of reagents for determination of exchangeable bases

1M CH3COONH4 (pH 7.0):

- 0.5 dm^3 distilled water, 70 ml ammonium hydroxide (NH_4OH) and 58 ml acetic acid (CH_3COOH). Water was added up to 900 ml. After cooling, the pH was adjusted to exactly 7. The solution was transferred into the 1 dm^3 volumetric flask. Made up to 1 dm^3 with distilled water.
- 100mg dm^{-3} stock solutions of K^+, Na^+, Ca^{2+}, and Mg^{2+}.
- 5000g dm^{-3} strontium solution: dissolved 15.215g $SrCl_2.6H_2O$ in 1 dm^3 distilled water.

APPENDIX C: Preparation of reagents for the extraction of trace elements

DTPA-TEA (pH 7.30) solution:

- Prepared 10 litres. Dissolved 149.2 g of reagent grade TEA, 19.67 g DTPA and 14.7g $CaCl_2$. $2H_20$ in approximately 200 ml of distilled water. Stirred until completely dissolved and diluted to 9 L. The pH was adjusted to 7.30±0.05 with HCl (1:1) and diluted to 10 L.

APPENDIX D: ANOVA Tables for soil, plant and blood plasma mineral analyses for Lusitu and Simamba

Appendix D-1: ANOVA (single factor) for soil minerals - Lusitu

Variable	Source of variation	SS	df	MS	F	p value
P	Between Groups	227469.92	2	113734.96	7.81	.016*
	Within Groups	101848.68	7	14549.81		
	Total	329318.60	9			
K	Between Groups	113100000	2	56530000	167.73	.000*
	Within Groups	2359068.00	7	337009.71		
	Total	115400000	9			
Ca	Between Groups	838900000	2	419400000	10.30	.008*
	Within Groups	285000000	7	40720000		
	Total	1124000000	9			
Mg	Between Groups	6961864.08	2	3480932.04	2.08	.195
	Within Groups	11670000	7	1667631.29		
	Total	18640000	9			
Cu	Between Groups	897.38	2	448.69	150.38	.000*
	Within Groups	20.88	7	2.98		
	Total	918.26	9			
Fe	Between Groups	798855.85	2	399427.92	34.58	.000*
	Within Groups	80846.49	7	11549.49		
	Total	879702.34	9			
pH	Between Groups	.57	2	.28	.30	.744
	Within Groups	6.51	7	.93		
	Total	7.08	9			

* Since $p<0.05$ the differences are significant

Appendix D-2: ANOVA (single factor) for soil minerals - Simamba

Variable	Source of variation	SS	df	MS	F	p value
P	Between Groups	338870.87	2	169435.43	4.71	.119
	Within Groups	107887.33	3	35962.44		
	Total	446758.21	5			
K	Between Groups	62500000	2	31250000	127.77	.001*
	Within Groups	733642.87	3	244547.62		
	Total	63230000	5			
Ca	Between Groups	1581000000	2	790400000	43.97	.006*
	Within Groups	53920000	3	17970000		
	Total	1635000000	5			
Mg	Between Groups	44900000	2	22450000	157.43	.001*
	Within Groups	427826.36	3	142608.78		
	Total	45330000	5			
Cu	Between Groups	883.05	2	441.52	2130	.000*
	Within Groups	.62	3	.20		
	Total	883.67	5			
Fe	Between Groups	556227.16	2	278113.58	31.79	.010*
	Within Groups	26243.84	3	8747.94		
	Total	582471.01	5			
pH	Between Groups	.45	2	.22	.41	.695
	Within Groups	1.66	3	.55		
	Total	2.11	5			

* Since $p<0.05$ the differences are significant

Appendix D-3: ANOVA (single factor) for plant minerals - Lusitu

Variable	Source of variation	SS	df	MS	F	p value
P	Between Groups	53880	2	26940	26.47	.000*
	Within Groups	24430	24	1017.72		
	Total	78310	26			
K	Between Groups	698800	2	349400	3.74	.038*
	Within Groups	2237000	24	93200		
	Total	2936000	26			
Ca	Between Groups	451700	2	225800	3.01	.068
	Within Groups	1797000	24	74860		
	Total	2248000	26			
Mg	Between Groups	339400	2	169700	26.85	.000*
	Within Groups	151700	24	6319.44		
	Total	491100	26			
Cu	Between Groups	809.433	2	404.71	3.15	.061
	Within Groups	3077.71	24	128.23		
	Total	3887.14	26			
Fe	Between Groups	2285296.90	2	1142648.45	7.01	.004*
	Within Groups	3908109.24	24	162837.88		
	Total	6193406.14	26			

* Since $p<0.05$ the differences are significant

Appendix D-4: ANOVA (single factor) for plant minerals - Simamba

Variables	Source of variation	SS	df	MS	F	p value
P	Between Groups	545300	2	272600	132.16	.000*
	Within Groups	24760	12	2062.93		
	Total	570000	14			
K	Between Groups	146600	2	73310	151.91	.000*
	Within Groups	5790.73	12	482.56		
	Total	152400	14			
Ca	Between Groups	1226000	2	613000	4.39	.037*
	Within Groups	1674000	12	139500		
	Total	2900000	14			
Mg	Between Groups	115000	2	57510	3.80	.053
	Within Groups	181500	12	15130		
	Total	296500	14			
Cu	Between Groups	65.69	2	32.84	7.67	.007*
	Within Groups	51.38	12	4.28		
	Total	117.07	14			
Fe	Between Groups	2960136.84	2	1480068.42	2.57	.118
	Within Groups	6911553.11	12	575962.75		
	Total	9871689.95	14			

* Since $p<0.05$ the differences are significant

Appendix D-5: ANOVA (single factor) for plasma minerals - Lusitu

Variable	Source of variation	SS	df	MS	F	p-value
P	Between Groups	911000	2	455500	15.517	.000*
	Within Groups	2554000	87	29354.86		
	Total	3465000	89			
K	Between Groups	116000	2	57991.10	158.560	.000*
	Within Groups	31819.07	87	365.73		
	Total	147800	89			
Ca	Between Groups	9728000	2	4864000	12.376	.000*
	Within Groups	34200000	87	393000		
	Total	43920000	89			
Mg	Between Groups	1720000	2	859900	22.468	.000*
	Within Groups	3330000	87	38275.03		
	Total	5050000	89			
Cu	Between Groups	115.59	2	57.79	6.189	.003*
	Within Groups	812.47	87	9.33		
	Total	928.07	89			
Fe	Between Groups	2369.81	2	1184.90	11.925	.000*
	Within Groups	8644.51	87	99.36		
	Total	11014.33	89			

* Since $p<0.05$ the differences are significant

Appendix D-6: ANOVA (single factor) for plasma minerals - Simamba

Variable	Source of variation	SS	df	MS	F	p-value
P	Between Groups	248.45	2	124.22	22.059	.000*
	Within Groups	568.79	101	5.63		
	Total	817.24	103			
K	Between Groups	89793.44	2	44896.72	107.960	.000*
	Within Groups	42002.12	101	415.86		
	Total	131800	103			
Ca	Between Groups	16050000	2	8027000	12.895	.000*
	Within Groups	62870000	101	6225000		
	Total	78930000	103			
Mg	Between Groups	1497000	2	748700	47.898	.000*
	Within Groups	1579000	101	15630.31		
	Total	3076000	103			
Cu	Between Groups	4720.86	2	2360.43	2.419	.094
	Within Groups	98542.44	101	975.66		
	Total	103300	103			
Fe	Between Groups	2910.72	2	1455.36	43.128	.000*
	Within Groups	3408.29	101	33.74		
	Total	6319.01	103			

* Since $p<0.05$ the differences are significant

APPENDIX E: Tables showing Benferroni t test for comparison of minerals between seasons in soil, plants and plasma

Appendix E-1: Benferroni t test for comparison of soil minerals and pH between seasons - Lusitu

Dependent Variable	(I) Season	(J) Season	Mean Difference (I-J)	Standard Error	p value	95% Confidence Interval	
						Lower Bound	Upper Bound
P	Wet	Cold dry	-3.466	98.487	1.000	-311.492	304.559
		Hot dry	-309.583*	92.127	.036	-597.715	-21.451
	Cold dry	Wet	3.466	98.487	1.000	-304.559	311.492
		Hot dry	-306.116*	92.127	.038	-594.248	-17.984
	Hot dry	Wet	309.583*	92.127	.036	21.451	597.715
		Cold dry	306.116*	92.127	.038	17.984	594.248
K	Wet	Cold dry	10.953	473.997	1.000	-1471.497	1493.403
		Hot dry	-6857.976*	443.384	.000	-8244.682	-5471.271
	Cold dry	Wet	-10.953	473.997	1.000	-1493.403	1471.497
		Hot dry	-6868.930*	443.384	.000	-8255.635	-5482.224
	Hot dry	Wet	6857.976*	443.384	.000	5471.271	8244.682
		Cold dry	6868.930*	443.384	.000	5482.224	8255.635
Ca	Wet	Cold dry	631.876	5210.070	1.000	-15662.900	16926.653
		Hot dry	-18373.100*	4873.580	.021	-33615.489	-3130.753
	Cold dry	Wet	-631.876	5210.070	1.000	-16926.653	15662.900
		Hot dry	-19005.000*	4873.580	.018	-34247.366	-3762.630
	Hot dry	Wet	18373.121*	4873.580	.021	3130.753	33615.489
		Cold dry	19004.998*	4873.580	.018	3762.630	34247.366
Mg	Wet	Cold dry	-.100	1054.400	1.000	-3297.783	3297.583
		Hot dry	-1703.216	986.299	.383	-4787.917	1381.483
	Cold dry	Wet	.100	1054.400	1.000	-3297.583	3297.783
		Hot dry	-1703.116	986.299	.384	-4787.817	1381.583
	Hot dry	Wet	1703.216	986.299	.383	-1381.483	4787.917
		Cold dry	1703.116	986.299	.384	-1381.583	4787.817
Cu	Wet	Cold dry	.326	1.410	1.000	-4.084	4.737
		Hot dry	-19.171*	1.319	.000	-23.297	-15.045
	Cold dry	Wet	-.326	1.410	1.000	-4.737	4.084
		Hot dry	-19.498*	1.319	.000	-23.624	-15.372
	Hot dry	Wet	19.171*	1.319	.000	15.045	23.297
		Cold dry	19.498*	1.319	.000	15.372	23.624
Fe	Wet	Cold dry	-2.693	87.747	1.000	-277.129	271.742
		Hot dry	-578.280*	82.080	.001	-834.991	-321.569
	Cold dry	Wet	2.693	87.747	1.000	-271.742	277.129
		Hot dry	-575.586*	82.080	.001	-832.297	-318.875
	Hot dry	Wet	578.280*	82.080	.001	321.569	834.991
		Cold dry	575.586*	82.080	.001	318.875	832.297
pH	Wet	Cold dry	.616	.787	1.000	-1.846	3.079
		Hot dry	.271	.736	1.000	-2.032	2.575
	Cold dry	Wet	-.616	.787	1.000	-3.079	1.846
		Hot dry	-.345	.736	1.000	-2.649	1.959
	Hot dry	Wet	-.271	.736	1.000	-2.575	2.032
		Cold dry	.345	.736	1.000	-1.959	2.649

* The mean difference is significant at the 0.05 level.

Appendix E-2: Benferroni t tests for comparison of soil minerals and pH between seasons - Simamba

Dependent Variable	(I) Season	(J) Season	Mean Difference (I-J)	Standard Error	p value	95% Confidence Interval	
						Lower Bound	Upper Bound
P	Wet	Cold dry	-6.195	189.638	1.000	-927.200	914.810
		Hot dry	-507.205	189.638	.226	-1428.210	413.800
	Cold dry	Wet	6.195	189.638	1.000	-914.810	927.200
		Hot dry	-501.010	189.638	.233	-1422.015	419.995
	Hot dry	Wet	507.205	189.638	.226	-413.800	1428.210
		Cold dry	501.010	189.638	.233	-419.995	1422.015
K	Wet	Cold dry	-1.160	494.518	1.000	-2402.862	2400.542
		Hot dry	-6846.875*	494.518	.002	-9248.577	-4445.172
	Cold dry	Wet	1.160	494.518	1.000	-2400.542	2402.862
		Hot dry	-6845.715*	494.518	.002	-9247.417	-4444.012
	Hot dry	Wet	6846.875*	494.518	.002	4445.172	9248.577
		Cold dry	6845.715*	494.518	.002	4444.012	9247.417
Ca	Wet	Cold dry	-457.000	4239.390	1.000	-21046.270	20132.270
		Hot dry	-34658.100*	4239.390	.011	-55247.395	-14068.854
	Cold dry	Wet	457.000	4239.390	1.000	-20132.270	21046.270
		Hot dry	-34201.100*	4239.390	.012	-54790.395	-13611.854
	Hot dry	Wet	34658.125*	4239.390	.011	14068.854	55247.395
		Cold dry	34201.125*	4239.390	.012	13611.854	54790.395
Mg	Wet	Cold dry	-.725	377.636	1.000	-1834.772	1833.322
		Hot dry	-5803.500*	377.636	.002	-7637.547	-3969.452
	Cold dry	Wet	.725	377.636	1.000	-1833.322	1834.772
		Hot dry	-5802.775*	377.636	.002	-7636.822	-3968.727
	Hot dry	Wet	5803.500*	377.636	.002	3969.452	7637.547
		Cold dry	5802.775*	377.636	.002	3968.727	7636.822
Cu	Wet	Cold dry	.020	.455	1.000	-2.191	2.231
		Hot dry	-25.725*	.455	.000	-27.936	-23.513
	Cold dry	Wet	-.020	.455	1.000	-2.231	2.191
		Hot dry	-25.745*	.455	.000	-27.956	-23.533
	Hot dry	Wet	25.725*	.455	.000	23.513	27.936
		Cold dry	25.745*	.455	.000	23.533	27.956
Fe	Wet	Cold dry	-3.540	93.530	1.000	-457.785	450.705
		Hot dry	-647.650*	93.530	.019	-1101.895	-193.404
	Cold dry	Wet	3.540	93.530	1.000	-450.705	457.785
		Hot dry	-644.110*	93.530	.019	-1098.355	-189.864
	Hot dry	Wet	647.650*	93.530	.019	193.404	1101.895
		Cold dry	644.110*	93.530	.019	189.864	1098.355
pH	Wet	Cold dry	-.235	.743	1.000	-3.847	3.377
		Hot dry	.430	.743	1.000	-3.182	4.042
	Cold dry	Wet	.235	.743	1.000	-3.377	3.847
		Hot dry	.665	.743	1.000	-2.947	4.277
	Hot dry	Wet	-.430	.743	1.000	-4.042	3.182
		Cold dry	-.665	.743	1.000	-4.277	2.947

* The mean difference is significant at the 0.05 level.

Appendix E-3: Benferroni t test showing comparison of plant minerals between seasons - Lusitu

Dependent Variable	(I) Season	(J) Season	Mean Difference (I-J)	Standard Error	p value	95% Confidence Interval	
						Lower Bound	Upper Bound
P	Wet	Cold dry	0.0787	0.478	1.000	-1.152	1.310
		Hot dry	-2.960*	0.463	.000	-4.153	-1.767
	Cold dry	Wet	-0.078	0.478	1.000	-1.310	1.152
		Hot dry	-3.039*	0.490	.000	-4.301	-1.778
	Hot dry	Wet	2.960*	0.463	.000	1.767	4.153
		Cold dry	3.039*	0.490	.000	1.778	4.301
K	Wet	Cold dry	5.269	4.579	.783	-6.515	17.054
		Hot dry	-7.451	4.435	.318	-18.866	3.964
	Cold dry	Wet	-5.269	4.579	.783	-17.054	6.515
		Hot dry	-12.720*	4.690	.037	-24.793	-0.647
	Hot dry	Wet	7.451	4.435	.318	-3.964	18.866
		Cold dry	12.720*	4.690	.037	0.647	24.793
Ca	Wet	Cold dry	-7.206	4.104	.276	-17.769	3.356
		Hot dry	2.863	3.975	1.000	-7.367	13.095
	Cold dry	Wet	7.206	4.104	.276	-3.356	17.769
		Hot dry	10.070	4.204	.074	-0.749	20.891
	Hot dry	Wet	-2.863	3.975	1.000	-13.095	7.367
		Cold dry	-10.070	4.204	.074	-20.891	0.749
Mg	Wet	Cold dry	1.587	1.192	.587	-1.481	4.656
		Hot dry	8.101*	1.155	.000	5.128	11.074
	Cold dry	Wet	-1.587	1.192	.587	-4.656	1.481
		Hot dry	6.513*	1.221	.000	3.370	9.657
	Hot dry	Wet	-8.101*	1.155	.000	-11.074	-5.128
		Cold dry	-6.513*	1.221	.000	-9.657	-3.370
Cu	Wet	Cold dry	-12.665	5.371	.081	-26.489	1.159
		Hot dry	-1.617	5.203	1.000	-15.008	11.773
	Cold dry	Wet	12.665	5.371	.081	-1.159	26.489
		Hot dry	11.047	5.502	.168	-3.114	25.208
	Hot dry	Wet	1.617	5.203	1.000	-11.773	15.008
		Cold dry	-11.047	5.502	.168	-25.208	3.114
Fe	Wet	Cold dry	-243.397	191.412	.647	-736.023	249.228
		Hot dry	472.340	185.410	.053	-4.838	949.518
	Cold dry	Wet	243.397	191.412	.647	-249.228	736.023
		Hot dry	715.737*	196.081	.004	211.094	1220.380
	Hot dry	Wet	-472.340	185.410	.053	-949.518	4.838
		Cold dry	-715.737*	196.081	.004	-1220.380	-211.094

* The mean difference is significant at the 0.05 level.

APPENDIX E-4: Benferroni t test showing comparison of plant minerals between seasons - Simamba

Dependent Variable	(I) Season	(J) Season	Mean Difference (I-J)	Standard Error	p value	95% Confidence Interval	
						Lower Bound	Upper Bound
P	Wet	Cold dry	0.726	0.879	1.000	-1.718	3.170
		Hot dry	-14.811*	0.972	.000	-17.514	-12.108
	Cold dry	Wet	-0.726	0.879	1.000	-3.170	1.718
		Hot dry	-15.537*	1.096	.000	-18.586	-12.488
	Hot dry	Wet	14.811*	0.972	.000	12.108	17.514
		Cold dry	15.537*	1.096	.000	12.488	18.586
K	Wet	Cold dry	-0.202	0.425	1.000	-1.384	0.980
		Hot dry	-7.880*	0.470	.000	-9.187	-6.573
	Cold dry	Wet	0.202	0.425	1.000	-0.980	1.384
		Hot dry	-7.678*	0.530	.000	-9.153	-6.203
	Hot dry	Wet	7.880*	0.470	.000	6.573	9.187
		Cold dry	7.678*	0.530	.000	6.203	9.153
Ca	Wet	Cold dry	-20.487*	7.233	.045	-40.591	-0.383
		Hot dry	-0.163	7.996	1.000	-22.389	22.062
	Cold dry	Wet	20.487*	7.233	.045	0.383	40.591
		Hot dry	20.324	9.021	.131	-4.750	45.398
	Hot dry	Wet	0.163	7.996	1.000	-22.062	22.389
		Cold dry	-20.324	9.021	.131	-45.398	4.750
Mg	Wet	Cold dry	5.419	2.381	.126	-1.200	12.038
		Hot dry	5.716	2.632	.152	-1.601	13.034
	Cold dry	Wet	-5.419	2.381	.126	-12.038	1.200
		Hot dry	0.297	2.970	1.000	-7.958	8.553
	Hot dry	Wet	-5.716	2.632	.152	-13.034	1.601
		Cold dry	-0.297	2.970	1.000	-8.553	7.958
Cu	Wet	Cold dry	1.237	1.267	1.000	-2.284	4.759
		Hot dry	5.479*	1.400	.006	1.585	9.373
	Cold dry	Wet	-1.237	1.267	1.000	-4.759	2.284
		Hot dry	4.241	1.580	.060	-.151	8.634
	Hot dry	Wet	-5.479*	1.400	.006	-9.373	-1.585
		Cold dry	-4.241	1.580	.060	-8.634	.151
Fe	Wet	Cold dry	566.125	464.743	.740	-725.615	1857.865
		Hot dry	1125.341	513.793	.147	-302.731	2553.414
	Cold dry	Wet	-566.125	464.743	.740	-1857.865	725.615
		Hot dry	559.216	579.636	1.000	-1051.866	2170.300
	Hot dry	Wet	-1125.341	513.793	.147	-2553.414	302.731
		Cold dry	-559.216	579.636	1.000	-2170.300	1051.866

* The mean difference is significant at the 0.05 level.

Appendix E-5: Benferroni t test showing comparison of plasma minerals between seasons - Lusitu

Dependent Variable	(I) Season	(J) Season	Mean Difference (I-J)	Standard Error	p-value	95% Confidence Interval	
						Lower Bound	Upper Bound
P	Wet	Cold dry	-0.031	5.41	1.000	-13.257	13.194
		Hot dry	-20.142*	5.10	.000	-32.612	-7.673
	Cold dry	Wet	0.031	5.41	1.000	-13.194	13.257
		Hot dry	-20.111*	4.03	.000	-29.969	-10.253
	Hot dry	Wet	20.142*	5.10	.000	7.673	32.612
		Cold dry	20.111*	4.03	.000	10.253	29.969
K	Wet	Cold dry	1.419	0.60	.064	-0.057	2.895
		Hot dry	-6.171*	0.57	.000	-7.562	-4.779
	Cold dry	Wet	-1.419	0.60	.064	-2.895	0.057
		Hot dry	-7.590*	0.45	.000	-8.690	-6.489
	Hot dry	Wet	6.171*	0.57	.000	4.779	7.562
		Cold dry	7.590*	0.45	.000	6.489	8.690
Ca	Wet	Cold dry	-69.899*	19.82	.002	-118.296	-21.502
		Hot dry	-0.207	18.69	1.000	-45.836	45.421
	Cold dry	Wet	69.893*	19.82	.002	21.502	118.296
		Hot dry	69.691*	14.77	.000	33.618	105.764
	Hot dry	Wet	0.207	18.69	1.000	-45.421	45.836
		Cold dry	-69.691*	14.77	.000	-105.764	-33.618
Mg	Wet	Cold dry	-2.482	6.18	1.000	-17.585	12.620
		Hot dry	-29.253*	5.83	.000	-43.492	-15.014
	Cold dry	Wet	2.482	6.18	1.000	-12.620	17.585
		Hot dry	-26.770*	4.61	.000	-38.027	-15.513
	Hot dry	Wet	29.253*	5.83	.000	15.014	43.492
		Cold dry	26.770*	4.61	.000	15.513	38.027
Cu	Wet	Cold dry	0.282*	0.09	.013	0.046	0.518
		Hot dry	0.314*	0.09	.003	0.092	0.536
	Cold dry	Wet	-0.282*	0.09	.013	-0.518	-0.046
		Hot dry	0.032	0.07	1.000	-0.143	0.208
	Hot dry	Wet	-0.314*	0.09	.003	-0.536	-0.092
		Cold dry	-0.032	0.07	1.000	-0.208	0.143
Fe	Wet	Cold dry	-0.773*	0.31	.048	-1.542	-.400
		Hot dry	0.371	0.29	.643	-0.353	1.097
	Cold dry	Wet	0.773*	0.31	.048	.400	1.542
		Hot dry	1.145*	0.23	.000	0.571	1.718
	Hot dry	Wet	-0.371	0.29	.643	-1.097	0.353
		Cold dry	-1.145*	0.23	.000	-1.718	-0.571

* The mean difference is significant at the 0.05 level.

Appendix E-6: Benferroni t tests showing comparison of plasma minerals between seasons - Simamba

Dependent Variable	(I) Season	(J) Season	Mean Difference (I-J)	Standard Error	p value	95% Confidence Interval	
						Lower Bound	Upper Bound
P	Wet	Cold dry	0.091	0.053	.282	-0.039	0.221
		Hot dry	-0.300*	0.061	.000	-0.450	-0.150
	Cold dry	Wet	-0.091	0.053	.282	-0.221	0.039
		Hot dry	-0.391*	0.059	.000	-0.536	-0.245
	Hot dry	Wet	0.300*	0.061	.000	0.150	0.450
		Cold dry	0.391*	0.059	.000	0.245	0.536
K	Wet	Cold dry	2.168*	0.460	.000	1.047	3.290
		Hot dry	-5.333*	0.530	.000	-6.625	-4.040
	Cold dry	Wet	-2.168*	0.460	.000	-3.290	-1.047
		Hot dry	-7.502*	0.512	.000	-8.750	-6.253
	Hot dry	Wet	5.333*	0.530	.000	4.040	6.625
		Cold dry	7.502*	0.512	.000	6.253	8.750
Ca	Wet	Cold dry	-80.828*	17.823	.000	-124.220	-37.437
		Hot dry	-2.614	20.540	1.000	-52.620	47.391
	Cold dry	Wet	80.828*	17.823	.000	37.437	124.220
		Hot dry	78.214*	19.843	.000	29.905	126.523
	Hot dry	Wet	2.614	20.540	1.000	-47.391	52.620
		Cold dry	-78.214*	19.843	.000	-126.523	-29.905
Mg	Wet	Cold dry	-2.805	2.824	.969	-9.680	4.070
		Hot dry	-29.461*	3.254	.000	-37.385	-21.537
	Cold dry	Wet	2.805	2.824	.969	-4.070	9.680
		Hot dry	-26.656*	3.144	.000	-34.311	-19.001
	Hot dry	Wet	29.461*	3.254	.000	21.537	37.385
		Cold dry	26.656*	3.144	.000	19.001	34.311
Cu	Wet	Cold dry	1.400	0.705	.150	-0.317	3.118
		Hot dry	1.442	0.813	.238	-0.537	3.421
	Cold dry	Wet	-1.400	0.705	.150	-3.118	0.317
		Hot dry	0.041	0.785	1.000	-1.870	1.954
	Hot dry	Wet	-1.442	0.813	.238	-3.421	0.537
		Cold dry	-0.041	0.785	1.000	-1.954	1.870
Fe	Wet	Cold dry	-0.746*	0.131	.000	-1.065	-0.426
		Hot dry	0.572*	0.151	.001	0.204	0.941
	Cold dry	Wet	0.746*	0.131	.000	0.426	1.065
		Hot dry	1.318*	0.146	.000	0.963	1.674
	Hot dry	Wet	-0.572*	0.151	.001	-0.941	-0.204
		Cold dry	-1.318*	0.146	.000	-1.674	-0.963

* The mean difference is significant at the 0.05 level.