INTERSPECIFIC VARIATION IN TRACE ELEMENT MICRONUTRIENT AND MACROELEMENT DENSITY BY USE OF ENERGY DISPERSIVE X-RAY FLOUROSCENCE (EDXRF) IN SELECTED INDIGENOUS FOOD PLANTS.

BY

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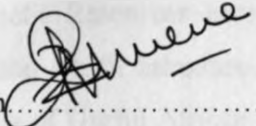UNIVERSITY OF NAIROBI
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2005

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university

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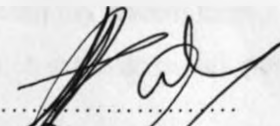
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ACKNOWLEDGMENT

DEDICATION

To my father Sebastian and my mother Eunice for financing my initial education, brothers and sisters for their day-to-day encouragement.

LIST OF TERMS AND ACRONYMS USED AND THEIR DEFINITIONS

Germplasm: Collections and assemblies of genotypes or populations representative of cultivars, genetic wild species e.t.c

Characterization: Records of those traits that are highly heritable and can easily be seen or determined by simple bioassay or analytical methods.

IPGRI-SSA: International Plant Genetic Resources Institute- Sub Saharan Africa.

Micronutrient-density: The amounts of trace elements of nutritional value.

EDXRF: Energy Dispersive X-Ray Fluorescence normally shortened to XRF.

K: Potassium

Ca: Calcium

Fe: Iron

Zn: Zinc

Cu: Copper

MIE: Micro elements (Fe, Zn, Cu and Mn)

MAE: Macro elements (K and Ca)

Mn: Manganese

Se: Selenium

I: Iodine

mm: millimeters

m: meters

ICGs: Indigenous Culti- Groups (Vegetables, cereals and fruits)

UACPs: Useful African Crop Plants

XRF: X-Ray Fluorescence Analysis

SOMICS: Soil Mineral Concentration Status

MINU-HHA: Micronutrients density in relation to hidden hunger alleviation

μg: microgram = 10^{-3} mg

mg: milligram = 10^{-3} g

ng: nanogram = 10^{-3} μg

μg/g: micrograms per gram

ppm: parts per million = μg g^{-1} = mg kg^{-1} = g t^{-1}

CGIAR: Consultative Group on International Agricultural Research

COMA: Committee on Medical Aspects of Food Policy

FAO: Food and Agricultural Organization

WHO: World Health Organization

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ABSTRACT

Many indigenous cultivars have disappeared within the lifespan of the present generation. In many areas, diets are based on fewer plant species. This coupled with increased population, low incomes and a misguided preference for expensive exotic foods, has contributed significantly to the problem of micronutrient malnutrition (hidden hunger), and increased levels of poverty and food insecurity in the country.

To plan national programs and strategies, data on the nutritional value of the indigenous food plants is required because they are a regular component of diets to many people.

One of the most efficient methods of improving the yield and nutritional value of subsistence crops is to improve the land races or weedy species being grown through selection or breeding. In order to accomplish this, genetic stocks/germplasm must be available for characterization. Unfortunately, systematic genetic collections on indigenous crops and an efficient analytical tool are lacking locally. Furthermore, many of African leafy vegetables, cereals and fruits so far known are so large that extensive characterization could be difficult as the numbers of samples that can be effectively evaluated for intrinsic characters such as micronutrient density are limited. Sensitive analytical techniques are therefore essential when preliminary assessment of quality might be important at germplasm level.

Germplasm characterization has traditionally been done by wet chemistry procedures. These procedures however, are expensive and time consuming. They also require laboratory skills and apparatus. Physiological techniques require expensive standards for calibration, can be also tedious and may not be practical especially at inter and intra-specific levels. Consequently, such procedures are not suited to screen/characterize a large number of germplasm samples.
Energy Dispersive X –Ray Fluorescence gained appeal as the method of characterization in that it is a nondestructive, rapid, multielement technique on which analysis can be done on microgram quantities across a large range of matrices i.e. solids liquids and solids. The method does not require standards for every element analyzed.

Traditional African agriculture employs a crop genetic diversity of a type, which embraces growing a variety of cultigens and/or marginal plant species (wild or semi cultivated). Due to consistent adaptability, many native types in use appear to posses' efficient mechanisms with

which to extract the little available nutrients and concentrate them in their tissues during their growth and development. Due to their genetic differences and species extent of uptake, tissue concentration varies With respect to these variations; there possibly exists a genetic diversity in phyto-micronutrient density, which at present time would be important if characterized by any known procedures.

A reconnaissance was carried out in three locations of Kenya; Mt. Elgon region, Lake Victoria region and Eastern region to characterize by Energy Dispersive X-ray fluorescence Spectroscopy (EDXRF) for inter-specific variation in micronutrient density in germplasm of selected indigenous vegetables, cereals and fruits. The purpose was to characterize thirteen indigenous species of plant samples falling under three categories: vegetables, cereals and fruits. The thirteen indigenous species of plant falling under the category of Useful African Crop Plants (UACPs) were collected namely: maize, finger millet, pearl millet, sorghum (cereals) cowpea, African nightshade, bush okra, spider weed (vegetables), Jackfruit, *Rhus* spp, *Fichus* spp and *Grewia* (indigenous fruits) and characterized for inter and intra specific variation in micronutrient density in respect to hidden hunger alleviation. In the laboratory, two macro- elements (MAEs) were determined; potassium (K) and calcium (Ca), and four trace micronutrients (MIEs) as iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu) on germplasm and its corresponding soils from sites of collection.

Populations of both plant and the corresponding soil material from three separate sites for each type of the eleven species were obtained from Mt. Elgon and Lake Victoria region while only five species were obtained from the eastern region of Kenya.

EDXRF raw data was empirically converted into characterization data and complete randomised design (CRD) used as the method for data analysis by Genstat statistical package. Pearson's 'r' was used to give correlation trends among the soil and plant macro and micronutrient elements.

After Energy Dispersive X –Ray Fluorescence analysis it was found out that there was significant variation ($P \leq 0.05$) in micronutrient density in respect to hidden hunger alleviation (MINU-HHA) variation among UACPs accessions even where grown under similar conditions. The vegetable category had significantly ($P \leq 0.01$) the highest micronutrient and macro element levels compared to the fruits and cerealsSoil macro and microelement concentrations differed from different sites

significantly (P≤0.01).

The interaction between species and sites in micronutrient and macro element content was significant (P≤0.01) indicating a strong genotype-macro and micro nutrient content interaction in populations sampled.

The variations in MINU-HHA imply a strong environmental modulation on the genotype to the extent that such variation was not only regional specific but soil specific as well.

Field population values without some kind of a standardization procedure (in light of the interaction component) are less informative with regard to the specific genotypic micronutrient and macro element contribution to hidden hunger. Separation of the genotype from the edaphic connection is in effect necessary in order to target the genetic potential for improving the farmer-preferred populations. The interaction further suggests the need to consider soil macro and micro-element management in farming with the indigenous resources.

The variations in MINU-HHA also imply that dietary diversity is important for nutritional adequacy.

1.0   INTRODUCTION

1.1   Background

The last century has brought more changes for the people of Kenya than perhaps any other time before. Western culture and modern science and technology are encroaching on traditional practices and eroding local knowledge. Modern times have brought new food habits and even several new crops. The plants from which indigenous foods were obtained are now suffering a double tragedy: Genetic erosion and loss of traditional knowledge. Many indigenous cultivars have disappeared within the lifespan of the present generation. In many areas, diets are based on fewer plant species. This coupled with increased population, low incomes and a misguided preference for expensive exotic foods, has contributed significantly to the problem of micronutrient malnutrition (hidden hunger), and increased levels of poverty and food insecurity in the country.

Increase in population leads to need for more food (WHO, 1992); source of which is mainly plants that supply a bulk of its dietary requirements. However, the current genetic food base in the country is too narrow to sustain our dietary requirements thus the need for alternative food sources such as cultivation of wild and indigenous food crops and plants (Anon, 1975, 1984, Waithaka and Chweya, 1991) becomes urgent. One of the mitigation methods is to direct efforts toward increasing productivity and improve nutrition of high yielding varieties of cereals and indigenous subsistence crops (Alteri and Merrik, 1987).

The nutritional status and composition of these less well-known genetic food resources might not only be high in quality but also more diverse than for exotic cultivars (FAO, 1993, Gomez, 1982).

Because of the importance of micronutrients and their impact on health, recently, efforts have been made to even genetically modify plant genetic resources with an aim of increasing the micronutrient content two or three times more than normal (Wertheim, 2000). In Sub Saharan Africa, interest in dietary diversity is now reviving interest in indigenous vegetables, cereals and fruits whose importance is yet to be fully documented (Anon, 1984).

This is through the realization that micronutrient malnutrition (hidden hunger) common and widespread in the world (CGIAR Micronutrient project, 1996). For instance, More than 2 billion people globally are iron deficient and the problem is severe enough to cause anaemia in 60 % of

the people. Roughly, 40% of non-pregnant women and 30% of pregnant women have anaemia worldwide (Fairbanks, 1994).

Results of a 1999-2000 national survey on anaemia and status of micronutrients- Vitamin A, iron and zinc in Kenya released on February 2002, show that seven out of ten Kenyan children in rural and low-income urban areas have little hope of leading a healthy life or escaping death before their third birthday due to serious anaemic and micronutrients deficiency conditions. For those who survive, they suffer from improper brain and intelligent quotient (IQ) development. When combined with high anaemic rates among the adult population, particularly mothers, the national loss occasioned by the deficiency is about 1.5 percent of Gross Domestic Product earnings. Nutritionists describe anaemia and iron deficiency as a national disaster. The report describes prevalence of micronutrient deficiencies in Kenya as unacceptably high when compared to World Health Organization standards (Ministry of Health Demographic Survey, 2000).

Micronutrient malnutrition refers to diseases caused by dietary deficiency of vitamins and minerals. Most severe problems of hidden hunger (high rates of illness and disability, reduced learning ability and productivity) are occurring in developing countries due to poverty, lack of access to a variety of foods and poor dietary practices attributed to lack of proper knowledge toward other factors. The consequence has high social and public costs, reduced work capacity in populations and tragic loss of human potential (FAO 1986).

Of the measures known to prevent and control micronutrient malnutrition among vulnerable populations (food-based strategies e.g. food production, dietary diversification and bio-fortification) are the most sustainable approaches for mitigating the effects of hidden hunger (CGIAR Micronutrient project, 1996; Grusak, 1999).

Based on this understanding, a micronutrient project, in various CGAIR centres, in 1996, initiated a project involving breeding staple food crops with high micronutrient to explore CGAIR germplasm banks for mineral and vitamin dense varieties of staple crops including rice, maize, beans and cassava. The target micronutrients were iron, zinc and iodine (Fassil et. al, 1996). The project focused in a pre-breeding study to determine among others the rate of genetic variability available for use in future breeding programmes.

To date, information is scanty on the extent of dietary diversity and quality of indigenous

vegetables, fruits and cereals. However, some of these indigenous plants are reported to have dietary potential for enhancing the local nutritional needs (Sehmi, 1999). It is in this respect that the present study sought to characterize thirteen indigenous food plants for M.I.E and M.A.E variation.

1.2   Research problem

Micronutrient malnutrition is a serious and widespread health problem in most developing countries. Conventionally, the relative importance of any crop is assessed from the total yield and sales recorded for such a crop. Unfortunately, nutritional contribution is often ignored. Consequently, important information on the quantity of micronutrient density of indigenous subsistence crops of Africa found in Kenya, which are rarely sold commercially, is lacking or limited in some cases. Subsequently, these species have been given low priority in most agronomic research and development (Alteri and Merrik, 1987, Brown, 1983)

Many of African leafy vegetables, cereals and fruits so far known are so large that extensive characterization could be difficult as the numbers of samples that can be effectively evaluated for intrinsic character such as micronutrient density are limited. Sensitive rapid analytical techniques are therefore essential when preliminary assessment of quality might be important at germplasm level.

Rapid changes in land use, modernization of agricultural practices and adoption of new varieties possessing a narrow genetic base have led to disappearance of wild species and potentially valuable germplasm may permanently be lost (Mathur and Ramantha Rao, 1999).

In Africa, and sub-Saharan Africa in particular, production and consumption of indigenous food plants has been declining (IFPRI, 1985). This is because traditional food plants particularly indigenous vegetables are widely believed by urban and peri-urban residents to be inferior to exotic ones.

Wertheim (2000), writing for a Los Angeles weekly says that Rosset (2000), an expert and coordinator of the Oakland based institute for food and development policy have noted that a primary reason for many vitamin and mineral deficiency in the developing world is lack of green leafy vegetables in the diet. However, the rural poor has a wealth of plant genetic resources

(mostly indigenous), which contain some mineral supplements but are inadequately used thus the local crop germplasm would be a cheaper and a possible effective source of micronutrient than commercial mineral supplements sold over the counters (Raymond 2001).

1.3   Justification of the study

Indigenous plants are a regular component of diet for millions in Africa. In Tanzania for example, wild vegetables account for 49% of vegetables consumed. They have always supplemented the diet in a geographical region where animal foods were unavailable or scarce (Uiso and Johns, 1996). The most common use of food from the wild is snacks. Traditionally, people ate fruit between meals while herding cattle or working in the field. Snack foods are especially important for children who need to eat more frequently than adults do. In addition, these wild fruits may supply micronutrients that are very important for the healthy growth of children, which may be deficient in the bulky cereal–based diet *Grewia spp* for example is a major nutritional resource for pastoralists in the dry zone (Maundu et. al., 1999). In Eastern Nigeria, Fulani agro-pastoralists use wild species for both food and medicine during drought (Lockett, 1999).

A survey in rural Kenya showed that over half of the students surveyed ate only wild fruits during the day in school (Grivetti, 2001); these fruits were a major source of vitamins and minerals. These species provide a broad range of micronutrients and in some areas; reliance upon them is critical especially during months preceding crop harvest of regular crops. Such species also play prominent roles in sustaining humans during periods of social unrest and military conflict and also during drought and other natural catastrophes (Grivetti, 2001).

Globally, however, agriculture has focused on only few cultivars at the expense of potentially edible wild species. The cultivars in use are actually high yielding and have become popular because of their yield and processing convenience or the prestige attached to their use (Grivetti, 2001).

For widespread use, indigenous crops have a problem since they are considered marginal crops in global agriculture. Modern knowledge about many of these indigenous vegetables, cereals and fruits in terms of utilization, cultivation techniques, the extent and structure of genetic variation and the potential for crop improvement through breeding is lacking (Waithaka and Chweya, 1991).

To plan national programs and strategies, data on the nutritional value of the indigenous food plants is required because the majority of the people consume them. The role played by the traditional food plants is major. Protein deficiency has always been a concern of the under privileged in the developing countries and Kenya is no exception. Protein deficiency causes increased morbidity and mortality among vulnerable groups (UNICEF, 1993). Protein is a basic nutrient and a potent adjuvant in nutrition rehabilitation of the sick or those marginally fed (WHO, 1992).

Whereas much work has been carried out in the Protein- Energy –Malnutrition (PEM), little work has been carried out on micronutrients deficiencies. With the realization that micronutrient deficiency is common, related to mortality and morbidity and that it differentially affects the vulnerable populations, there has been an increased interest in the content of micronutrients in various diets (FAO, 1986).

Although wild fruits supply micronutrients that are very important for the healthy growth of children and people who use them as snacks during herding, or working in the field, they are still treated as minor crops that do not require immediate particular attention (Maundu et. al., 1999).

This should not be so because if hunger periods lead to actual starvation, or calamities such as war cause emergencies, a range of wild indigenous plants provide a life saving buffer as in the case of *Balanites pedicellaris* and *Boscia coriacea*, among the Turkana of north western Kenya (Maundu et. al., 1999). Unfortunately, the change in people's eating habits in favour of introduced cultivars such as potato, rice, and wheat has decreased the production and consumption of indigenous crops such as the millets and sorghums.

Traditional African agriculture employs a crop genetic diversity of a type, which embraces growing a variety of cultigens and/or marginal plant species (wild or semi cultivated). Many native types in use appear to posses' efficient mechanisms with which to extract the little available nutrients and concentrate them in their tissues during their growth and development. Due to their genetic differences and species extent of uptake, tissue concentration varies (Shacklette, 1980). With respect to these variations, there possibly exists a genetic diversity in phyto-micronutrient density, which at present time would be important if characterized by any known procedures.

In terms of production systems, it should also be noted that indigenous leafy vegetables, fruits and cereals are adapted to harsh or drought environments under low input agriculture compared to other crops. There are therefore chances that natural selection might have produced a variety of uptake-efficient and or uptake-inefficient genotypes.

1.4   Objectives

The overall objective of this study therefore, was to characterize germplasm of African indigenous food plants for micronutrient and macro element density.

The specific objectives were to:
1. Determine the variation in micronutrient and macro element densities in 13 species of African food plants.
2. Evaluate the soil mineral element concentration with respect to micronutrient density.

1.5   Hypothesis

Three indigenous culti-groups (ICGs) may or may not be micronutrient rich sources in relation to hidden hunger alleviation (MINU-HHA) according to XRF density analysis.

1.6   Expected output / significance of the study

As shown in the proposed conceptual model flow diagram (Fig. 1), the starting point of reasoning is that XRF would provide a means as a pre breeding tool to plant breeders to characterize indigenous plant genetic resources for macro and micro nutrient element contents. Plant breeders in turn would initiate breeding programmes that would help to isolate outstanding germplasm for direct use and/or further breeding. The knowledge of the composition of indigenous cereals, vegetables and fruits through an efficient characterization means, will enhance diversification towards a more nutritious diet through production (farmers cultivating mineral rich good crop) and consumption of high micro and macro nutrient dense crops. This in effect is expected to help combat the ill effects of hidden hunger (health of vulnerable group is improved) and consequently promote conservation (Akundabweni, 2004).

Lack of access to a variety of foods and poor dietary practices attributed to lack of proper knowledge (Timoteweose and Mulungeta, 2000) has led to the most severe problems of hidden hunger. However, some of these indigenous plants are reported to have dietary potential for

enhancing the local nutritional needs (Sehmi and Maundu et, al., 1999).
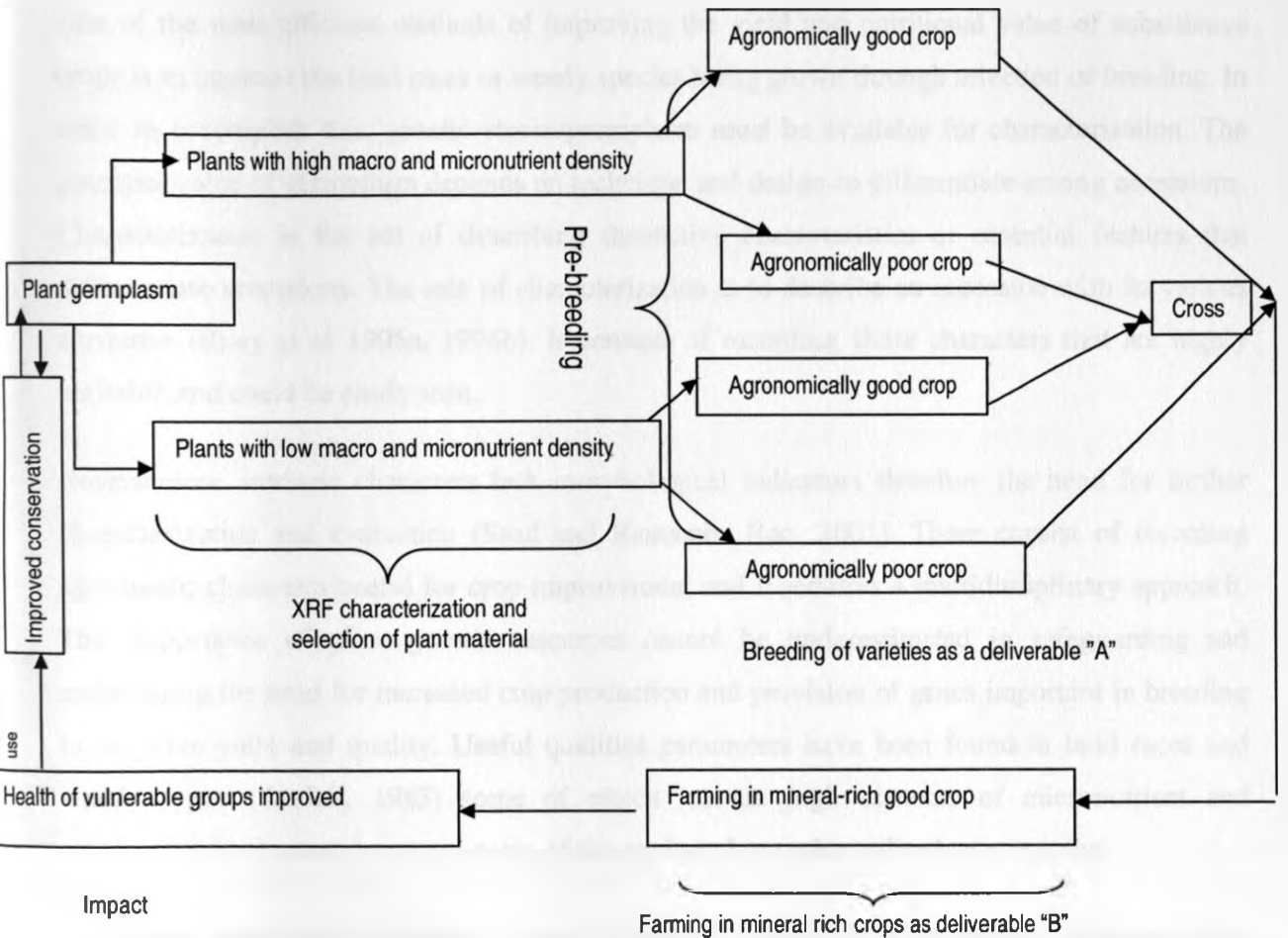
Figure 1: Chart of expected impact after XRF germplasm characterization

In Kenya, vegetables are used to accompany carbohydrate based staple dishes of mainly maize, sorghum and finger millet flour (Mukiibi 1988) during meal times. The staples normally lack important nutrients that are found in the vegetables (Maundu, et. al., 1999). Although Juma (1989) identified and enumerated a sizable number of edible food plants in Kenya, chemical composition data on these edible food plants is scarce. Most researchers carried work out on the European types of food plants, which are more profitable than the indigenous plants.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Germplasm characterization

One of the most efficient methods of improving the yield and nutritional value of subsistence crops is to improve the land races or weedy species being grown through selection or breeding. In order to accomplish this, genetic stocks/germplasm must be available for characterization. The potential value of germplasm depends on technique and design to differentiate among accessions. Characterization is the act of describing distinctive characteristics or essential features that differentiate accessions. The role of characterization is to describe an accession with its various attributes (Riley et al 1996a, 1996b). It consists of recording those characters that are highly heritable and could be easily seen.

Nevertheless, intrinsic characters lack morphological indicators therefore the need for further characterization and evaluation (Saad and Ramantha Rao, 2001). These consist of recording agronomic characters useful for crop improvement and it requires a multidisciplinary approach. The importance of plant genetic resources cannot be underestimated in safeguarding and maintaining the need for increased crop production and provision of genes important in breeding to improve yield and quality. Useful qualities parameters have been found in land races and weedy types (Tindall, 1983) some of which include high contents of micronutrient and macronutrient element density in some of the neglected or under utilized crop species.

Indigenous plant species continue to serve as genetic reservoirs for biodiversity. However; they are eroding rapidly and being replaced by exotic cultivars; yet these species are important sources of disease resistance, pest resistance and they provide physiological adaptations that are not found in most of the domesticated species (Ramantha Rao and Tao, 1993). Particular attention has to be paid to the traditional cultivars due to the increased pressure on agriculture, as they are the most threatened species (Saad and Ramantha Rao, 2001). The genetic resources that include the wild and weedy species that are used in agriculture, forestry and horticulture are also in danger because of deforestation and developmental activities (e.g. urbanization and building). As a result, some forest species especially in the tropics are clearly endangered (Mathur and Ramantha Rao, 1999).

Given the seriousness of conservation and use of plant genetic resources, there is an urgent need for assemblage, characterization and evaluation of genetic diversity to enable developing informed conservation measures (Saad and Ramantha Rao, 2001).

The key to successful use of variability from broad gene pools require desirable traits available in the germplasm (Saad and Ramantha Rao, 2001) and this will require a systematic evaluation and characterization of germplasm (Ramantha Rao, 1980). Characterization and evaluation of germplasm may serve two functions: first, the characters that are recorded on individual accessions can serve as diagnostic descriptors for the germplasm accessions. The second function is related to the plant material use. Both characterization and evaluation result in recording of traits that help the user identify accessions with desirable traits for crop improvement and use (Saad and Ramantha Rao, 2001).

The analyses and characterization of genetic diversity has always been a concern (Brown et al, 1989). Genetic diversity plays a fundamental role in evolutionary theory because natural selection chooses among the variants that occur within the population based on their adaptation to their immediate environment. The ultimate result is that variation within populations is converted to variation between populations and finally into variation between species. The situation is analogous to crop improvement. Here the goal is to fix agronomically useful genetic variants within cultivars by selective breeding. Consequently, agriculturists are fundamentally concerned with the quality and extent of genetic diversity (Brown et al, 1989).

Over the years, the convectional methods of detecting and analysing genetic diversity has been expanded from analyses of discrete morphological variants to statistical analyses of quantitative variants, biochemical assays and finally to molecular assays (Schachtman and Barker, 1999). In detecting discrete morphological variants, plant accessions are characterized by use of a list of descriptors against a check. This is done for those traits that are highly heritable and can easily be seen by eye and are equally expressed in all environments.

Molecular markers although new are being used extensively to investigate the genetic basis of agronomic traits and to facilitate the transfer and accumulation of desirable traits between breeding lines. A number of techniques have been particularly useful for genetic analysis. For example, collections of RFLP probes have been very versatile and important for the generation of genetic maps, construction of physical maps, the establishment of systemic relationships between

genomes, and marker assisted breeding. Numerous examples of specific genes that have been identified as tightly linked to RFLP markers are available for the improvement of specific agronomic traits in almost all major crops. Specific examples include viral, fungal and bacterial resistance genes in maize, wheat, barley, rice, tomatoes and potatoes. Additional examples include insect resistance genes in maize, wheat and rice as well as drought and salt tolerance in sorghum. These markers often used in conjunction with bulked segregant analysis and detailed genetic maps; provide a very efficient method of characterizing and locating natural and induced mutated alleles at genes controlling interesting agricultural traits. Markers have also been used to identify the genes underlying quantitative variation for height, maturity, disease resistance and yield in virtually all major crops. In particular, the PCR-based techniques have been useful in the assessment of biodiversity, the study of plant and pathogen populations and their interactions; and identification of plant varieties and cultivars. Amplified DNA techniques have produced sequence-tagged sites that serve as landmarks for genetic and physical mapping.

The convectional procedures however, are time consuming and expensive. Other techniques, such as Near Infra Red Spectroscopy (NIRS), although faster, require expensive standards for calibration. In addition, traits lacking morphological indicators such as micronutrients cannot be determined by morphological descriptors. Consequently, such procedures are not suited to screen/characterize a large number of germplasm samples (Akundabweni, 2004 Personal communication)

Furthermore, many of African leafy vegetables, cereals and fruits so far known are so large that extensive characterization could be difficult as the numbers of samples that can be effectively evaluated for intrinsic character such as micronutrient density are limited. Sensitive rapid analytical techniques are therefore essential when preliminary assessment of quality might be important at germplasm level.

Energy Dispersive X-ray, Fluorescent Analysis (EDXRF), is appropriate for elemental determination of samples (International Atomic Energy Agency, 1997). Furthermore, EDXRF has been applied to many aspects of soil science and compares favourably with other methods of analyses (Ashcroft, 1970).
The ease of sample preparation and the fact that the same sample can be used to determine many elements often simplifies the analysis of 'difficult' elements or samples (Hemingway, 1986). EDXRF is therefore a useful tool for multi-element survey across major and minor elements.

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2.2   Effect of soil factors on uptake and accumulation of macro and micronutrients

Hydrogen ion concentration (pH) values from 5.5 to 6.5.pH determine the availability of soil nutrients. Nutrients may be present but may first require conversion to an "available" form that the plant is capable of taking up and utilizing. Acidity promotes the weathering of rocks that releases K^+, Mg^{2+}, Ca^{2+}, and Mn^{2+} and increases the solubility of carbonates, sulfates, or phosphates. The amount of rainfall and decomposition of organic matter in soils are major factors in lowering the soil pH and facilitating nutrient uptake via the soil solution. This is only possible when the soil has enough moisture to solubilize the nutrients and the nutrients were originally available in the parent material. Increasing solubility facilitates absorption by the root. Carbon dioxide is produced as a result of the decomposition of organic material and equilibrates with soil water in the reaction

$$CO_2 + H_2O \leftrightarrow H^+ + HCO_3$$

This reaction releases hydrogen ions, lowering the pH of the soil. Microbial decomposition of organic material also produces ammonia and hydrogen sulfide that can be oxidized in the soil to form the strong acids nitric (HNO_3) and sulfuric ($H2SO_4$), respectively. Hydrogen ions also displace K^+, Mg^{2+}, Ca^{2+}, and Mn^{2+} from the cat ion exchange complex in a soil. Leaching then may remove these ions from the upper soil layers, leaving a more acid soil. By contrast, the weathering of rock in arid regions releases K^+, Mg^{2+}, Ca^{2+}, and Mn^{2+} to the soil, but because of the low rainfall, these ions do not leach from the upper soil layers, and the soil remains alkaline.

Soil aeration and soil temperature are among other factors that influence plant nutrient uptake. Warmer root temperatures increase the rate of growth (Cooper, 1973) and the absorption and utilization of nutrients (Joiner, 1983). Temperature also influences the growth and development of roots affecting the amount of root surface available for nutrient and water uptake (Jones, 1983)

Oxygen is needed in the soil to help roots with uptake processes. Where there is no oxygen, such as in flooded sites, sugar cannot be utilized by the plants to produce energy for nutrient uptake. Nutrients are generally absorbed against concentration gradient consequently respiratory energy is required for nutrient uptake (Jones, 1983). In order for respiration to continue in the roots, oxygen must be available in the root zone. Roots, which become totally submerged or waterlogged for long period, will suffer from a lack of oxygen. This leads to slow growth, senescence and abscission of leaves and adventitious rooting of stems (Jackson, 1980)

2.3   Effect of plant factors on uptake and accumulation of macro and micronutrients

The tissue elemental concentration variation in plants is based on genetic differences among species and the species extent of uptake. Due to their genetic differences and species extent of uptake, tissue concentration varies (Shacklette, 1980).

The most striking example of species difference occurs with selenium. Certain species of *Astragalus* growing on seleniferous soils contain 3,000-5,000 ppm selenium (Underwood, 1981). While other species may contain only 10-20 ppm selenium when grown on the same soil.

Differences between grains grown on the same soil are less dramatic, but just as significant. For example, wheat and oats will often contain 35-40 ppm manganese, while barley will only have 14-16 ppm and corn 5-8 ppm manganese when grown in the same environment. In these cases, changing energy source in the diet can have a dramatic effect on the amount of supplemental manganese required (Spears, 1994).

In general, depending on age, legumes are higher in calcium, potassium, magnesium, copper, zinc, iron, and cobalt than grasses. In contrast, grasses tend to be higher in manganese and molybdenum than legumes when grown on the same soil. Forage trace mineral concentrations are more affected by maturity than that of grains. Generally, there is a rapid uptake of mineral during early growth and a gradual dilution as the plant matures. Copper, zinc, iron, cobalt and molybdenum are the most common elements affected by plant maturity (Underwood 1981). For example, copper levels in Timothy hay decreased from 11 to 5 ppm as maturity increased from the early vegetative to the full bloom stage.

Species differences greatly affects rooting depth and rooting density, which in turn will affect accumulation of micronutrients and macro elements in the plants. Hydrogen ion concentration (pH) is an important property of soils that affects the growth of plant roots and soil microorganisms. Root growth is generally favoured in slightly acidic soils, which also determine the availability of soil nutrients. Plants with high rooting density will be able to accumulate higher concentrat ions since a higher surface area is available for absorption. Where as those with deep roots will be able to mine minerals from lower horizons and make them available for their use.

It is also known that the extraradical mycelium of arbuscular mycorrhizae fungi can increase the volume explored by plant roots for uptake of mineral nutrients (Bolan 1991). When nutrients of low mobility such as Zn, Cu and Fe are in short supply, uptake of these nutrients by plant roots can often be increased by formation of a mycorrhizal association (Faber et. al. 1990) Mycorrhizal plants generally took up more zinc.

Plant condition and competition are other factors that will affect nutrient uptake by plants. Plants under stress will be less able to take up nutrients, generally due to a reduced or damaged root system and if the roots of many plants occupy an area, a reduced amount of nutrients will be available for each hence low concentration in plants.

2.4   Role of macro and microelements in human health

There is a growing awareness of the need for knowing the trace elements content in soils and plants. Although only required in small amounts by plants and humans, their deficiencies can have just as much effect as of macronutrient elements.

Major emphases have been put on macronutrient elements as yield-increasing fertilizers for which research have emphasized information on nitrogen, phosphorous and potassium (Constant and Seldrick 1991, Evans, 1999). Where deficient, the growing plants are mostly supplemented by applying fertilizers enriched with these nutrients (Simon et al, 1998).

Determination of micronutrient-trace elements on the other hand, forms the basis for nutritional evaluation in food crops; this is through the realization that 'hidden hunger' due to deficiency is a widespread problem. Infact, several metabolic and pathophysiological disorders are a potential consequence of their deficiency in most third world countries (House, 1998). The following are some of the micronutrients trace elements that are considered beneficial or essential for proper growth and development especially for the vulnerable groups (women and children) in Africa (CGIAR, 1996)

2.4.1   Iron

Iron a metallic chemical element; is the fourth most abundant element in the earth's crust, of which it constitutes about 5% by weight and is believed to be the major component of the earth's core. Iron is found distributed in the soil and is found dissolved in ground waters and the ocean to

a limited extent. It is rarely found uncombined in nature, but iron ores and minerals are abundant and widely distributed. Iron is biologically significant. Because iron is a component of hemoglobin, a red oxygen-carrying pigment of the red blood cells of vertebrates, iron compounds are important in nutrition; one cause of anemia is iron deficiency. It is estimated that more than 2 billion people globally are iron deficient and the problem is severe enough to cause anaemia in 60 % of the people. Roughly, 40% of non-pregnant women and 30% of pregnant women have anaemia worldwide (Fairbanks, 1994).

Iron deficiencies during childhood and adolescence impair physical growth and mental development; hence low learning capacity. In adults, iron deficiency reduces the capacity for physical labour (WHO, 1992).

Iron occurs widely in foods of animal and plant origin. Meat, fish and other animal products, which are best sources of iron, are often too expensive for most people in the developing countries; therefore, they are not available to the poor. Green leaves incidentally happen to be the most important source of micronutrients for the less privileged (Imungi and Porter, 1984).

The green leafy vegetables native to many tropical countries have iron levels that are superior to exotic vegetables are considered good sources by European standards (Latham, 1966, Ifon and Bassir, 1979). Gomez (1982) compared cabbage with indigenous Kenyan leafy vegetables as sources of several nutrients and showed that Kenyan green vegetables were superior to cabbage. The values of iron for the Kenyan vegetables varied between 2.3-11.8mg/g. Cabbage had negligible iron content. Values of iron determined by Sankara Rao and Deosthale (1980), in indigenous cereals ranged from 4.2-8.0mg/100g. According to them, finger millet had the highest value of 8.0mg/100g. Maundu et al (1999), from various literature sources reported a range of 1.9-7.4mg/g of iron in various indigenous fruit trees.

2.4.2 Zinc

Zinc compounds are numerous and are widely used. Zinc is essential to the growth of many kinds of organisms, both plant and animal. It is a constituent of insulin, which is used in the treatment of diabetes. Chief sources of zinc are the sulfide ore; Zinc ores are widely and abundantly distributed throughout the world.

Research findings released at the First Regional Conference on Trace Elements Research in Africa organized by Trace Element Satellite Centre of Unesco (TESCU), held in Nairobi in 2002, showed that as early as 1989 micronutrient zinc was documented as possessing antiviral, anti

bacterial and anti cancer properties and that zinc deficiency symptoms were similar to those of HIV/Aids patients. Mbakaya et. al, 2002 conducted a study to evaluate the role of zinc in transmission and progression of HIV/AIDS. A group of forty-four people at various stages of disease progression were recruited from the Association of people living with Aids (Tapwak). The group consented to use nutritional supplement that contained zinc and selected vitamins and proteins in the management of their health. After 24 months period, their serum zinc levels as well as their virology/immunology profiles were determined as having increased. Their acquired immunity as measured by optical density (OD) of HIV antibodies had also increased substantially after the supplementation. The research warns that the body zinc deficiency should not be tolerated as it could enhance susceptibility to the killer disease and especially so in nutritionally vulnerable populations (TESCU, 2000).

In general, meat products and shellfish are the best sources of zinc. Fruits and vegetables are categorized as poor sources since they contain less than 2mg/g of fresh product (Imungi and Potter 1985). Murage (1990) found between 63-74 mg/g in *Solanum nigrum* on a Nitisol soil at Kabete Kenya. Ifon and Bassir, (1979), determined the mineral content of vegetables commonly consumed in Nigeria. The values ranged from 0.6-13.5mg/g of dry matter. Sankara Rao and Deosthale (1980), found values of zinc in indigenous cereals to range from 2.3-3.1 mg/100g.

2.4.3 Potassium

Potassium does not occur uncombined in nature but is found widely distributed in sylvite (KCl), carnallite ($MgCl_2 \cdot KCl$), feldspar, mica, and other minerals. It is the seventh most abundant element in the earth's crust and the sixth most abundant of the elements in solution in the oceans. It is found in mineral waters, brines, and salt deposits.

Potassium is an essential nutrient for plants and animals. , Found in all living tissues Potassium is the major intracellular cation in the human body. Characterized by its multifunctionality, it affects functions of the cardiovascular, digestive, endocrine, respiratory and neurological systems. Its deficiency induces growth retardation and inhibition of protein synthesis.
Sehmi (1993) determined the mineral content of foods commonly consumed in Kenya. Potassium levels of indigenous green vegetables ranged from 81.25-175 mg/100g while that of indigenous cereals ranged from 60-862mg/100g. Maundu et al, (1999) quotes values as high as 240.9 mg/g of potassium in some indigenous fruit trees.

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2.4.4 Calcium

Although calcium is the fifth most abundant element in the earth's crust, of which it constitutes about 3.6%, it is not found uncombined. It is found widely distributed in its compounds, e.g., Iceland spar, marble, limestone, feldspar, apatite, calcite, dolomite, fluorite, garnet, and labradorite. It is a constituent of most plant and animal matter.

Calcium is essential to the formation and maintenance of strong bones and teeth. In the human adult the bone calcium is chiefly in the form of the phosphate and carbonate salts. A sufficient store of vitamin D in the body is necessary for the proper utilization of calcium. Calcium also functions in the regulation of the heartbeat and in the conversion of prothrombin to thrombin, a necessary step in the clotting of blood (COMA, 1991).

The richest sources of calcium are animal products and seafood; unfortunately, this is not available to all. Green leaves, therefore, become the calcium resource, which is commonly available for the poor. Leung (1968), Oomen and Grubben (1977) Ifon and Bassir (1979) have made reports on the calcium content of vegetables consumed in the tropics.

Gomez (1982) determined the calcium content of some Kenyan leafy vegetables. Calcium values ranged from 55-618mg/g. Sankara Rao and Deosthale (1980) determined calcium content of some indigenous cereals: sorghum, pearl and finger millet. Calcium values ranged from 15-398mg/100g. Maundu et al, (1999) acknowledges that data on nutrient levels in indigenous fruit trees is rare but he gives a range of 47-895mg/100g of potassium for various fruit trees.

2.4.5 Copper

Copper a metallic chemical element; is present in minute amounts in the animal body and is essential to normal metabolism. The principal ore of copper is chalcopyrite, a sulfide of copper and iron, also called copper pyrite.

Copper is essential in enzymes required for heart function, bone formation, energy metabolism, elastin synthesis, normal hair growth and red blood cell formation. Since copper deficiency is not widely recognized, many patients have been misdiagnosed as having iron deficiency, scurvy, rickets and even cancer (Encyclopaedia of Food Science and Food Tech., 1993).

2.4.6 Manganese

Manganese is a pinkish-gray metallic chemical element; symbol Mn, It is the first element in-group VII of the periodic table. Manganese is found in abundance in nature. Pyrolusite (MnO_2) is the major ore. Compounds of manganese are widely used in industry. Manganese is needed as a nutrient in small amounts by many plants and animals and by humans.

Manganese deficiency includes impaired growth, skeletal abnormalities, impaired reproductive performance and defects in lipid and carbohydrate metabolism. Manganese functions as a constituent of mettallo-enzyme and as an enzyme activator. Little information is available on manganese and copper content of indigenous food crops. Sankara Rao and Deosthale (1980), working on sorghum and millet found the values of manganese and copper to range from 1.15-5.59mg/100g for manganese and 0.47-1.06mg/g for copper respectively.

2.4.7 Iodine

Iodine, a nonmetallic chemical element, symbol I, is a dark-gray to purple-black, lustrous, solid element with a rhombic crystalline structure. It is the least active of the halogens. When heated it passes directly from the solid to the vapor state.

The element is obtained from salt deposits and from salt brines. Iodine is important in medical treatment and in small amounts is essential to human nutrition. In the thyroid gland it becomes a part of the iodine-containing hormones. Goiter, a swelling of the thyroid, is often a symptom of inadequate iodine in the diet.

Iodine deficiency is the greatest single cause of brain damage and mental retardation in the world. The principal role of this hormone is to regulate cellular metabolism. In infants, adequate supplies of thyroid hormone are necessary for the development of central nervous system (Welch et al, 1991, Hetzel, 1986, Hetzel and Marberly, 1986).

2.4.8 Selenium

Selenium is a nonmetallic chemical element; symbol Se; directly below sulfur in the periodic table. Selenium sometimes occurs in conjunction with sulfur deposits and often occurs as the selenide (especially of copper, lead, silver, and iron) in sulfide ores. Nonetheless, selenium is one of the elements needed in trace amounts in the animal and human diet. Lack of selenium leads to cretinism, cardiovascular complications and certain cancers in areas of extreme soil deficiency.

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Fish, meat, poultry, whole grains, and dairy products are good sources of this mineral nutrient in the human diet.

Although in some areas selenium is absorbed from the soil by vegetation in quantities sufficient to poison livestock, selenium is an important micronutrient in the body. The deiodinase regulatory enzyme for the thyroid hormone is selenium dependant.
Maximum safe intake of selenium is $400\mu g/g$.

Deficiency in other less studied micronutrients may be similarly widespread with equally serious consequences on health as shown on the table below.

Table 1: Diet -related problems in the developing world

Problem	Links to diet	People affected	Impacts
Insufficient food	Calories, protein and all other minerals	At least 840 million	Lost work productivity, impaired physical and cognitive development; excess mortality; social unrest
Low birth weight (2kg)	Insufficient bioavailable Zn, Fe	35% of children 0-5 yrs	Impaired physical development; excess morbidity and mortality
Vitamin A Deficiency	Insufficient pro-vitamin rich foods	250 million (14m with xerophthalmia)	Impaired Cognitive development; excess morbidity and mortality
Anaemia	Insufficient bioavailable Fe	2.1million (including 42% of all women)	Lost work productivity, impaired physical and cognitive development; excess morbidity
Goitre	Insufficient I and or Se	200 million cases (1.6 billion at risk)	Lost work productivity, excess still births, abortions and infant deaths
Cretinism	Insufficient I and or Se	6 million births per yr.	Severe neurological impairment
Cardiomyopathy	Insufficient Se	400 million at risk	Lost work productivity, excess morbidity and mortality

*Other deficiencies, notably those of energy, protein, calcium and at least some vitamins (e.g. Vitamins A and C), also contribute to many of these and other less widespread problems of malnutrition.
(Source: CGIAR Micronutrient project update no. 1 1996).

Some of the sources of such beneficial trace elements include edible wild plants (Grivetti, 2001) especially leafy vegetables (Latham, 1966, Ifon and Bassir, 1979, Imungi and Potter, 1985)

Some trace elements are essential such that recommended dietary allowances (RDA) have been established to meet the nutrient needs of all healthy persons. RDA has been established for Fe, Se, Zn and I. In addition, an estimated safe and adequate daily dietary intake (ESADDI) by humans has been established for Cr, F, Mn and Mo (National Research Council, 1989). The RDA is the level of dietary intake considered adequate to meet the nutrient requirement need of a healthy person. An ESADDI, on the other hand, is a range from a minimum to a maximum intake value that should not be exceeded habitually.

Table 2 provides a summary of micronutrient-trace elements considered as being essential or beneficial to the nutritional health of people and animals. Table 3 provides a summary of various groups of people and estimates of micronutrient-trace elements allowance required for proper health in the body.

Table 2: Trace elements established to be either essential or beneficial for humans or animals

[a]RDA established for people	[b]ESADDI established for people	Additional*
Iodine	Chromium	Arsenic
Iron	Copper	Boron
Selenium	Fluorine	[c]Cobalt
Zinc	Manganese	Nickel
	Molybdenum	Silicon
		Vanadium

[a] Recommended dietary allowance established (National Research Council, 1989).
[b] Estimated safe and adequate daily dietary intake established (National Research Council 1989).
[c] Required in form of vitamin B12 (cobalamine) (National Research Council, 1989).
* Additional trace elements that are considered essential but RDA or ESADDI has not been established

Table 3: Individual Trace elements recommendation estimate by age and developmental stage (RDA)

Trace mineral	Low birth wt. Preterm-neonates	Normal infants (0.5-1yr)	Children (7-10yrs)	Adolescents (15-18yrs) Males	Females	Adult males (25-50yrs)	Adult females (25-50yrs)
Fe (mg)	-	10	10	12	15	10	15
I (mg)	30-60	50	120	150	150	150	150
Zn (mg)	1000	5	10	15	15	15	12
Cr (μg)	0.1-2.5	20-60	50-200	50-200	50-250	50-200	50-200
Se (μg)	1.3-3.0	15	30	50	70	70	55
Cu (mg)	120-150	0.06-0.07	1-2	1.5-2.5	1.5-2.5	1.5-2.5	1.5-3
Mo (μg)	0.3	20-60	50-150	75-250	75-250	75-250	75-250
Mn (mg)	0.75-7.5	0.6-1.0	2-3	2-5	2-5	2-5	2-2

Adapted from National Research Council, 1989

Many natural fruits and vegetables species have the potential to contribute substantially towards the well-being of the population as a source of food supplement, and nutritionally balanced diets in addition to enhancing both household income and national revenue. Several under-utilized fruits and vegetables species are rich in vitamins and minerals and therefore diversification towards their consumption is essential for nutritional adequacy. Unfortunately, they have yet to have the impact, as they still remain marginal to major crops. First, locals view them as inferior when compared to exotic counter parts given the wider utilization of the latter (Okigbo 1977).

Secondly, most of them tend to be bitter tasting. Thirdly, some are considered to be among the world's worst weeds e.g. *Solanum villosum* (Holm, et. al., 1977).

Opole et. al, (1991) has further noted that popularisation of indigenous plant resources is also limited by other reasons; for instance: (a) government policy appears to emphasize on the production of exotic plants at the expense of indigenous plants as source of revenue (b) people's belief that consumption of exotic foodstuffs enhances one's social status and (c) the change in people's eating habits in favour of introduced cultivars such as potato, rice, and wheat has decreased the production and consumption of indigenous crops such as the millets and sorghums.

As many locals have progressively moved away from indigenous species, diets today are based on fewer plant species compared to earlier days. This has led to lack of access to a variety of indigenous rich foods. Poor dietary practices are now being attributed to lack of proper knowledge on the potential of local foods in reducing severe problems of hidden hunger in developing countries.

2.5   Principles and rationale behind use of XRF in plant and soil characterization

When a primary x-ray excitation source from an x-ray tube or a radioactive source strikes a sample, the x-ray can either be absorbed by the atom or scattered through the material. The process in which an x-ray is absorbed by the atom by transferring all of its energy to an innermost electron is called the "photoelectric effect." During this process, if the primary x-ray had sufficient energy, electrons are ejected from the inner shells, creating vacancies. These vacancies present an unstable condition for the atom. As the atom returns to its stable condition, electrons from the outer shells are transferred to the inner shells and in the process give off a characteristic x-ray whose energy is the difference between the two binding energies of the corresponding shells. Because each element has a unique set of energy levels, each element produces x-rays at a unique set of energies, allowing one to non-destructively measure the elemental composition of a sample. The process of emissions of characteristic x-rays is called "X-ray Fluorescence," or XRF. Analysis using x-ray fluorescence is called "X-ray Fluorescence Spectroscopy." In most cases the innermost K and L shells are involved in XRF detection. A typical x-ray spectrum from an irradiated sample will display multiple peaks of different intensities. (Fig 2)

X-Ray Fluorescence of Lead from ^{109}Cd
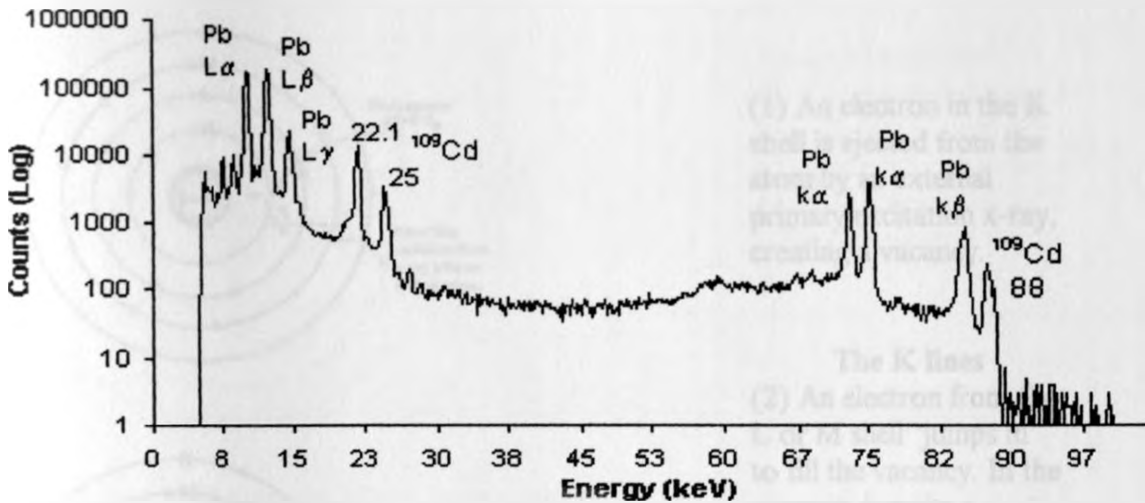
Spectrum taken using Amptek XR-100CR 25mm^{2}X500µm X-Ray Detector (20µs shaping time) and Amptek MCA8000A Multichannel Analyzer.

Fig. 2 X- ray fluorescence of lead using ^{109}Cd

The characteristic x-rays are labeled as K, L, M or N to denote the shells they originated from. Another designation alpha (α), beta (β) or gamma (γ) is made to mark the x-rays that originated from the transitions of electrons from higher shells. Hence, a Ka x-ray is produced from a transition of an electron from the L to the K shell, and a Kb x-ray is produced from a transition of an electron from the M to a K shell, etc. Since within the shells there are multiple orbits of higher and lower binding energy electrons, a further designation is made as α 1, α 2 or β 1, β 2, etc. to denote transitions of electrons from these orbits into the same lower shell.

The XRF method is widely used to measure the elemental composition of materials. Since this method is fast and non-destructive to the sample, it is the method of choice for field applications and industrial production for control of materials. Depending on the application, XRF can be produced by using not only x-rays but also other primary excitation sources like alpha particles, protons or high-energy electron beams.

Sometimes, as the atom returns to its stable condition, instead of emitting a characteristic x-ray it transfers the excitation energy directly to one of the outer electrons, causing it to be ejected from the atom. The ejected electron is called an "Auger" electron. This process is a competing process to XRF. Auger electrons are more probable in the low Z elements than in the high Z elements (Fig 3 (4)).

Fig. 3 X-Ray Fluorescence Process Example: Titanium Atom (Ti=22)
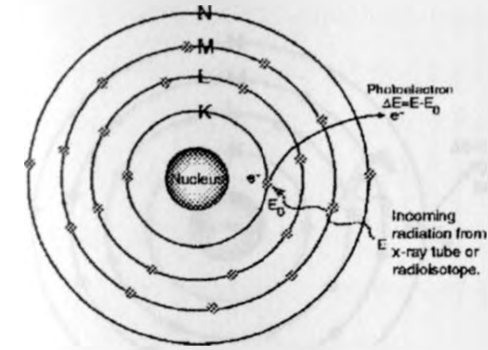
(1) An electron in the K shell is ejected from the atom by an external primary excitation x-ray, creating a vacancy.

The K lines
(2) An electron from the L or M shell 'jumps in' to fill the vacancy. In the process, it emits a characteristic x-ray unique to this element and in turn, produces a vacancy in the L or M shell
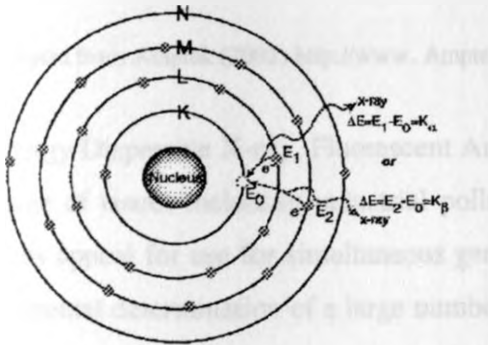
The L lines
(3) When a vacancy is created in the L shell by either the primary excitation x-ray or by the previous event, an electron from the M or N shell "jumps in" to occupy the vacancy. In this process, it emits a characteristic x-ray unique to this element and in turn, produces a vacancy in the M or N shell.
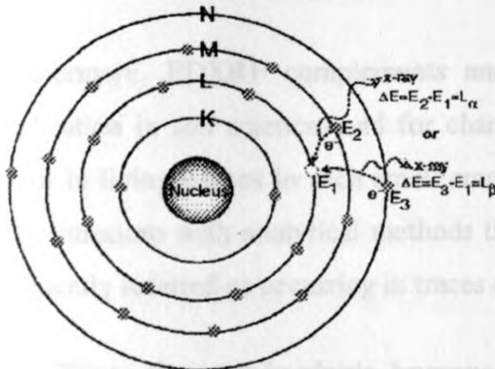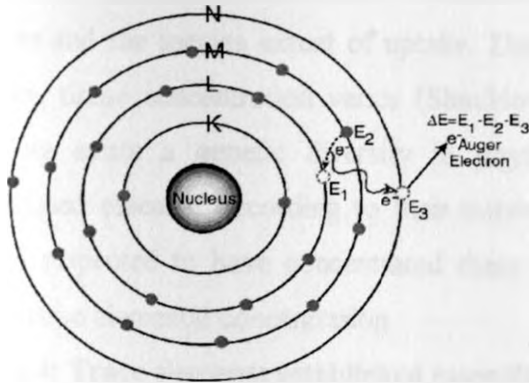
"Auger" Electron
(4) The excitation energy from the inner atom is transferred to one of the outer electrons causing it to be ejected from the atom.

Adapted from Amptek (2002) http://www. Amptek. com/pdf .xrf .pdf

Energy Dispersive X-ray, Fluorescent Analysis (EDXRF) has been employed as a test to a wide range of issues including industrial pollution and heavy metal contamination (IAEA, 1999); it finds appeal for use for simultaneous generation of multi-element data making it appropriate for elemental determination of a large number of mineral elements. The technique therefore becomes a useful tool for multi-element determination for both major and minor elements.

Furthermore, EDXRF complements and compares well with other analytical methods for application in soil sciences and for characterization of plant species. Many of such elements occur in living tissues in such small amounts that early workers were unable to determine their concentrations with analytical methods then available (Underwood, 1999). They were therefore frequently referred as occurring in traces and the term trace elements was used to describe them.

2.6 Trace elements in plants, humans and soils

Using XRF procedure, trace elements can now be estimated in biological as well as geological materials with great accuracy and precision (Adrian and Egan, 1989). At present twenty-six of the naturally occurring elements are known to be essential for animal life. Eleven of them are in fact major elements: carbon, hydrogen, oxygen, nitrogen, sulphur, calcium, phosphorus, potassium sodium, chlorine, and magnesium. Microelements are: iron, zinc, cobalt, molybdenum, selenium, iodine, chromium, fluorine, tin, vanadium, arsenic and boron (see Table 4).

2.6.1 Plants

The tissue elemental concentration variation in plants is based on genetic differences among species and the species extent of uptake. Due to their genetic differences and species extent of uptake, tissue concentration varies (Shacklette, 1980). With respect to these variations, there possibly exists a genetic diversity in phyto-micronutrient density. In this study, elements established essential according to their nutrient value (Table 4) were identified and indigenous plants suspected to have concentrated them in their tissues subjected to analysis to determine their tissue elemental concentration.

Table 4: Trace elements established essential according to their nutrient value

[a]Major/Macro	[b]Trace/Micro	[c]Ultra-trace	[d]Beneficial
Calcium	Zinc	Boron	Barium
Phosphorus	Iron	Molybdenum	Bromine
Magnesium	Silicon	Selenium	Cadmium
Sulphur	Manganese	Nickel	Lead
Potassium	Copper	Vanadium	Lithium
Chloride	Fluoride	Arsenic	Tin
Sodium	Iodine		
	Chromium		

[a] Needed in amounts greater than 100mg per day and represent 1%or less of body weight.
[b] Essential in much smaller amounts, less than 100mg / day and makes up less than 0.01%of body weight.
[c] Required in amounts of less than 50 ng/g in diet of animals.
[d] May contribute to biological processes but essentiality not yet established.
* The underlined elements were of interest to this study.
(Source: Encyclopaedia of Food Science and Technology, Vol. 5 1993).

2.7   African indigenous food plants

2.7.1   The cereal group

a) Finger millet *(Eleusine coracana)* Swahili name 'Wimbi'

This is a grass usually 0.5-1 m high. Its head is dirty green in colour and it splits into 5-7 spikes (fingers) usually 5-10 cm long. The grain is reddish brown to dark brown.

Food uses:

The grain is normally used to make flour used for the preparation of (*uji*) porridge and *ugali* (African bread). It is normally mixed with sorghum and maize in these preparations. Among the Luo; sour milk and melted butter is added to the *ugali* made from finger millet and this is wrapped in banana leaves and eaten by warriors. Fresh flour is put in water for a day or two to

ferment and dried over fire in balls (*mbare*). Flour and grain are also used for local beer brewing, especially among the Luo, Kuria and the Luhya. The ethno botany extends across the western and the central parts of the country.

b) Pearl millet *(Pennisetum glaucum)* Swahili name 'Mawele'

This is a tall grass usually 1.5-2.5 m. The stem is often branched and in many cases several stems arising from the rootstock. Its head is cylindrical and grows up to 20cm long. The grains are 1.5-2.5mm long, greenish grey and oval in shape. It is cultivated at the drier parts of the country around the Lake region and especially the Ukambani areas.

Food uses:

The grain is ground into flour, which is used in the preparation of *uji* or *ugali*.

Among the Kamba, the flour may be mixed with fermented milk and eaten on its own or fermented on a gourd to form porridge.

Medicinal uses:

Grain flour is said to be excellent for diarrhoea remedial.

c) Sorghum*(Sorghum vulgare)* Swahili name 'Mtama'

This is a strong annual perennial grass with stems usually 1-2 m high, often with prop roots at the lowest nodes. The inflorescence is a large terminal branched panicle, which may be compact or loosely held. The seeds are grains of various colours ranging from white to red and dark brown.

Food uses:

The grain is ground into flour and used for making porridge and *ugali*. Commonly used among the Luo, Turkana, Tharaka, Tugen, Marakwet, Luhya, Kikuyu, Kamba, Embu and among the Mijikenda at the coast. The flour may be used to make traditional beer. The stems of some cultivars are sweet and are chewed like sugarcane. This cereal follows maize in its distribution countrywide. It is found distributed fairly around the country especially in the central, eastern, western and the rift valley.

d) Maize/corn *(Zea mays)* Swahili name 'Mahindi'

This is a tall grass with a large stalk measuring up to 2 m long. Leaves are long and arching with evenly ruffled edges. The seeds are grains unusually large for grasses. Corn is one of the most commonly grown foods in the world.

Food uses:

The seed can be eaten raw or cooked before it is fully ripe the mature seed can be dried and used whole or ground into flour. The seed is mixed with other seed legumes to make *githeri* among the Kikuyu, *muthokoi* among the Kamba and *nyoyo* among the Luo. The flour is used to make *uji* or *ugali*. The starch is often extracted from the grain and used in making confectionery and noodles. The dried seed of certain varieties can be heated in an oven when burst to make 'Popcorn'. The seed can also be sprouted and used in making breads and cereals.

Medicinal uses:

The corn silks are cholagogue, demulcent, diuretic, lithontripic, mildly stimulant and vasodilator. They also act to reduce blood sugar levels and so are used in the treatment of diabetes mellitus. A decoction of the leaves and roots is used in the treatment of strangury and dysuria.

Maize has many medical and industrial uses all over the world. Although not an indigenous plant in Kenya, maize has been adopted and has replaced many indigenous plants.

2.7.2 Vegetables

a) Black nightshade*(Solanum nigrum complex)* Swahili name 'Mnavu'

This is an erect herbaceous plant, which grow up to 1m or more. The stems are ridged and soft, occasionally with soft miniature prickles. Its leaves have long petioles; blades up to 15 cm long and are elliptic, entire or undulate in shape. Flowers are small, white and borne on a branched inflorescence. Fruits are green, turning orange, red or yellow at maturity. The seeds are small almost round flattened, pale yellow. The *Solanum* vegetable is composed of various varieties, the most common in East Africa being the *S. macrocarpon, S. scabrum, and S. villosum.*

Food uses:

The leaves of this plant are widely used as a vegetable in Kenya. Normally they are cooked with amaranth (Pokot, Luo) and eaten with *ugali*. Also used as fodder for cattle.

Medicinal uses:

Unripe fruits are applied to aching teeth (Makueni) and squeezed on baby's gums to ease pain during teething (Kajiado, Kitui) Leaves are used for stomachache treatment in Machakos. Its roots boiled in milk and used as tonic in Masailand. Leaves and fruits are pounded and used to extract juice for tonsillitis in Machakos.

b) Jute mallow *(Corchorus olitorius)* Swahili name 'Mlenda'

This is an erect woody herb, usually 0.5-1.2 m tall. Leaves reach upto 15 cm long, stalked, ovate to elliptic, margin serrated. Leaves are usually with basal protrusions. Flowers are yellow and fruit is a short-stalked, cylindrical capsule that splits into 5 parts. Seeds are greyish black and angled. The bush okra belongs to the jute family. It originated from Asia but naturalized in Africa and tropical America. The ethno botany extends across the Kamba, Kisii, Luhya, Turkana, Tugen, and the Giriama.

Food uses

The leaves of this vegetable are widely used as a vegetable in Kenya and the rest of Africa. It is normally cooked with other vegetables e.g. cowpea as it is slippery.

When cooked with cowpeas and milk, it is given to lactating mothers among the Luo people. Leaves are pounded in a mortar and cooked with meat and flavored with lemon among the Mijikenda people of coast province.

Medicinal uses:

Scrapings from the root are put into tooth cavities to ease pain. Being a member of the jute family, the bark of this plant is a source of commercial jute fiber. Where the plant grows it may locally be common but generally rare in most other parts of the country.

c) Spider plant *(Cleome gynandra)* Swahili name 'Mkabili'

This is an erect herb, which grows up to 1.3 m high. Stems are hairy, rather oily. Leaves on long stalks usually divided into 3, 5, or 7 leaflets, to 7 cm long. Its flowers are white or pink and are borne on a long much-branched inflorescence. The fruit of this plant is a long -stalked capsule splitting to release small rough, greyish black seeds. It originated from Africa or tropical Asia. Its leaves contain 5 % protein, 6 % carbohydrate and high in vitamin A and C. Its bitter taste is derived from polyphenolics, which constitute 0.9 % of the edible leaf. It tolerates infertile soils and short-term drought.

Food uses:

Leaves of this plant often with its flowers are widely used as a vegetable in Kenya, especially in the western and the coastal areas. The leaves are bitter and are cooked together with other vegetables. Among the Luos, this is served together with *ugali* made from finger millet flour to important visitors such as the in-laws as a sign of respect. Among the Kisii, it is almost

mandatory for women to eat this before and after childbirth. Circumcised boys consume it also during the period of recuperating.

Medicinal uses:

Root infusion is used for chest pain treatment among the Kamba people. The vegetable is cure for constipation and diarrhea for the Luo people. The leaves are pounded with a little water and the extract drunk as a treatment for *chira* (a condition with AIDS like symptoms but associated with witchcraft), among the Luo people of western Kenya.

d) Cowpea *(Vigna unguiculata)* Swahili name 'Kunde'

This is an erect, trailing, or climbing herb with three leaflets. The leaflets grow up to 10 cm long or more, ovate, rhomboid or lanceolate, entire or lobed at the base. Flowers are of various colours, borne on axillary inflorescence composed of a long stalk usually held vertically and with several flowers towards the end. Fruits are pods to 15cm long, straight, usually hanging. The vegetable is native to Africa. It is drought tolerant.

Food uses:

The leaves and seeds of this plant are used as food for most communities in Kenya. Some communities grow cowpeas mainly for vegetables (Luhya), which may be cooked alone or with other types and eaten with *ugali*. The leaves are cooked with *Corchorus spp*, milk and butter added and fed to breast-feeding mothers. The seeds may be cooked with maize or sorghum to make *nyoyo* among the Luo. Seeds may be boiled and eaten alone. It is a very variable species normally grown together with other crops

Medicinal uses:

Raw leaves are chewed for relief of heartburn condition among the Masai.

2.7.3   Fruits

a) Kwazulu Natal rhus *(Rhus natalensis)* Swahili name 'Mtishangwe'
This is a spreading shrub and grows up to 5 m high. Leaves form 3 leaflets and its flowers are greenish yellow. Fruits are small, 1.5-2.5 mm in size, green, turning reddish brown on ripening, shiny and numerous. It is widely distributed along the coast, central, rift valley, and the western part of the country.

Food uses:

The fruits from this tree have a sweet – sour taste and mainly consumed by children among the Luhya people. Roots are used to make herbal soup among the Kikuyu. Tender shoots and young leaves are chewed, among the Masai people; the bark of this tree is used to make herbal tea.

Medicinal uses:

The leaves are used for heartburn, roots for influenza, and abdominal pains, cough and stomachache among the Kamba people. Juice extract from the roots is taken as a remedy for diarrhea among the Digo. The wood from this tree is also used for firewood, charcoal, and toothbrushes. Roots are a source of dye.

b) Jackfruit *(Artocarpus heterophylus)* Swahili name 'Mfenesi'

This is a tall tree growing up to 20 m. Its fruits are large pods with the shape of an enormously overgrown pear, measuring as much as 90 cm long and weighing up to 40 kg. It has a thick rind that is pale green, dotted with sharp hexagonal spines. Large brown seeds each surrounded by a layer of yellow pulp about half a centimetre thick occupy the centre of the fruit. Each huge fruit hangs by a stout stalk from a strong branch or the trunk itself. This tree is native to Asia but has been naturalized in some parts of Africa. It is widely spread in the coastal and the western part of the country.

Food uses:

The yellow pulp of the fruit is eaten when ripe. The seeds are roasted and eared like groundnuts. Common in the western region of Kenya

c) Sycamore fig *(Ficus sycomorus)* Swahili name 'Mkuyu'

This is a large tree to 20 m with an upright branching habit and a dense or open rounded or occasionally spreading crown; the leaves are rough. Its fruits are figs 2 cm across, slightly hairy, borne on small leafless branches.

Food uses:

The figs from this tree are fleshy sweet and are eaten raw. Figs are split open stored usually in honey (Pokot). Dry figs may be ground into flour, which may be stored or mixed with grain flour and used to prepare *atap*, a type of thick porridge (Turkana). Figs are cooked and eaten (Tugen)

Medicinal uses:

Medicinal sap used for toothache (Kikuyu) and powdered bark infusion for dysentery (Kamba)

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The wood from this plant is used for other carpentry work.

d) Baobab *(Adansonia digitata)* Swahili name 'Mbuyu'

This is a huge deciduous tree growing up to 15m, with a disproportionately large trunk and a twisted branching habit and its leaves are digitate. The leaflets are up to 13cm long. Its fruit is to 25cm long, with shiny yellowish green or rusty soft hairs and a hard oval or round shell, often grooved longitudinally. The seeds are hard, embedded in a cream or white pulp. The tree is found growing in the drier parts of the country mainly towards the coast and the Ukambani areas.

Food uses:

The dry cream-colored pulp in the pod is eaten raw or is dissolved in water, stirred to a milky state, seeds sieved off and the juice used as sauce or added to porridge. Seeds are roasted like groundnuts (Kitui). Soft tuber tops are cooked and eaten in times of famine. Germinating seeds are also eaten. Young leaves are used as vegetable among the Giriamas. The pulp-coated seeds are colored and sold as sweets in coastal towns (Swahili).

Medicinal uses:
Bark concoction used for steam bathing of infants with high fever. Juice made from pulp is drunk to treat fever (Giriama). Fiber from trunk is used as string and for weaving baskets and ropes.

e) Grewia *(Grewia bicolor)* Swahili name 'Mkone'

This is a spreading shrub tree with a light crown and grows up to 7m high with branches hanging. The bark is smooth or fissured and dark gray in color. The leaves are usually toothed and asymmetrical at the base. The flowers are yellow, and are borne on short stalks. The fruits are orange when ripe and rather hairy. Also found growing in drier parts of the country among the Kambas, Luos and the Masai.
Food uses:

Fruits are eaten raw; the pulp, which is sweet, is sucked off the seeds and then the seeds are discarded. Occasionally the whole fruit may be crushed and eaten. Seeds are hard however.

Medicinal uses:
The bark chewed is and other times placed in cuts as a bandage among the Kambas in Kitui. A cold infusion of the root is drunk for chest treatments among the Masai. Root decoction is used for diarrhea treatment for humans and when mixed with other species for extraction of afterbirth in cattle. The slimy pounded bark is applied locally ti relieve body itches among the Pokot

people. The wood is extract is tough and is used to make knives, spears, clubs, bows and arrows by the Luo people and for carving among the Kamba. The bark is used for string and rope making as well.

2.7.4 Soils

One major objective of chemical inventory of the soils on which food crops are grown is to determine its ability to supply essential elements in the right proportions and in adequate amounts throughout the growing season (The Fertilizer Institute, 1979).

Until the advent of sostiphicated analytical techniques, most plant diagnoses relied upon visual deficiency symptoms, crop history, soil series, soil pH and other variables as guides in identifying micronutrient disorders (Donahue et al, 1983).

The appropriate content of minerals in plants is essential both for health of the plant and the nutrient supply to man and animals that feed on them. Soils supply plants with organic mineral nutrients in the form of dissolved ions. These mineral nutrients include metallic elements such as potassium, calcium, iron copper, and cobalt as well as other non-metallic elements. The plant takes these elements out of the soil solution and incorporates them into the thousands of different organic compounds that constitute plant tissue. A fundamental role of soil in supporting plant growth is to provide a continued supply of these minerals in amounts and proportions appropriate for plant growth (Underwood, 1999).

The concentration of nutrients in plant tissues seems to be a function of its level in the nutrient solution or in soils. The pattern of this however differs among the plant species and plant parts (Kabata and Pendias, 1984).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

Three transectoral regions (Mt. Elgon region, Lake-basin region and eastern region were sampled. Populations were variously obtained directly from the farmers' fields in their wild or semi-cultivated state. A farmer's list was obtained from the district agricultural offices of the various regions and randomised for sampling.

The experiment was carried out from September 2002 to September 2003. The general description of the areas sampled and accompanying details are as described.

3.1.1 Mt. Elgon region

Bungoma district is mainly situated on the slopes and foothills of Mt. Elgon at latitude 0° 32′ north and longitude 34° 33′ east and at an altitude of 1370m in west Kenya. The area features well distributed annual average rainfall of 1200-1800m (Appendix 1). The seasonal rain distribution is 500-100mm during the long rains and 430-800mm during the second rains. Valleys and higher areas characterize the landscape. The soils in this area are deep, moderate to deep red - reddish brown ferralsols (Jaetzoldt and Schmidt, 1982 IIa).

Three sites were selected for sampling in Mt. Elgon region: - Chwele, Kanduyi and Nalondo. Every accession obtained was assigned a code number (MR) according to the number of germplasm accession of the plant material. The same codes were used for soil material but the word soil added to differentiate them. Of the total 76 accessions obtained in the three regions, 33 came from Bungoma.

3.1.2 Lake Region

The lake region is situated around the shores of Lake Victoria at a latitude 0° 38′ south and longitude of 34° 35′ east and an altitude of 1463 m. The area experiences a bimodal rainfall pattern with an annual average rainfall of 1100-1500 mm (Appendix 2).

The physiography of the area is varied ranging from pronounced scarps down to the Kano plains. The soils in the region are well-drained, deep-to-deep dark reddish brown, friable clay dystric Nitisols (Jaetzoldt and Schimidt, 1982 IIa)

Three sites were selected for sampling in the Lake region: - Maseno, Neewa and Esivalu. The next batch of 29 accessions came from Maseno as shown below:

3.1.3 Kibwezi (eastern region)

Kibwezi area is located in Machakos district in the eastern part of Kenya at a longitude 2° 35′ south and a latitude of 32° 28′ east, and at an altitude of 914 m. The rainfall pattern in this area is bimodal totalling to a range of 500-1300 mm annually on average (Appendix 3). The topography is varied consisting mainly of hills and plateaus. The area is dominated by well-drained, moderately deep-to-deep red, reddish brown friable firm sandy clay-to-clay chromic luvisols (Jaetzoldt and Schimidt, 1982 II c).

Three sites were selected for sampling in eastern region: - Masongaleni, Kasemeini and Lukenya. The remaining four accessions were obtained from Kibwezi area.

3.2 Plant material

Thirteen indigenous plant species from the three regions were sampled under three categories as shown in the table below.

Table: 5   Plant materials collected for XRF analysis

Cereal group		
Common name	Botanical name	Swahili name
Finger millet	*Eleusine coracana*	'Wimbi'
Pearl millet	*Pennisetum glaucum*	'Mawele'
Sorghum	*Sorghum vulgare*	'Mtama'
Maize	*Zea mays*	'Mahindi'
Vegetables		
African nightshades	*Solanum complex*	'Mnavu'
Jute mallow	*Corchorus olitorius*	'Mulenda'
Spider plant	*Cleome gynandra*	'Mkabili'
Vegetable Cowpea	*Vigna unguiculata*	'Kunde'
Fruits		
Kwa Zulu Natal rhus	*Rhus natalensis*	'Mtishangwe'
Jack fruit	*Artocarpus heterophylus*	'Mfenasi'
Baobab	*Adansonia digitata*	'Mbuyu'
Grewia	*Grewia bicolor*	'Mkone'

3.3 Sampling procedure

3.3.1 Vegetable material

Young fully expanded leaves at the growing tips of African nightshades, Jute mallow, Spider plant and Cowpea species of vegetables were randomly sampled from fields in various sites located in Bungoma, Lake Region and Kibwezi. A handful of leaves were collected for analysis

The harvested leaves were cleaned using distilled water to remove any dust or soil particles. Since the material was to be transported all the way from the sites, it was put in a container made of plastic material and cooled to a temperature of $4^{\circ}C$.

3.3.2 Fruit material

Mature fruits ready for harvesting were randomly picked from various selected tree species, cleaned with distilled water. The edible part was separated from the rest of the fruit and this was used for analysis. Similarly, the material was cleaned, put in a container made of plastic material and cooled to a temperature of $4^{\circ}C$ during transportation.

3.3.3 Cereals

Mature cereal grains ready for harvesting of finger millet, pearl millet, sorghum and maize plants directly growing from the fields in the various sites were variously picked, cleaned, and packed ready for transport.

Although not an indigenous crop, maize is an important cereal crop in Kenya. It has replaced many indigenous crop species that were formerly used by many communities in Kenya. Currently, maize is the most widely grown cereal crop in Kenya and indeed all over the world. Due to the importance of maize as a food crop in the Kenyan communities, maize was included in this study as a control. During the study however, it was noted that its elemental concentration was the lowest among the cereals that were selected for the study.

3.3.4 Soil material

While collecting plant material, soil material was collected from various points in the same fields. Three sub samples were collected from various points in the fields using an auger at a depth of 30 cm bulked and then packaged into polyethylene bags. The soils samples were labelled as MRS

with "S" denoting a soil sample. Each region denotes a certain soil type, Bungoma (reddish brown Ferrasols), Lake-region (dystiric Nitisols) and Eastern (Luvisols) whose content must have had an effect on nutrient-density of the plants due to the genotype x environment interaction (soil x plant interaction in this case).

3.5 Sample preparation and analysis

After oven drying for 48 hours, at 95° C, either the dried soil or plant material was ground using a grinder repeatedly until the sample was relatively fine, were passed through sieves of different sizes until particles sizes of less than 50 μm were obtained.

For each sample, fine pellets 2.5cm in diameter weighing between 100-200 mg/cm^2 were prepared for EDXRF analysis. This was done by adding considerable amount of sample in a steel die and applying 10-15 tones of pressure with the pellet-pressing machine. In case the pellet did not bind up, starch or cellulose was added as a binder. The sample and cellulose were homogenized using a pestle and mortar and thereafter pellets made. The weights of the sample pellets were determined from measurements. For each sample, three pellets were prepared for analysis.

Amounts of sample and the binder were weighed so that the binder would not constitute more than 30% of the total weight of the sample. The dilution factor was determined from weights of sample materials and starch, which was used in the correction of elemental concentration.
EDXRF spectrometer used consisted of Cd-109 radioisotope source; Canberra Si (Li) detector, an ORTEC spectroscopy shaping amplifier mode 571, ORTEC high voltage supply bias model 459, ORTEC liquid nitrogen monitor, a Canberra multichannel analyzer (S-100) interfaced with a 486 programmed personal computer.

The programmed personal computer was used for spectral data storage and quantitative analysis using AXIL and QAES software (Van Espen et al 1985). The resolution of the Si (Li) detector used was 195 ev for manganese (Mn) Kα line at 5.9 kev.

For each pellet sample, the intensity measurements were taken on sample alone and sample with multi-element target accordingly for correction of absorption matrix effects, using Emission Transmission Technique (Sparks, 1975, Giauque et al, 1979). The prepared pellet was irradiated with Cd-109 radioisotope source as an excitation source for 2000 seconds and then for another

100 seconds with a molybdenum target for organic matrix absorption correction. Subsequently, elemental concentration values were calculated using the intensity equation developed for intermediate samples based on fundamental parameters (FPM) (Mangala 1999; 1987).

3.6 Data analysis

Analysis of Variance (ANOVA) was done to determine significant effects of treatments using Genstat statistical package 6.1edition (Payne, et. al, 2002) at P≤0.05. Complete Randomised Design (CRD) was used with two factors: species and site and potassium and calcium as macro elements and iron, zinc, manganese, copper as micronutrients as dependent variables. Each species type was replicated three times from three sites of each sampling area.

By use of bar charts, data obtained from micronutrient element analyses (concentrations in μg/g) were plotted against species from different regions/sites in order to obtain the temporal pattern on different nutrient elements that were analysed during the study.

A plant –Soil correlation was done to determine the plant macro and micronutrient element relationship. Pearson's' correlation was used for this purpose (SPSS version 10). The correlation depicted by letter 'r'. was computed using the formula

$$\text{Pearson's correlation} = \quad r = \dfrac{\Sigma XY - \dfrac{\Sigma X \Sigma Y}{N}}{\sqrt{\left[\Sigma X^2 - \dfrac{(\Sigma X)^2}{N}\right] \cdot \left[\Sigma Y^2 - \dfrac{(\Sigma Y^2)}{N}\right]}}$$

Pearson's correlation denoted as 'r' was used to determine any significant linear relationships between plant and soil macro and micronutrient elements and generate plant soil correlation data as shown in the results section.

3.6.1 Mineral Nutrient Density for crop germplasm (μg/g) as determined by X-ray Dispersive Fluorescence (XRF)

As a first step, generated XRF raw data needed to be empirically converted to characterization data; such that HIMA/HIMI represented the highest range and TOLOMA/TOLOMI the lowest range for macro and micronutrients respectively and appropriately ranked as shown in Table 6.

Table 6: The empirical conversion process of raw XRF data to XRF characterization data

Macronutrients				Micronutrients			
Nutrient density range definition	Nutrient range in μg/g	Genodensotype	Rank	Nutrient Density Range Definition	Nutrient range in μg/g	Genodensotype	Rank
High Macronutrient Density (HIMA)	90,000-70,000	HIMA	1	High Micro Nutrient Density (HIMI)	2,000-1,500	HIMI	1
	69,999-50,000	HIMA II	2		1,499-1,000	HIMII	2
	49,999-30,000	HIMAIII	3		999-500	HIMIII	3
Low Macro Nutrient Density	29,999-10,000	LOMA	4	Low Micronutrient Density	499-200	LOMI	4
Very Low Macronutrient Density	9,999-500	VELOMA	5	Very Low Micronutrient Density	199-50	VELOMI	5
Too Low Macronutrient Density	below 200	TOLOMA	6	Too Low Micronutrient Density	below 50	TOLOMI	6

The data arrangement as shown in the Table 7 enabled for to a genotypic characterization by two-way contingency table into a macro /macronutrient element XRF genotyping.

Table 7:   A two-way contingency table of (MAE x MIE) XRF germplasm genotyping according to seed range indicators as developed by Akundabweni (personal communication)

Nutrient range definition	High Micro nutrient (HIMI)	Low Micronutrient (LOMI)	Very Low Micronutrient (VELOMI)	Too Low Micronutrient (TOLOMI)
High Macronutrients (HIMA) HIMAI HIMA II HIMAIII	HIMI- HIMAI HIMI-HIMA II HIMI-HIMAIII	HIMAI- LOMI HIMA II- LOMI HIMAIII-LOMI	HIMAI- VELOMI HIMA II- VELOMI HIMAIII- VELOMI	HIMAI- TOLOMI HIMA II- TOLOMI HIMAIII-TOLOMI
Low Macro nutrient (LOMA)	HIMI-LOMA	LOMA-LOMI	VELOMI-LOMA	TOLOMI-LOMA
Very Low Macronutrient (VELOMA)	HIMI-VELOMA	LOMI-VELOMA	VELOMI-VELOMA	TOLOMI-VELOMA
Too Low Macronutrient (TOLOMA)	HIMI-TOLOMA	LOMI-TOLOMA	VELOMI -TOLOMA	TOLOMI-TOLOMA

Prefix HI=High LO =Low, VELO=Very low, LO=Low, TOLO=Too Low, while suffix MA=Macronutrient element and MI-Microelement.

CHAPTER FOUR

4.0 RESULTS

4.1 Accessioning of materials collected

Various plant materials collected from the three regions were assigned codes and accession numbers. The following tables indicate the materials collected from each region and the assigned codes.

Table 8:   Mt. Elgon region germplasm accession

Region	Mt. Elgon region germplasm accession numbers		
Species	Sites		
	Chwele	Nalondo	Kanduyi
African nightshades	MR7	MR 18	MR 29
Spider plant	MR 6	MR 17	MR 28
Jute mallow	MR 5	MR 16	MR 27
Vegetable cowpea	MR 4	MR 15	MR 26
Maize	MR 1	MR 12	MR 23
Finger millet	MR 2	MR 13	MR 24
Sorghum	MR 3	MR 14	MR 25
Pearl millet	***	***	***
Jack fruit	MR 10	MR 21	MR 32
Kwa Zulu Natal rhus	MR 9	MR 20	MR 31
Grewia	MR8	MR19	MR30
Sycamore fig	MR 11	MR 22	MR 33
Baobab	***	***	***

*** Species not encountered during sampling

Table 9:   Lake basin region germplasm accession

Region	Lake basin region germplasm accession numbers		
Species	Sites		
	Esivalu	Neewa	Maseno
African nightshades	MR 40	MR 51	MR 58
Spider plant	MR 39	MR 50	MR 57
Jute mallow	MR 38	MR 49	MR 56
Vegetable cowpea	MR 37	MR 48	MR 55
Maize	MR 34	MR 45	MR 52
Finger millet	MR 35	MR 46	MR 53
Sorghum	MR 36	MR 47	MR 54
Pearl millet	***	***	***
Jack fruit	MR 43	***	MR 61
Kwa Zulu Natal rhus	MR 42	***	MR 60
Grewia	MR 41	***	MR 59
Sycamore fig	MR 44	***	MR 62
Baobab	***	***	***

*** Species not encountered during sampling

Table 10:   Eastern region germplasm accession

Region	Eastern region germplasm accession numbers		
Species	Sites		
	Kasemeini	Masongaleni	Lukenya
African nightshades	***	***	***
Spider plant	***	***	***
Jute mallow	***	***	***
Vegetable cowpea	MR 66	***	MR 75
Maize	MR 63	MR 68	MR 72
Finger millet	***	***	***
Sorghum	MR 65	MR 70	MR 74
Pearl millet	MR 64	MR 69	MR 73
Jack fruit	***	***	***
Kwa Zulu Natal rhus	***	***	***
Grewia	***	***	***
Sycamore fig	***	***	***
Baobab	MR 67	MR 71	MR 76

*** Species not encountered during sampling

4.2   Mineral nutrient density (μg/g $\pm$ 1 sd) variation on cereal germplasm acquisitioned from farmers' fields

4.2.1   Elemental variation of maize populations on farmer's field

Potassium, and iron differed significantly in maize germplasm accessions from various sites at $p \leq 0.05$. (Table 11)However, copper, calcium selenium and manganese were below detection limits while zinc differences were only slight.

Maize from the eastern region had the highest range of both total health elements and micronutrient element levels with range of 2743 to 4273 μg/g for total health and 144 to 210 μg/g for micronutrient elements, respectively. Sample MR 68 from Masongaleni in particular gave the highest micronutrient elements with an average of 206 $\pm$ 27 μg/g with iron levels average 115 $\pm$ 26 μg/g.

Germplasm accessions from the Lake region had the highest macro element concentration with a range of 2400 to 4198 μg/g. Sample MR 45 from Neewa was particularly rich in macro element concentration average of 4142 $\pm$ 243μg/g. Maize samples concentrated similar amounts of calcium and manganese in all the accessions for the regions sampled while only very low amounts of zinc were noted ranging from 28-38μg/g. The copper levels for all samples analysed were below 10, which implies that the germplasm in this group is under VELOMI-VELOMA classification.

4.2.2 Elemental variation of finger millet populations on farmer's field

Significant differences in mineral density were noted for finger millet populations at $P \leq 0.05$. When compared to maize, finger millet populations had relatively higher concentrations of macro and micronutrient element with Mt. Elgon region registering higher macro elements than the Lake region. In fact, finger millet had the highest mineral concentration among the cereals sampled. Similarly, potassium levels were higher for samples from Mt. Elgon region while slight differences were noted for calcium and zinc. Copper levels were below detection limit.

Sample MR 35 from Esivalu in the Lake region had the highest in manganese levels (226 ± 22 $\mu g/g$) while sample MR 53 (80 ± 16) had the lowest levels. Sample MR 24 from Kanduyi in Mt. Elgon region had the highest levels for iron average of 228 ± 29 $\mu g/g$ resulting in higher micronutrient element levels of 390 ± 24 $\mu g/g$. Slight differences were noted for zinc with a range of 21 to $30 \mu g/g$ for all the samples analysed. Sample MR 53 had the highest potassium levels average 9060 ± 865 and total health elements levels (11157 ± 1110) which resulted in germplasm classification as being LOMI-VELOMA (Table 12).

Table 11: Mineral nutrient density (µg/g ± 1 sd) variation in maize populations on farmer's field (n =3)

| Accession | Region | Site | M.A.E | | | M.I.E | | | | | | Genodensotype |
			K	Ca	Macro T.H.E	Mn	Fe	Cu	Zn	Micro T.H.E	T.H.E	
MR63-M	Eastern	Kaseme	2023 ± 200	<600	2602 ± 240	<60	99± 11	<10	23 ± 3	182 ± 18	2785 ± 247	Velomi- Veloma
MR72-M	Eastern	Lukenya	3487± 337	<600	4066 ± 437	<60	55 ± 5	<10	28 ± 2	146 ± 13	4211 ± 423	Velomi-Veloma
MR68-M	Eastern	Masonga	2597 ± 214	<600	3176 ± 319	<60	115 ± 26	<10	26 ± 3	206 ± 27	3381 ± 177	Lomi-Veloma
	Range		**1971- 3433**	**<600**	**2550 - 4012**	**<60**	**56 - 122**	**<10**	**22 - 28**	**144 -210**	**2743 - 4273**	
MR34-M	L.region	Esivalu	1647 ± 151	<600	2226 ± 251	<60	36 ± 7	<10	32 ± 3	137 ± 12	2363 ± 257	Velomi- Veloma
MR52-M	L.region	Maseno	2950 ± 226	<600	3529 ± 326	<60	46 ± 7	<10	30 ± 3	137 ± 12	3666 ± 329	Velomi- Veloma
MR45-M	L.region	Neewa	3563 ± 243	<600	4142 ± 243	<60	41 ± 6	<10	28 ± 3	135 ± 13	4277 ± 238	Velomi- Veloma
	Range		**1831 - 3609**	**<600**	**2400 - 4198**	**<60**	**35-47**	**<10**	**28 - 33**	**131 - 141**	**1383 - 5487**	
MR1-M	Mt. Elgon	Chwele	2340 ± 216	<600	2919 ± 216	<60	39 ± 4	<10	29 ± 3	129 ± 12	3047 ± 211	Velomi- Veloma
MR23-M	Mt. Elgon	Kanduyi	3293± 315	<600	3796 ± 314	<60	69 ± 8	<10	35 ± 4	169 ± 18	3965 ± 339	Velomi- Veloma
MR12-M	Mt.Elgon	Nalondo	2413± 298	<600	2992 ± 296	<60	45 ± 5	<10	36 ± 3	141 ± 14	3134 ± 307	Velomi- Veloma
	Range		**2062 - 3302**	**<600**	**3033 - 3437**	**<60**	**33 - 69**	**<10**	**28- 38**	**124 - 168**	**2749- 4015**	

Table 12: Mineral nutrient density (µg/g ± 1 sd) variation in finger millet populations on farmer's field (n =3)

| Accession | Region | Site | M.A.E | | | M.I.E | | | | | T.H.E | Genodensotype |
			K	Ca	Macro T.H.E	Mn	Fe	Cu	Zn	Micro T.H.E		
MR35-Fm	L. region	Esivalu	5153 ± 504	2017 ± 201	7170 ± 626	226 ± 22	64 ± 7	<10	24 ± 4	326 ± 27	7496 ± 640	Lomi-Veloma
MR53-Fm	L. region	Maseno	9060 ± 565	1923 ± 162	10983 ± 1019	80 ± 10	57 ± 5	<10	28 ± 3	174 ± 12	11157 ± 1110	Velomi-Veloma
MR46-Fm	L. region	Neewa	8316 ± 566	2013 ±168	10330 ± 733	132 ± 13	58 ± 6	<10	21± 2	228 ± 16	10557 ± 729	Lomi-Veloma
	Range		**5577 - 9443**	**1694 - 2274**	**7493 - 11495**	**82 – 210**	**48 - 71**	**<10**	**21- 28**	**174 - 311**	**7736 - 11738**	
MR2-Fm	Mt. Elgon	Chwele	8743 ± 800	2147± 203	10890 ± 1001	76 ± 14	66 ± 6	<10	22 ± 4	174 ± 17	11063 ± 1141	Velomi-Veloma
MR24-Fm	Mt. Elgon	Kanduyi	8217 ± 799	1887 ± 183	10103 ± 987	125 ± 12	228 ± 22	<10	27 ± 3	390 ± 34	10494 ± 998	Lomi-Veloma
MR13-Fm	Mt. Elgon	Nalondo	7637 ± 710	2203 ± 270	9840 ± 969	129 ± 18	89 ± 9	12 ± 1	28 ± 6	256 ± 27	10096 ± 1050	Lomi-Veloma
	Range		**6553 - 9845**	**1546 - 2610**	**8213- 12341**	**70 ± 150**	**49 – 206**	**<10**	**21 – 30**	**166 - 380**	**8487- 12615**	

Macro T.H.E. = Macronutrient total health elements
Micro T.H.E. = Micronutrient total health elements
T.H.E. = Total health elements
M. A .E. = macronutrient elements
M. I.E. = micronutrient elements

4.2.3 Elemental variation of sorghum populations on farmer's field

Macro and micronutrient density concentrations differed significantly P≤0.05 in sorghum germplasm accessions. Sorghum germplasm from the eastern region had the highest total health element levels for all the samples analysed with macro elements accounting for 97% of the total health elements concentration. Sample MR 70 from Masongaleni in particular had an unusually high level of potassium (26967 ± 2600 $\mu g/g$) when compared to other germplasm accessions from other sites; this resulted in higher levels of total health elements for this accession. There were no significant differences in calcium and magnesium in all sorghum accessions. The levels for calcium were below the detection (<600) and those for manganese below 60 in all the samples analysed for this study.

Sample MR 25 from Mt. Elgon. Kanduyi site was extremely rich in iron content (274-± 26$\mu g/g$) and consequently had higher micronutrient element levels in comparison to the other accessions. Sample MR 74 from Lukenya in eastern region had twice the amount of copper registered for other samples. Only slight differences were noted for zinc, which had an average of 35$\mu g/g$ for most samples analysed. Most germplasm in this group was classified as being LOMI-VELOMA (Table 13).

4.2.4 Elemental variation in pearl millet populations on farmer's field

While no significant differences were noted for all accessions of potassium, calcium, manganese, copper and total health elements P≤0.05, significant differences were noted for micronutrient elements and iron where sample MR 73 from Lukenya in eastern region had the highest micronutrient levels (1035 ± 105 $\mu g/g$) and an average iron concentration of 922 ± 92 $\mu g/g$. This accession was classified as HIMI III-VELOMA. MR 69 from Masongaleni site had the lowest micronutrient element levels (245 ± 43$\mu g/g$). Calcium, manganese, and copper concentrations are similar in values for all the pearl millet germplasm accessions. Sample MR 64 from eastern, Kasemeini in particular had the highest zinc concentration levels of 53 ± 4$\mu g/g$ but zinc concentration was unusually low in sample MR 69 (27 ± 5$\mu g/g$). The pearl millet cereal group was therefore classified as being LOMI-VELOMA (Table 14).

Table 13: Mineral nutrient density (µg/g ± 1 sd) variation in sorghum populations on farmer's field (n =3)

Accession	Region	Site	M.A.E K	Ca	Macro T.H.E.	M.I.E Mn	Fe	Cu	Zn	Micro T.H.E	T.H.E	Genodensotype
MR65-Sor	Eastern	Kasemeini	3113 ± 312	<600	3692 ± 332	<60	213 ± 15	<10	39 ± 3	318 ± 27	4011 ± 316	Lomi-Veloma
MR74-Sor	Eastern	Lukenya	3597 ± 330	<600	4176 ± 410	<60	238 ± 21	<10	30 ± 2	337 ± 33	4513 ± 461	Lomi-Veloma
MR70-Sor	Eastern	Masongaleni	26967 ± 2600	<600	27546 ± 2706	<60	115 ± 10	<10	36 ± 4	195 ± 22	27741 ± 2698	Velomi-Himall
		Range	**3600- 26900**	**<600**	**4200 -27600**	**<60**	**130 - 248**	**<10**	**30 – 40**	**215 ± 353**	**3050 - 27800**	
MR36-Sor	L. region	Esivalu	3273 ± 307	<600	3739 ± 344	<60	78 ± 14	12 ±1	23 ± 2	170 ± 25	3909 ± 340	Velomi-Veloma
MR54-Sor	L. region	Maseno	3277 ± 315	<600	3856± 315	<60	78 ± 16	<10	32 ± 5	170 ± 21	4025 ± 626	Velomi-Veloma
MR47-Sor	L. region	Neewa	3097 ± 274	<600	3676 ± 274	<60	76 ± 15	<10	24 ± 3	164 ± 24	3840 ± 276	Velomi-Veloma
		Range	**2569- 3861**	**<600**	**3130 - 4384**	**<60**	**69 - 86**	**<10**	**21- 31**	**156 – 180**	**3897 - 4053**	
MR3-Sor	Mt. Elgon	Chwele	4103 ± 325	<600	4682 ± 425	<60	101 ± 10	<10	28 ± 4	193 ± 42	4875 ± 959	Velomi-Veloma
MR25-Sor	Mt. Elgon	Kanduyi	3597 ± 254	<600	4314 ± 370	<60	274 ± 26	<10	37 ± 4	374 ± 27	4688 ± 379	Lomi-Veloma
MR14-Sor	Mt. Elgon	Nalondo	4520 ± 450	<600	5099 ± 490	<60	78 ± 13	<10	32 ± 3	176 ± 17	5275 ± 489	Velomi-Veloma
		Range	**3441- 4705**	**<600**	**4089 - 5309**	**<60**	**56 - 280**	**<10**	**28 -38**	**148- 380**	**4381 - 5531**	

Table 14: Mineral nutrient density (µg/g ± 1 sd) variation in pearl millet populations on farmer's field (n =3)

Accession	Region	Site	M.A.E K	Ca	Macro T.H.E.	M.I.E Mn	Fe	Cu	Zn	Micro T.H.E	T.H.E	Genodensotype
MR64-Pm	Eastern	Kaseme	4567 ± 280	<600	5145 ± 280	<60	124 ±1 3	<10	53 ± 5	239 ± 21	5385 ± 281	Lomi-Veloma
MR73-Pm	Eastern	Lukenya	4053 ± 241	<600	4632 ± 241	<60	922 ± 92	<10	47 ± 7	1035 ± 91	5667 ± 286	Himilll -Veloma
MR69-Pm	Eastern	Masonga	3726 ± 336	<600	4372 ± 419	<60	154 ± 30	<10	27 ± 2	245 ± 23	4617 ± 583	Lomi- Veloma
		Range	**1181 - 4575**	**<600**	**4247 - 5185**	**<60**	**361 - 439**	**<10**	**40 - 56**	**462 - 542**	**5068 - 5778**	

Macro T.H.E. = Macronutrient total health elements
Micro T.H.E. = Micronutrient total health elements
T.H.E. = Total health elements
M. A .E. = macronutrient elements
M. I.E. = micronutrient elements

4.3   Elemental variation of leaf tissue mineral nutrient density (μg/g ± 1 sd) on vegetable populations acqusitioned from farmer's field.

4.3.1   Elemental variation in leafy vegetable cowpea populations on farmer's field

Although macronutrient total health elements were highest in the Lake region samples when compared to the other regions, Mt. Elgon region samples had the highest potassium levels on average. Significant variation was noted for all elements sampled in cowpea germplasm ($P \leq 0.05$). But copper concentrations were below detection limit.

Sample MR 15 from Nalondo in the Mt. Elgon region had the highest levels for potassium levels with an average of $37733 \pm 1003\mu$g/g while sample MR 26 from Kanduyi had the lowest potassium ($13033 \pm 1218\mu$g/g) levels. Calcium concentrations were fairly uniform for most samples analysed except for sample MR 75 from Lukenya in eastern region, which had very low amounts of calcium ($3363 \pm 301\mu$g/g).

Sample MR 48 from Lake-basin sampled at Neewa had particularly high iron levels ($1690 \pm 122\mu$g/g) and consequently resulted in a higher micronutrient element concentration (2255 ± 239) and the highest total health elements ($55988 \pm 3551\mu$g/g) when compared to other populations sampled. The macro element ranking for this accession was rank 2 while micronutrient elements were ranked as 1 (Table 15).

Sample MR 55 from Maseno had high amounts of manganese levels ($1027 \pm 115\mu$g/g) and high levels of macronutrients total health elements, which therefore resulted in MAE-MIE ranking for this accession as being 3 and 1 respectively (Table 15).

4.3.2   Elemental variation in leafy vegetable jute mallow populations on farmer's field

Germplasm accessions of Jute mallow populations from the Lake region had the highest micronutrient and macro element concentrations on average for most species sampled. Significant differences in all macro and micronutrient elements were noted $P \leq 0.05$ for all Jute mallow populations sampled copper levels were beyond detection limit.

Sample MR 56 from Maseno in the Lake region had the highest total health element levels ($53369 \pm 3130\mu$g/g) and was particularly rich in micronutrient elements ($1402 \pm 95\mu$g/g); iron ($1210 \pm 95\mu$g/g), Manganese ($125 \pm 12\mu$g/g) and macronutrient total health elements in general. Sample MR 38 from the same region in Esivalu site followed in iron concentration levels ($777 \pm$

75μg/g) and micronutrient elements (900 ± 85μg/g) and was ranked as 2-2. Sample MR 27 from Kanduyi in Mt. Elgon region had relatively higher levels of zinc (85 ± 8μg/g) when compared to all other accessions sampled for analysis (Table 16).

Table 15: Mineral nutrient density (µg/g ± 1 sd) variation in leafy vegetable cowpea populations on farmer's field (n =3)

Accession	Region	Site	M.A.E			M.I.E						M.A.E-M.I.E ranking
			K	Ca	MacroT.H.E.	Mn	Fe	Cu	Zn	MicroT.H.E	T.H.E	
MR66-Cp	Eastern	Kaseme	19533 ± 1302	19667 ± 1914	39200 ± 3214	174 ± 15	420± 37	<10	48 ± 5	655 ± 51	39855 ± 3239	3-3
MR75-Cp	Eastern	Lukenya	11766 ± 251	3363 ± 301	15130 ± 715	313 ± 29	202 ± 20	<10	16 ± 2	543 ± 41	15672 ± 1547	4-3
		Range	11151 - 20149	2390 - 20640	13568 - 40762	166 - 320	288 - 420	<10	14 - 50	525 - 673	14103 - 41425	
MR37Cp	L. region	Esivalu	19533 ± 1296	21167 ± 2191	40700 ± 3293	286 ± 24	534 ± 52	<10	41 ± 5	873 ± 83	41573 ± 3304	3-3
MR55-Cp	L. region	Maseno	26600 ± 6022	13857 ± 1351	40457 ± 3795	1027 ± 115	835 ± 73	13 ± 1	79 ± 7	1958 ± 102	42415 ± 4241	3-1
MR48-Cp	L. region	Neewa	28333 ± 2588	25400 ± 2474	53733 ± 5370	491 ± 42	1690 ± 122	<10	55 ± 6	2255 ± 239	55988 ± 3551	2-1
		Range	18307- 31337	13784 - 26498	34611 - 55315	438 - 1030	474 - 1564	<10	37 - 79	982 - 2408	35887 - 57431	
MR4-Cp	Mt. Elgon	Chwele	36266 ± 3624	12413 ± 1276	48680 ± 4119	278 ± 21	333 ± 24	<10	73 ± 14	701 ± 61	49381 ± 4373	2-3
MR26-Cp	Mt. Elgon	Kanduyi	13033 ± 1218	10373 ± 1094	23407 ± 2294	93 ± 15	392 ± 38	11 ± 1	36 ± 3	536 ± 43	23942 ± 2320	3-3
MR15-Cp	Mt. Elgon	Nalondo	37733 ± 1003	12000 ± 1250	49733 ± 4294	113 ± 11	518 ± 50	<10	46 ± 5	690 ± 70	50423 ± 4651	3-3
		Range	15622 - 42400	8364 - 14826	25016 - 56196	67 -255	301 - 527	<10	27- 75	504- 780	39678 - 50820	

Table 16: Mineral nutrient density (µg/g ± 1 sd) variation in leafy vegetable jute mallow populations on farmer's field (n =3)

Accession	Region	Site	M.A.E			M.I.E						M.A.E-M.I.E ranking
			K	Ca	Macro T.H.E	Mn	Fe	Cu	Zn	Micro T.H.E	T.H.E	
MR38-Olito	L. Region	Esivalu	19366 ± 1450	8500 ± 580	27867 ± 1164	77± 8	777 ± 75	<10	35 ± 6	900 ± 85	28766 ± 173	4-3
MR56-Olito	L. Region	Maseno	39233 ± 3305	12733 ± 1272	51967 ± 3003	125 ± 12	1210 ± 95	12 ± 1	50 ± 6	1402 ± 95	53369 ± 3130	2-2
MR49-Olito	L. Region	Neewa	22100 ± 2107	12300 ± 1271	34400 ± 3251	91 ± 11	695 ± 91	<10	24 ± 7	824 ± 93	35224 ± 2588	3-3
		Range	17490 - 39310	8717 - 13639	27028 - 59128	68 - 128	646 - 1242	<10	23 – 49	987 - 1497	27811 - 53427	
MR5-Olito	Mt. Elgon	Chwele	21466 ± 2444	7543 ± 735	29010 ± 2479	55 ± 6	739 ± 53	11 ± 1	48 ± 3	858 ± 70	29868 ± 2547	4-3
MR27-Olito	Mt. Elgon	Kanduyi	21800 ±1 721	15017 ± 1506	36817 ± 2762	48 ± 8	268 ± 15	<10	85 ± 8	418 ± 12	37234 ± 2774	3-4
MR16-Olito	Mt. Elgon	Nalondo	21067 ± 2009	11633 ± 923	32700 ± 2622	40 ± 9	271 ± 16	<10	29 ± 1	355 ± 9	33055 ± 2615	3-4
		Range	19776 - 23112	7843 - 15953	28589 - 37095	36 - 50	190 - 662	<10	29 -85	303 - 883	30407 - 37364	

Macro THE. = Macronutrient total health elements
Micro T.H.E. = Micronutrient total health elements
T.H.E. = Total health elements
M. A .E. = macronutrient elements
M. I.E. = micronutrient elements

4.3.3 Elemental variation in leafy vegetable spider plant populations on farmer's field

Spider plant accessions from the Mt. Elgon region had relatively higher macro and micronutrient element levels and consequently resulted in high total health elements when compared to accessions from the Lake region. Significant differences were noted for all minerals ($P \leq 0.05$) in spider plant accessions obtained from various regions.

Sample MR 28 from Kanduyi in Mt. Elgon region had the highest total health element levels for all samples analysed ($54466 \pm 5112 \mu g/g$) when compared to the rest of the samples and was therefore ranked the highest in micronutrient element concentrations. Sample MR 17 from Nalondo in Mt. Elgon region followed with a concentration of $54033 \pm 3652 \mu g/g$ for macro elements and a T.H.E concentration of $55443 \pm 3809 \mu g/g$, respectively. It was also rich in manganese ($154 \pm 15 \mu g/g$) and iron ($1160 \pm 107 \mu g/g$) levels. The M.I.E- M.A.E ranking for this accession was 2-2.

Sample MR 57 from the Lake region had the highest iron and manganese concentration levels of $1816 \pm 16 \mu g/g$ and $231 \pm 14 \mu g/g$ respectively and consequently resulted in the highest MIE concentration of $2153 \mu g/g$. Sample MR 39 from Esivalu followed in iron ($1556 \pm 159 \mu g/g$) and micronutrient elements ($1897 \pm 105 \mu g/g$) concentration. It also had relatively higher amount of zinc ($153 \pm 20 \mu g/g$) when compared to the other populations sampled for this study. The ranking for this accession was of 3-1 for MAE and MIE respectively (Table 17).

4.3.4 Elemental variation in leafy vegetable African nightshade populations on farmer's field

Significant differences ($P \leq 0.05$) were noted for all the minerals in African nightshade populations sampled from various regions in the farmers' fields. Mt. Elgon region had higher in macro element content than the Lake region. Sample MR 18 from Nalondo in Mt. Elgon region had the highest total heath element levels than for most samples analysed ($116932 \pm 2827 \mu g/g$). It was particularly rich in potassium content, which accounted for 98 % of total mineral concentration; the sample had also high levels of iron ($1513 \pm 129 \mu g/g$), and copper ($13 \pm 2 \mu g/g$). It ranked the highest in both macro and micronutrient concentrations.

Sample MR 29 from Kanduyi in the Mt. Elgon region followed in iron concentration of ($1110 \pm 108 \mu g/g$) and registered the highest zinc levels ($72 \pm 6 \mu g/g$). MAE-MIE ranking for this accession was 1-2 (Table 18).

Table 17: Mineral nutrient density (µg/g ± 1 sd) variation in leafy vegetable spider plant populations on farmer's field (n =3)

Accession	Region	Site	M.A.E			M.I.E						M.A.E-M.I.E ranking
			K	Ca	Macro T.H.E	Mn	Fe	Cu	Zn	Micro T.H.E	T.H.E	
MR39-Cle	L.Region	Esivalu	24533 ± 2181	21300 ± 2115	45833 ± 4494	176 ± 20	1556 ± 159	<10	153 ± 20	1897 ± 105	47731 ± 4777	3-1
MR57-Cle	L.Region	Maseno	30833 ± 3057	10633 ± 709	41467 ± 3875	231 ± 18	1816 ± 16	<10	92 ± 18	2153 ± 177	43620 ± 3990	3-1
MR50-Cle	L.Region	Neewa	30867 ± 1069	12157 ± 1204	43023 ± 3655	199 ± 21	1113 ± 100	<10	104 ± 10	1429 ± 103	44453 ± 3693	3-2
		Range	**24814 - 32674**	**9262 - 21130**	**38825 - 9232**	**173 - 231**	**1129 - 1865**	**<10**	**81 - 153**	**1436 - 2216**	**38213 - 52321**	
MR6-Cle	Mt. Elgon	Chwele	30633 ± 2970	13843 ± 1303	44477 ± 4472	200 ± 20	1009 ± 110	<10	110 ± 10	1331 ± 131	45808 ± 4504	3-2
MR28-Cle	Mt. Elgon	Kanduyi	37800 ± 1587	15267 ± 1101	53067 ± 1101	143 ± 14	1157 ± 70	10 ± 1	84 ± 8	1399 ± 71	54466 ± 5112	2-2
MR17-Cle	Mt. Elgon	Nalondo	37933 ± 1747	16100 ± 1617	54033 ± 3652	154 ± 15	1160 ± 107	<10	81 ± 7	1410 ± 140	55443 ± 3809	2-2
		Range	**31371 - 39539**	**12727 - 17413**	**44593 -56457**	**133- 200**	**960 - 1256**	**<10**	**78 - 106**	**1226 -1534**	**45834 - 55978**	

Table 18: Mineral nutrient density (µg/g ± 1 sd) variation in leafy vegetable African nightshade populations on farmer's field (n =3)

Accession	Region	Site	M.A.E			M.I.E						M.A.E-M.I.E ranking
			K	Ca	Macro T.H.E.	Mn	Fe	Cu	Zn	Micro T.H.E	T.H.E	
MR40-Sol	L.Region	Esivalu	25600 ± 2306	23633 ± 1850	49233 ± 4152	<60	310 ± 25	10 ± 1	34 ± 6	411 ± 27	49644 ± 4175	3-4
MR58-Sol	L.Region	Maseno	29667 ± 1789	10307 ± 1044	39973 ± 950	205 ± 20	886 ± 65	<10	71 ± 6	1175 ± 30	41148 ± 958	3-2
MR51-Sol	L.Region	Neewa	42900 ± 4073	10967 ± 1063	53867 ± 5371	247 ± 26	1036 ± 100	<10	65 ± 6	1359 ± 112	55225 ± 5473	2-2
		Range	**24498 - 42946**	**8333 - 24605**	**40672 - 54710**	**73 - 263**	**710 - 1078**	**<10**	**39 – 75**	**542 - 1420**	**44600 - 55744**	
MR7-Sol	Mt. Elgon	Chwele	24400 ± 2377	5967 ± 565	30367 ± 3067	145 ± 12	787 ± 64	<10	70 ± 7	1013 ± 83	31380 ± 3149	3-2
MR29-Sol	Mt. Elgon	Kanduyi	40933 ± 3017	22067 ± 1674	63000 ± 1523	198 ± 14	1110 ± 108	<10	72 ± 6	1394 ± 123	64394 ± 1523	1-2
MR18-Sol	Mt. Elgon	Nalondo	89567 ± 18404	25633 ± 1041	115200 ±2827	137 ± 15	1513 ± 129	13 ± 2	63 ± 6	1733 ± 127	116932 ± 2827	1-1
		Range	**20804 - 82462**	**16581- 25700**	**67468 - 115200**	**127 - 193**	**700 - 1572**	**<10**	**59 - 78**	**932 - 1828**	**30176 - 116936**	

Macro T.H.E. = Macronutrient total health elements
Micro T.H.E. = Micronutrient total health elements
T.H.E. = Total health elements
M. A .E. = macronutrient elements
M. I.E. = micronutrient elements

4.4 Elemental variation in mineral nutrient density ($\mu g/g \pm 1$ sd) on fleshy fruit populations acquisitioned from farmer's field

4.4.1 Elemental variation in fleshy fruit Grewia populations on farmer's field

Germplasm accessions from the Lake region had higher micronutrient and macro element concentrations than those from Mt.Elgon region. Significant differences ($P \leq 0.05$) were however noted for all minerals in Grewia germplasm accessions.

Sample MR 59 from Lake region at Maseno site had the highest manganese levels ($176 \pm 25\mu g/g$). Sample MR 19 from Mt.Elgon in Nalondo site had the highest zinc (36 ± 4 $\mu g/g$), micronutrient elements (392 ± 23 $\mu g/g$)) and total health elements levels ($26898 \pm 2201\mu g/g$) when compared to other samples analysed. It was particularly rich in potassium, which accounted for 98% of its total mineral content. MAE-MIE ranking for this accession was 3-4. Sample MR 30 has relatively higher iron (229 ± 24 $\mu g/g$) concentration than other Grewia accessions sampled for analysis in the study (Table 19).

4.4.2 Elemental variation in fleshy fruit Jack fruit populations on farmer's field

Germplasm accessions from the Lake region had higher micronutrient and macro element concentrations than those from Mt. Elgon region. Jackfruit germplasm tended to concentrate similar amounts of micronutrient and macro element levels for all samples analysed. Sample MR 61 was highest in iron, copper and micronutrient levels compared to other jackfruit accessions. Only slight differences ($P \leq 0.05$) were noted in micro and macro element levels analysed for Jackfruit populations. MAE –MIE ranking for most jackfruit samples was 4-5 (Table 20).

Table 19: Mineral nutrient density (μg/g $\pm$ 1 sd) variation in fleshy fruit Grewia populations on farmer's field (n =3)

Accession	Region	Site	M.A.E			M.I.E					T.H.E	M.A.E-M.I.E ranking
			K	Ca	Macro T.H.E.	Mn	Fe	Cu	Zn	Micro T.H.E		
MR41-Gre	L.Region	Esivalu	8867 ± 850	5273 ± 295	14140 ± 1243	103 ± 8	223 ± 20	<10	32 ± 3	371 ± 36	14510 ± 1247	4-4
MR59-Gre	L.Region	Maseno	17767 ± 1563	8590 ± 788	26356 ± 2320	176 ± 25	131 ± 13	<10	32 ± 3	351± 35	26708 ± 2354	4-4
		Range	8306 - 18326	5124 - 8738	13353 - 27143	94 - 186	126 - 228	<10	31 – 33	337 - 385	13720 - 27498	
MR8-Gre	Mt. Elgon	Chwele	10336 ± 1045	5480 ± 525	15816 ± 1520	97 ± 15	111 ± 12	<10	22 ± 2	241± 24	16057 ± 1580	4-4
MR30-Gre	Mt. Elgon	Kanduyi	9793 ± 973	6453 ± 574	16246 ± 1538	116 ± 12	229 ± 24	<10	29 ± 5	386 ± 34	16632 ± 1589	4-4
MR19-Gre	Mt. Elgon	Nalondo	20567 ± 2026	5940 ± 535	26506 ± 2155	152 ± 16	187 ± 18	11 ± 1	36 ± 4	392 ± 23	26898 ± 2201	3-4
		Range	7965 - 20565	4690 - 7226	13609 - 26437	85.1 – 159	146 – 203	<10	21 – 37	247- 433	13891 - 26833	

Table 20: Mineral nutrient density (μg/g $\pm$ 1 sd) variation in fleshy fruit jack fruit populations on farmer's field (n =3)

Accession	Region	Site	M.A.E			M.I.E					T.H.E	M.A.E-M.I.E ranking
			K	Ca	Macro T.H.E.	Mn	Fe	Cu	Zn	Micro T.H.E		
MR61-Jf	L.Region	Maseno	22466 ± 2254	2386 ± 236	24853 ± 2455	57± 11	160 ± 18	12 ± 1	10 ± 1	243 ± 18	25096 ± 2500	4-4
		Range	20927 - 28408	2050 - 2632	23467 - 30549	49 - 87	56 - 168	<10	9 - 14	170 - 248	23323 - 31111	
MR11-Jf	Mt. Elgon	Chwele	24267 ± 2427	1998 ± 185	26265 ± 2614	64 ± 6	64 ± 20	12 ± 1	10 ± 1	156 ± 15	26421 ± 2641	4-5
MR32-Jf	Mt. Elgon	Kanduyi	26866 ± 2139	2460 ± 212	29326 ± 2290	80 ± 7	55 ± 6	<10	14 ± 2	163 ± 17	29490 ± 2295	4-5
MR21-Jf	Mt. Elgon	Nalondo	20000 ± 2000	995 ± 92	20994 ± 2054	<60	77 ± 6	<10	13 ± 2	156 ± 16	21150 ± 2180	4-5
		Range	21727 - 25695	1582 - 2452	25326 - 29732	58 - 74	44 - 88	<10	12- 24	132 - 184	23653 - 27721	

Macro T.H.E. = Macronutrient total health elements
Micro T.H.E. = Micronutrient total health elements
T.H.E. = Total health elements
M. A .E. = macronutrient elements
M. I.E. = micronutrient elements

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4.4.3 Elemental variation in fleshy fruit Kwazulu Natal rhus populations on farmer's field

Kwazulu Natal rhus species had significantly higher levels of manganese and iron (P≤0.05) levels when compared to other fruit species.

In particular, MR 42 (584 ± 52µg/g) from the Lake region had the highest iron content in comparison to all the other samples of Kwazulu Natal rhus populations. Other samples that had high iron content include; sample MR 31 from Kanduyi in Mt. Elgon with an average of 562 ± 50µg/g and sample MR 20 from Nalondo in Mt.Elgon region with an average of 500 ± 50µg/g of iron. Sample MR 20 had the highest manganese and micronutrient element content and its MAE-MIE ranking was 4-3 (Table 21).

4.4.4 Elemental variation in fleshy fruit Sycamore fig populations on farmer's field

Sycamore fig germplasm from the Lake region had relatively high concentrations of total heath elements compared to germplasm from Mt. Elgon region. Sample MR 44 from Lake Basin in Esivalu had the highest total health elements levels (42838 ± 2016µg/g). It was particularly rich in potassium, which accounted for 98% of its total mineral content. Sample MR 10 had the highest levels of manganese, iron, zinc and micronutrient element levels. MAE-MIE ranking for this accession was 3-4 (Table 22).

4.4.5 Elemental variation in fleshy fruit baobab fruit spp populations on farmer's field

Baobab germplasm tended to concentrate similar amounts of both micro and macronutrients and no significant differences (P≤0.05) were noted for most elements. Zinc manganese and copper were below detection limit in baobab samples analysed. However, slight differences were noted for potassium and calcium (Table 23) for most baobab samples analysed.

In all the plant germplasm sampled, selenium was below detection limit (trace) whereas iodine could not detected owing to the limitations of the technique.

Table 21: Mineral nutrient density (μg/g $\pm$ 1 sd) variation in fleshy fruit Kwazulu Natal rhus populations on farmer's field (n =3)

Accession	Region	Site	M.A.E			M.I.E						M.A.E-M.I.E ranking
			K	Ca	Macro T.H.E.	Mn	Fe	Cu	Zn	Micro T.H.E	T.H.E	
MR42-Rhus	L.Region	Esivalu	11596 ± 1101	4440 ± 442	16036 ± 1506	164 ± 15	584 ± 52	<10	36 ± 4	798 ± 51	16835 ± 1488	4-3
MR60-Rhus	L.Region	Maseno	11900 ± 1158	7593 ± 692	19493 ± 1249	159 ± 15	184 ± 15	<10	29 ± 5	384 ± 38	19877 ± 1301	4-4
		Range	6155 - 17341	5815 - 7517	11887 - 23643	92 - 232	363 - 405	<10	26 – 38	353 - 827	12549 - 24161	
MR9-Rhus	Mt. Elgon	Chwele	14467 ± 1456	7777 ± 438	22243 ± 2122	238 ± 25	238 ± 20	<10	31 ± 3	518 ± 41	22761 ± 2117	
MR31-Rhus	Mt. Elgon	Kanduyi	16300 ± 1647	5490 ± 550	21790 ± 2160	172 ± 17	562 ± 50	<10	34 ± 6	781± 50	22570 ± 2245	4-3
MR20-Rhus	Mt. Elgon	Nalondo	16600 ± 2306	6110 ± 600	22710 ± 2104	268 ± 25	500 ± 50	<10	34 ± 3	815 ± 79	23525 ± 2304	4-3
		Range	13537 - 18039	5192 - 7774	20263 - 24231	173 - 279	279 - 587	<10	29 – 40	554 - 856	20918 - 24986	

Table 22: Mineral nutrient density (μg/g $\pm$ 1 sd) variation in fleshy fruit Sycamore fig populations on farmer's field (n =3)

Accession	Region	Site	M.A.E			M.I.E						M.A.E-M.I.E ranking
			K	Ca	Macro T.H.E.	Mn	Fe	Cu	Zn	Micro T.H.E	T.H.E	
MR44-Fic	L.Region	Esivalu	34500 ± 344	8136 ± 712	42636 ± 1015	75 ±12	67 ± 10	12 ± 1	42 ± 4	202 ± 13	42838 ± 2016	3-4
MR62-Fic	L.Region	Maseno	32400 ± 2029	8136 ± 712	40536 ± 1726	68 ± 15	88 ± 10	<10	41 ± 4	212 ± 21	40748 ± 1733	3-4
		Range	31249 - 35651	7424 - 8848	37736 - 45436	59 - 85	64 - 92	<10	38 – 44	197- 215	38423 - 45163	
MR10-Fic	Mt. Elgon	Chwele	31233 ± 1025	3976 ± 105	35210 ± 1066	115 ± 10	115 ± 5	11 ± 1	45 ± 4	292 ± 11	35502 ± 1072	3-4
MR33-Fic	Mt. Elgon	Kanduyi	18733 ± 1604	6276 ± 523	25010 ± 1126	50 ± 6	100 ± 10	10 ± 1	31 ± 3	196 ± 17	25205 ± 1140	4-5
MR22-Fic	Mt. Elgon	Nalondo	18700 ± 1435	7620 ± 390	26320 ± 2532	91 ± 7	98 ± 9	<10	27 ± 4	230 ± 20	26549± 2640	4-4
		Range	18700 - 36802	5723 - 7191	25107 - 35585	55 - 115	84 - 124	<10	21 - 47	179 - 299	25191 - 35979	

Macro T.H.E. = Macronutrient total health elements
Micro T.H.E. = Micronutrient total health elements
T.H.E. = Total health elements
M. A .E. = macronutrient elements
M. I.E. = micronutrient elements

Table 23: Mineral nutrient density (µg/g ± 1 sd) variation in fleshy fruit Baobab spp populations on farmer's field (n =3)

Accession	Region	Site	M.A.E					M.I.E				
			K	Ca	Macro T.H.E.	Mn	Fe	Cu	Zn	Micro T.H.E	T.H.E	M.A.E-M.I.E ranking
MR67-Bao	Eastern	Kaseme	21533 ± 2135	2286 ± 174	23820 ± 2146	<60	50 ± 5	<10	<10	124 ± 12	23944 ± 2146	4-5
MR71-Bao	Eastern	Masonga	20133 ± 1013	2469 ± 221	22603 ± 2203	<60	69 ± 6	<10	<10	146 ± 14	22748 ± 2250	4-5
MR76-Bao	Eastern	Lukenya	20033 ± 2450	3133 ± 311	23166 ± 2264	<60	58 ± 5	<10	<10	132 ± 15	2398 ± 236	4-5
		Range	**18722 - 22410**	**1633 - 3625**	**21025 - 25367**	**<60**	**48 - 68**	**<10**	**<10**	**121- 147**	**14195 - 23531**	

Macro T.H.E. = Macronutrient total health elements
Micro T.H.E. = Micronutrient total health elements
T.H.E. = Total health elements
M. A .E. = macronutrient elements
M. I.E. = micronutrient elements

4.5   II: Soil content as a basis for plant characterization.

Due the relationship between soils and plants, characterization of micronutrient density in plants cannot be done in the absence of soil analysis because nutrient-element densities are highly interactive between genotypes and soil environments. Characterization of nutrient-dense genotypes ought therefore to take into account the component of genotype environment interactions. The results of elemental content of soil types analyzed from various regions are as shown in table 24 below.

Table 24:   Table of means of nutrient content in soils of different regions in μg/g

Regions	Sites	K	Ca	M.A.E	Fe	Zn	Cu	Mn	M.I.E	M.A.E+M.I.E
					Elements					
Mt. Elgon region	Chwele	10963	3361	14278	18780	36.3	6.34	241.5	19076	33355
	Kanduyi	12151	1975	14126	26355	39.16	6.52	358.9	26771	40898
	Nalondo	6434	2199	8634	17370	37.64	9.52	271.2	17700	26334
	Mean	9850	2512	12346	20835	37.7	7.46	290.5	21183	33529
	se	919.6	850.35	1464.7	1443.6	5.1	1.95	41.6	1464.7	2341.85
	%cv	11.4	41.5	8.5	8.5	16.7	32.7	17.6	8.5	8.6
Lake region	Esivalu	20239	3747	23986	30936	64.6	11.48	927	31951	55937
	Maseno	7842	2430	10272	52718	103.3	11.67	2905	55751	66023
	Neewa	8234	3440	11665	61704	96.1	11.76	4841	66650	78366
	Mean	12105	3206	15308	48453	88	11.63	2891	51451	66775
	se	3367.7	454.6	3471.6	2784.75	8.8	2.4	271.35	2856.45	4540.1
	%cv	34	17.3	27.7	7	12.2	25.5	11.5	6.8	8.3
Eastern region	Kasemeini	3530	3922	7451	14636	44.31	7.95	217.7	14918	22369
	Lukenya	11273	4373	15646	11971	22.72	7.47	210.6	12224	27870
	Masongaleni	8101	6534	14635	20041	31.8	13.76	312.4	20411	35046
	Mean	7635	4943	12577	15549	32.94	9.73	246.9	15851	28428
	se	1514.45	660	1822.45	2889.8	4.55	2.8	29.15	2894.15	3698.15
	%cv	23.6	15.9	17.3	22.1	16.6	34.4	14.1	21.8	15.5

4.5.1   Potassium

Soil potassium levels were highest in the Lake region with Esivalu (20010 μg/g) registering relatively higher concentrations than samples analysed from any other region. Although samples from the other sites did not differ significantly in soil potassium content, results of Kanduyi site in Mt. Elgon region followed in second position and those from Lukenya were third. The eastern region in general and Kasemeini in particular had the lowest potassium concentrations in the soil (Fig.4).
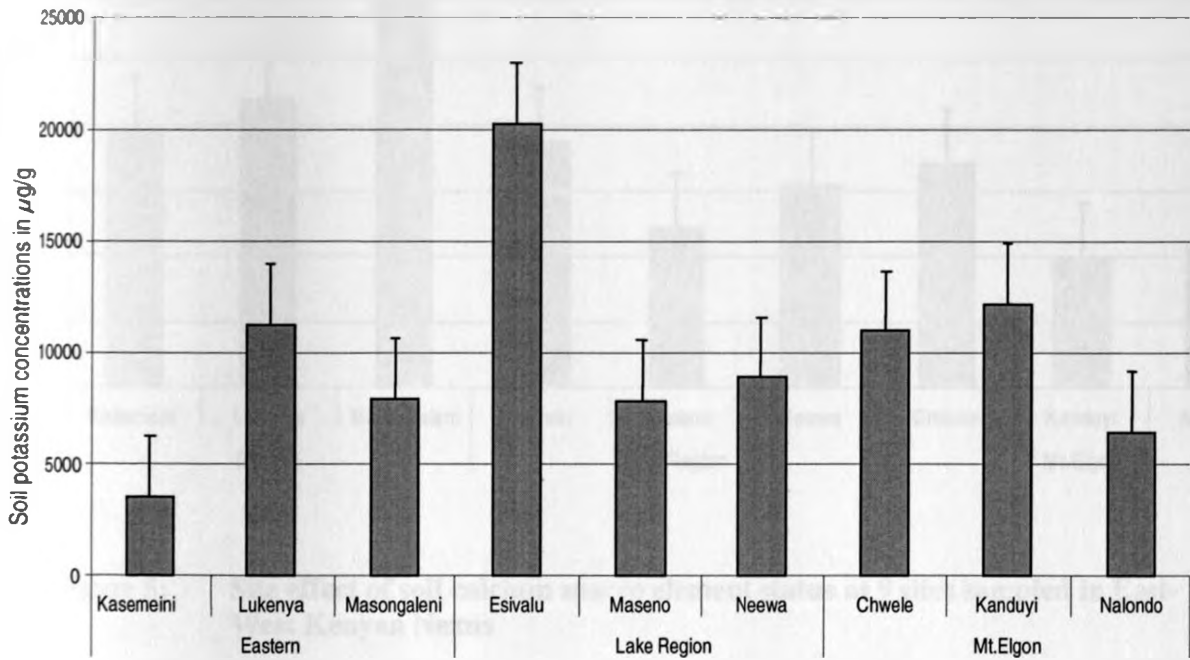
Figure 4: **Site effect of soil potassium macro element status at 9 sites sampled in East- West Kenyan Nexus**

Vertical bars are standard error bars at p ≤0.05

4.5.2 Calcium

Soil calcium levels were highest in the eastern region samples with Masogaleni (6480 $\mu g/g$) registering relatively higher concentration than any other sampled site. Although the other sites did not differ significantly in soil Ca content, overall Mt. Elgon samples region had the lowest calcium concentrations in the soils (Fig.5).
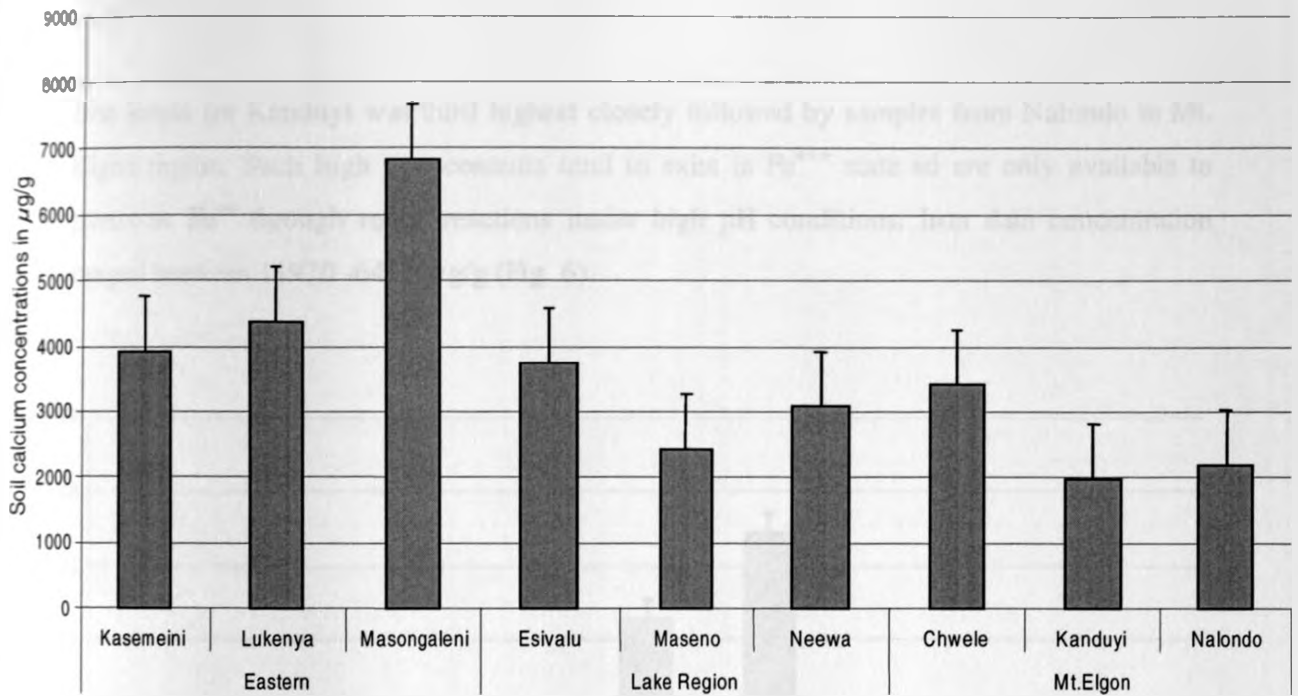
Figure 5:   **Site effect of soil calcium macro element status at 9 sites sampled in East-West Kenyan Nexus**

Vertical bars are standard error bars at p ≤0.05

4.5.3 Iron

According to Akundabweni (2004) studies, Kabete Nitisols showed the highest mean soil iron level. He found that Nitisols from central Kenya also known as 'acid' soils are generally characterized by low pH that enhances the solubility of iron normally required by plants. Similarly, Nitisols from the Lake region for this study had higher levels of iron compared to the other samples analysed. Iron levels from Maseno and Neewa soil samples were highest followed by those from Esivalu (all from Lake basin region).

Iron levels for Kanduyi was third highest closely followed by samples from Nalondo in Mt. Elgon region. Such high iron contents tend to exist in Fe^{+++} state ad are only available to plants as Fe^{++} through redox reactions under high pH conditions. Iron data concentration ranged between 11970 -64366μg/g (Fig. 6).
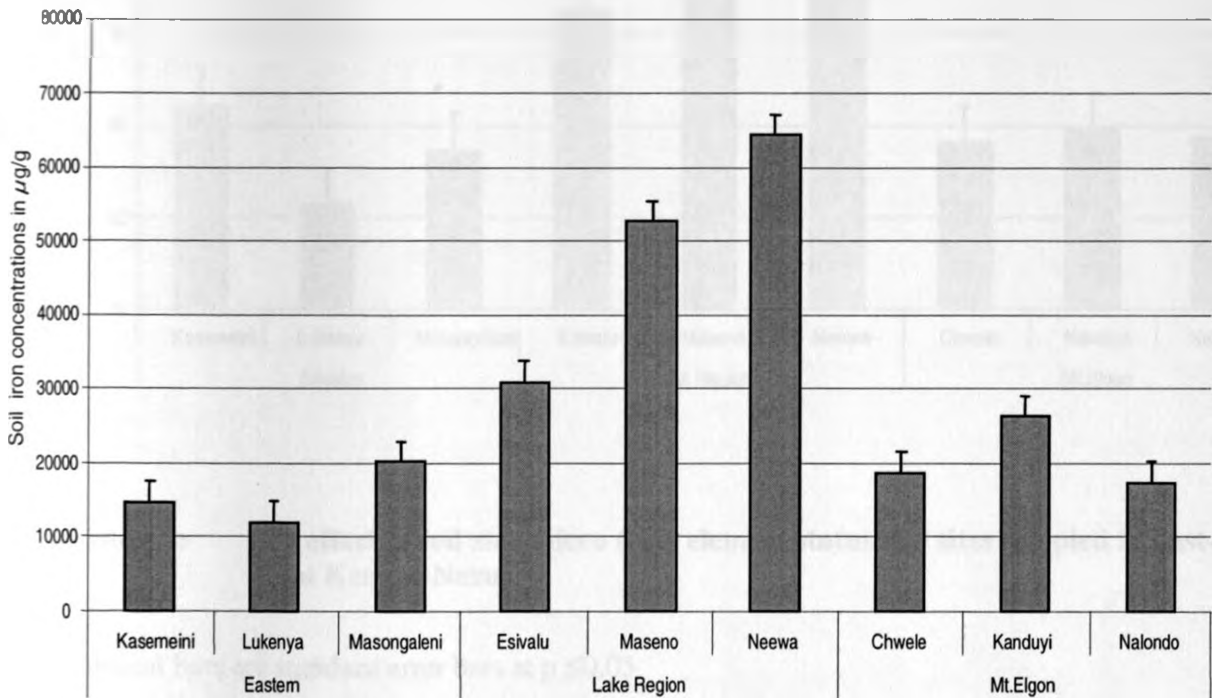
Figure 6: **Site effect of soil iron micro trace element status at 9 sites sampled in East-West Kenyan Nexus**

Vertical bars are standard error bars at p ≤0.05

4.5.4   Zinc

Zinc is one of the micronutrients of nutritional importance. Despite the relatively lower soil concentrations of soil Zn relative to iron, a Maseno soil sample had the highest values (103μg/g) of soil zinc followed by those from Esivalu and Neewa all within the Lake basin. Coincidentally the area with high zinc had also the highest levels for iron. The Lake region was followed by eastern region with Kasemeini (44μg/g) registering the highest levels of zinc in this region. Zinc content in soils is shown in Fig. 7.
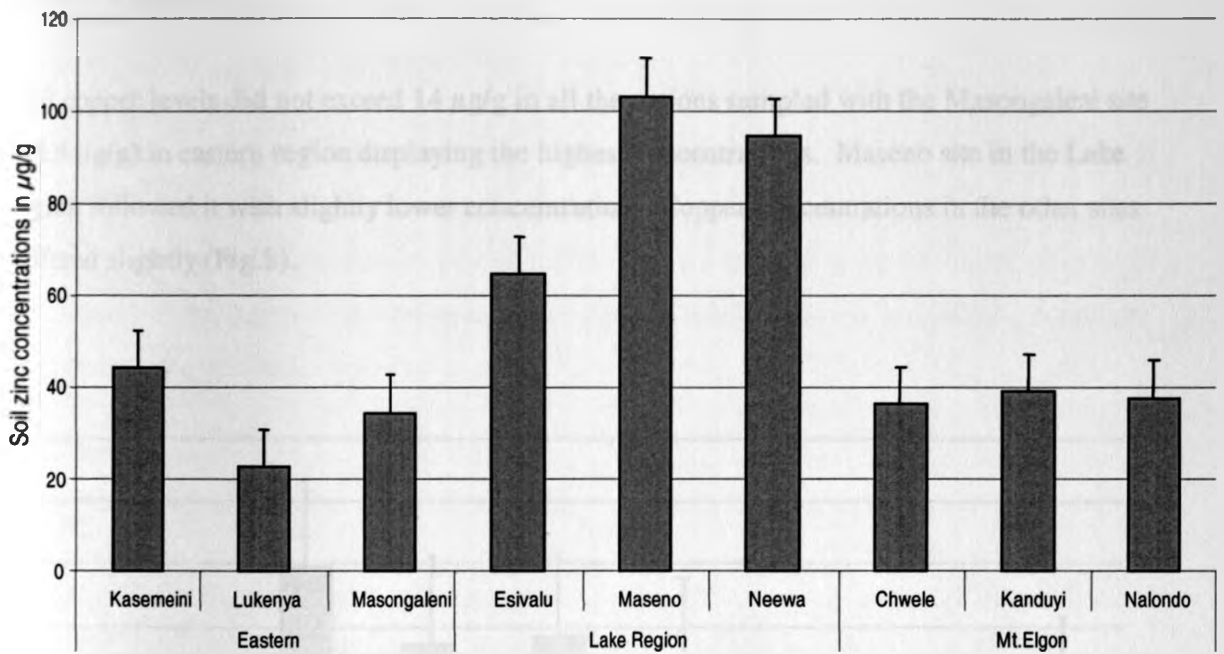
Figure 7: **Site effect of soil zinc micro trace element status at 9 sites sampled in East-West Kenyan Nexus**

Vertical bars are standard error bars at p ≤0.05

4.5.5 Copper

Soil copper levels did not exceed 14 $\mu g/g$ in all the regions sampled with the Masongaleni site (13.8 $\mu g/g$) in eastern region displaying the highest concentrations. Maseno site in the Lake region followed it with slightly lower concentrations. Copper concentrations in the other sites differed slightly (Fig.8).
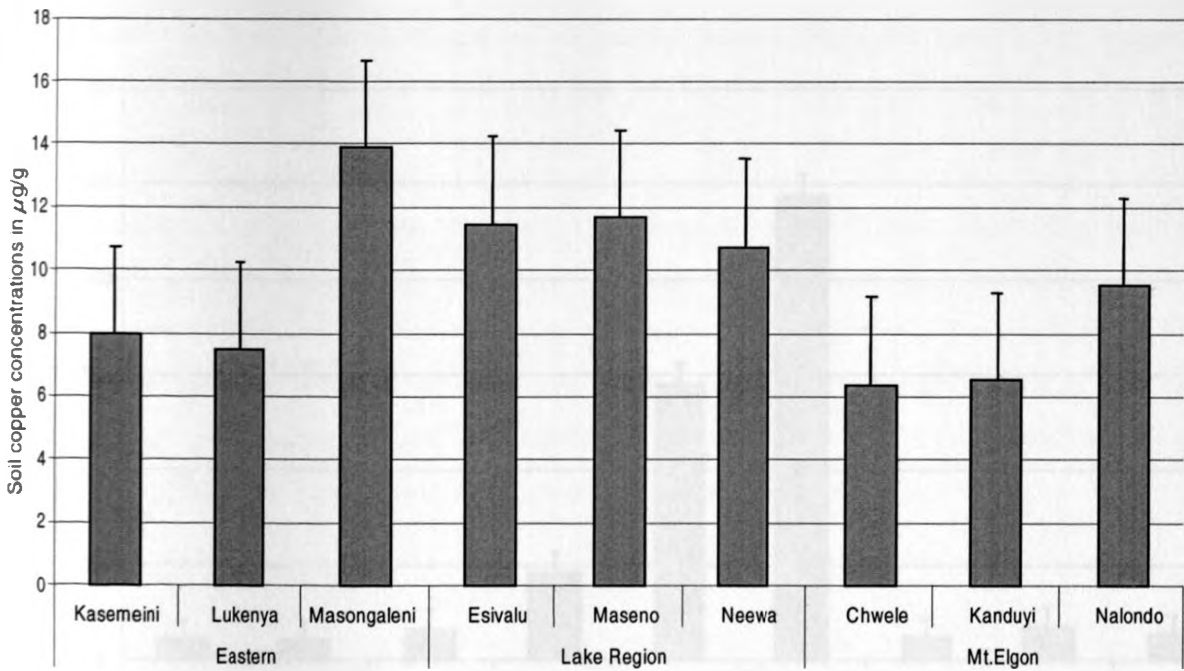
Figure 8: **Site effect of soil copper micro trace element status at 9 sites sampled in the East- West Kenyan Nexus**

Vertical bars are standard error bars at p ≤0.05

4.5.6 Manganese

Soil manganese levels were higher in samples from the Lake basin when compared to those sampled from the eastern and western regions (Fig.9).

The microelement (M.I.E) data for the two regions suggest the Lake basin area in particular could be an important site for micronutrient density characterization in plant samples in light of their relatively higher levels compared to levels found in samples from other sites considered in the study. This statement presupposes that solubility and availability conditions for uptake mechanism are ambient.
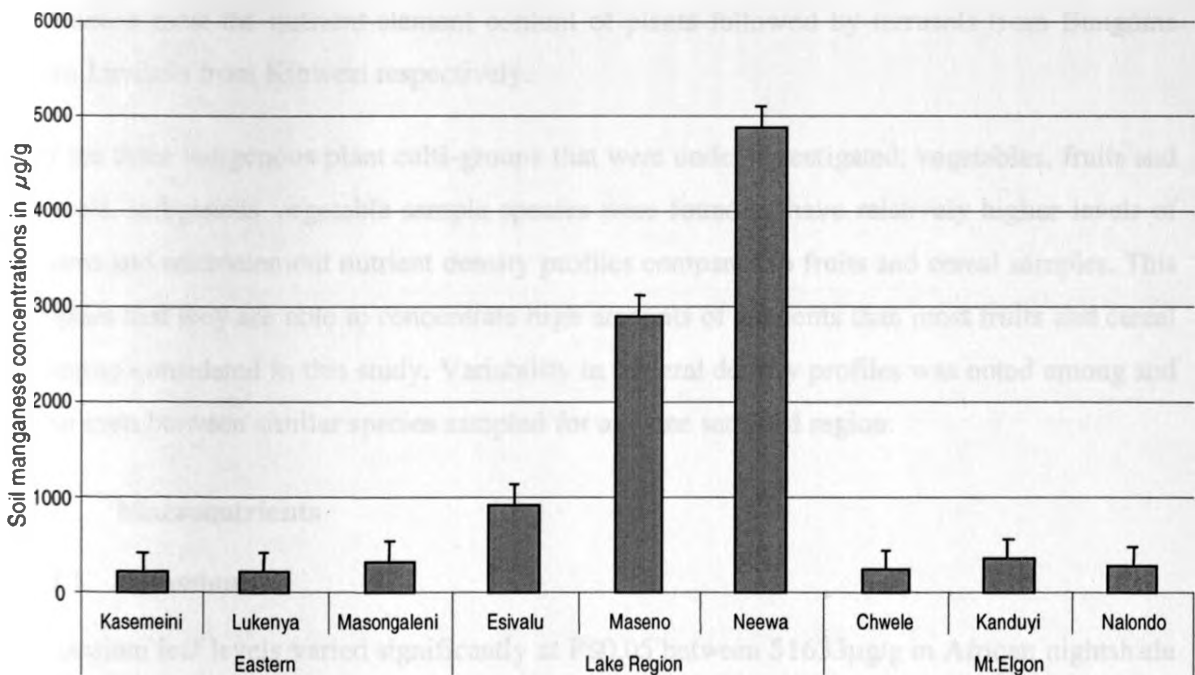
Figure 9:   **Site effect of soil manganese micro trace element status at 9 sites sampled in the East- West Kenyan Nexus**

Vertical bars are standard error bars at p ≤0.05

Like in all the plant species, iodine was not measured in the soil samples and selenium was below the detection limit (<12).

4.6   III: Species-region (soil) element relationships.

4.6.1   Uptake of mineral densities of selected plant species within three Indigenous Culti-groups (ICGs) from three regions after XRF characterization

Plant concentrations are a dual function of soil mineral levels and the plant genotype uptake and assimilation efficiency. Results presented in the foregoing sections imply therefore that the phenotypic micronutrient status must be evaluated in the context of the soil medium upon which the plants are established. The following tables and figures show results of the soil XRF analysis of various plant populations that had been characterized.

The following results show a possible contribution of soil types (region) to micronutrient element content of different species of plants. Nitisols from the Lake-region appear to influence most the nutrient-element content of plants followed by ferrasols from Bungoma then Luvisols from Kibwezi respectively.

Of the three indigenous plant culti-groups that were under investigated; vegetables, fruits and cereals, indigenous vegetable sample species were found to have relatively higher levels of macro and microelement nutrient density profiles compared to fruits and cereal samples. This implies that they are able to concentrate high amounts of nutrients than most fruits and cereal samples considered in this study. Variability in mineral density profiles was noted among and also even between similar species sampled for any one sampled region.

4.7   Macronutrients

4.7.1   Potassium

Potassium leaf levels varied significantly at $P \leq 0.05$ between 51633μg/g in African nightshade vegetable samples from Mt. Elgon region which had the highest concentrations to 2702μg/g in maize samples obtained from Kibwezi, eastern region.

Cowpea and spider plant vegetable sample species with range between 19166μg/g - 29011μg/g and 28744μg/g - 35455μg/g respectively also had relatively higher concentrations than the rest of the vegetable species analysed (Fig 10).

For the fruits, *Ficus* populations exceeded the other fruit species in potassium concentrations followed by jackfruit species. For most cereal samples, the potassium levels did not exceed 11000μg/g other than pearl millet and sorghum sample species from eastern region, which

had potassium concentrations of 14555µg/g and 11225µg/g respectively (Fig 10).

Figure 10: **Potassium concentrations in on-farm populations of 13 plant species in the East- West Kenyan Nexus**

KEY: Mz=Maize, Pm=Pearl millet, Sor=Sorghum, Fm=Finger millet, (cereals) Gre=Grewia, Rhus =Kwa Zulu Natal rhus, Jf=Jackfruit, Fic=Sycamore fig, Bao=baobab, (Fruits) Sol=African nightshades, Olito=Jute mallow Cp=cowpea and Cleo=Spider plant (vegetables).
Vertical bars are standard error bars at p ≤0.05

4.7.2 Calcium

Calcium levels varied significantly at P≤0.05 (Appendix 4a) between 20141µg/g in cowpea vegetable sample species from Lake region, which had the highest concentrations, and 579µg/g in maize and sorghum species samples from the eastern region with the lowest concentrations (Fig 11).

The following populations of vegetable species also registered high in calcium concentrations levels; African nightshade with a range of 14969µg/g - 24033µg/g, spider plant (14696µg/g - 15070µg/g) and Jute mallow species (11177µg/g-11397µg/g) for Mt. Elgon and Lake region, respectively (Fig 11).

Figure 11:   Calcium concentrations in on-farm populations of 13 plant species in the East- West Kenyan Nexus

KEY: Mz=Maize, Pm=Pearl millet, Sor=Sorghum, Fm=Finger millet, (cereals) Gre=Grewia, Rhus =Kwa Zulu Natal rhus, Jf=Jackfruit, Fic=Sycamore fig, Bao=baobab, (Fruits) Sol=African nightshades, Olito=Jute mallow Cp=cowpea and Cleo=Spider plant (vegetables).
Vertical bars are standard error bars at p ≤0.05

Although calcium levels in fruit species did not exceed 9000µg/g in all the samples analysed, Sycamore fig species had the highest calcium concentrations followed by Grewia and Kwa Zulu Natal rhus samples.

In cereal samples, calcium levels did not exceed 2100µg/g in all the sampled populations and did not vary significantly but only for finger millet, concentrations that were higher than the other cereal species analysed (Fig 11).

4.7.3 Macronutrients total health elements (Potassium plus Calcium)

Different plant species within the sampled indigenous culti-groups varied widely in their mineral content. According to Figure 12, the vegetable category species from any one given region in general, had relatively higher levels of major mineral contents compared to the rest of the species in the fruit or cereal groups.

Figure 12:   Total macro elements (Potassium + Calcium) concentrations in on-farm populations of 13 plant species in the East- West Kenyan Nexus

KEY: Mz=Maize, Pm=Pearl millet, Sor=Sorghum, Fm=Finger millet, (cereals) Gre=Grewia, Rhus =Kwa Zulu Natal rhus, Jf=Jackfruit, Fic=Sycamore fig, Bao=baobab, (Fruits) Sol=African nightshades, Olito=Jute mallow Cp=cowpea and Cleo=Spider plant (vegetables).
Vertical bars are standard error bars at p ≤0.05

African nightshade vegetable sample species had higher levels of macronutrient total health elements compared to other vegetable species analysed. In particular, African nightshade species (69522µg/g) from Mt.Elgon region had relatively higher levels of macronutrient total health elements compared to other vegetable sample species sampled for analysis from the same region. This was followed by spider plant (50525µg/g) from the same region, and by cowpea (44963µg/g) and Jute mallow (38077µg/g) from the Lake region.

Sycamore fig fruit sample species (41586μg/g) had relatively higher levels of macronutrient elements followed by Jackfruit and by baobab samples from the regions sampled in this study. When compared to the vegetables and fruits samples, the cereals samples had the lowest levels of macronutrient element contents. The highest levels of major nutrient content in cereals samples were noted for pearl millet species samples (15157μg/g) from the eastern region while those of sorghum and maize samples had the lowest levels (Fig.12).

4.8   Micronutrients

4.8.1   Iron

Iron levels varied significantly at P≤0.05 between 1495μg/g in spider plant vegetable samples species from the Lake region, which had the highest iron concentrations, and 12μg/g in finger millet samples obtained from the eastern region, which had the lowest values. Other vegetable sample species that had higher iron concentrations were Jute mallow (894μg/g) from the Lake region, spider plant (1108μg/g) from Mt. Elgon region and African nightshade (1136μg/g) from Mt. Elgon region (Fig13).

Figure 13:   Iron concentrations in on-farm populations of 13 plant species in the East- West Kenyan Nexus

KEY: Mz=Maize, Pm=Pearl millet, Sor=Sorghum, Fm=Finger millet, (cereals) Gre=Grewia, Rhus =Kwa Zulu Natal rhus, Jf=Jackfruit, Fic=Sycamore fig, Bao=baobab, (Fruits) Sol=African nightshades, Olito=Jute mallow Cp=cowpea and Cleo=Spider plant (vegetables).

Vertical bars are standard error bars at p ≤0.05

Different fruit species sampled tended to concentrate similar levels of iron (<200μg/g) other

than Kwa Zulu Natal rhus whose levels ranged from 384-433µg/g for Mt. Elgon region and Lake Region where significant differences were observed between Kwa Zulu Natal rhus and the other fruit species having the highest in the fruit species. Baobab from eastern region had 58µg/g, which was the lowest iron level in the fruit category.

Cereals samples analysed from the different areas did not exceed 100µg/g other than the levels pearl millet and sorghum samples species from eastern (average of 400µg/g and 188µg/g), respectively. Cereals samples did not vary significantly in iron content (Fig. 13).

4.8.2 Zinc

Zinc levels varied significantly at $P \leq 0.05$ (Appendix 4b) between 116µg/g in spider plant vegetable species species from the Lake region, representing the highest concentration, and 10µg/g in baobab samples obtained from the eastern region with the lowest (Fig. 14).

Figure 14:   Zinc concentrations in on-farm populations of 13 plant species in the East-West Kenyan Nexus

KEY: Mz=Maize, Pm=Pearl millet, Sor=Sorghum, Fm=Finger millet, (cereals) Gre=Grewia, Rhus =Kwa Zulu Natal rhus, Jf=Jackfruit, Fic=Sycamore fig, Bao=baobab, (Fruits) Sol=African nightshades, Olito=Jute mallow Cp=cowpea and Cleo=Spider plant (vegetables).
Vertical bars are standard error bars at p ≤0.05

Levels for zinc in different vegetable species from the sampled areas ranged from 35-58 µg/g

for cowpea from the Lake and eastern regions, 36-54µg/g for Jute mallow from the Lake and Mt. Elgon region, 92-116µg/g for spider plant from Mt. Elgon region and the Lake region respectively.

Other than jackfruit and baobab samples that had extremely low levels of zinc, the other fruit samples species had almost similar zinc concentrations ranging from 29µg/g -32µg/g in Grewia and 22µg/g- 41µg/g in Sycamore fig for Mt. Elgon region and Lake region respectively. Levels in Kwa Zulu Natal rhus species ranged from 32-33µg/g.

Cereal sample species appeared to concentrate similar levels of zinc with pearl millet having 42µg/g as the highest level of zinc in the cereal category and which had significant differences from the other cereal sample species. Zinc levels in the other cereal sample species analysed did not exceed 35µg/g and with no significant variation (Fig. 14).

4.8.3 Copper
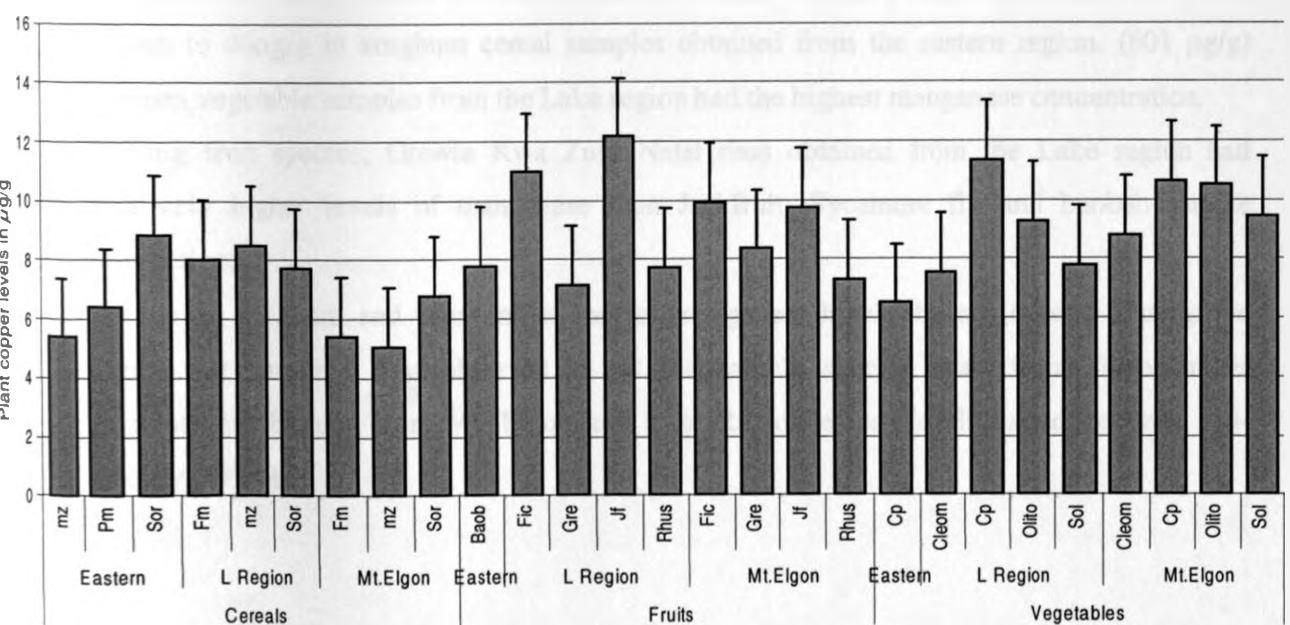
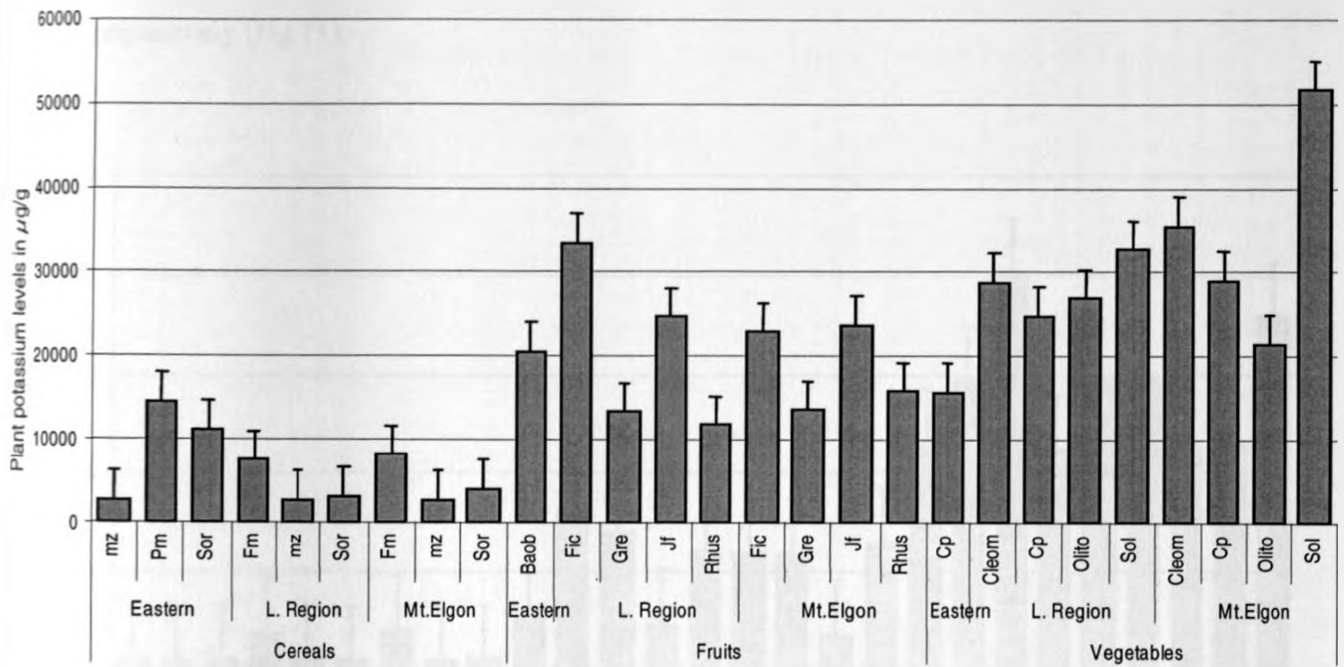**Figure 15:** **Copper concentrations in on-farm populations of 13 plant species in the East- West Kenyan Nexus**

KEY: Mz=Maize, Pm=Pearl millet, Sor=Sorghum, Fm=Finger millet, (cereals) Gre=Grewia, Rhus =Kwa Zulu Natal rhus, Jf=Jackfruit, Fic=Sycamore fig, Bao=baobab, (Fruits) Sol=African nightshades, Olito=Jute mallow Cp=cowpea and Cleo=Spider plant (vegetables).

Vertical bars are standard error bars at p ≤0.05

Although copper levels varied significantly at P≤0.05 (Appendix 4b) in Jackfruit populations from the Lake region and in maize samples from the Mt. Elgon region, sample species from other sites appeared to accumulate similar levels of copper. There were no significant differences in copper concentration in most sample species analysed or any one given region (Fig. 15).

It was noted that while the cereal category had the lowest concentrations of any given element, there were no significant differences between the cereal category and those of other plant sample species categorized as the fruit and vegetables on copper concentrations.

Apart from the fruit species, copper levels in most plant species did not exceed 10 µg/g (Fig. 15).

4.8.4 Manganese

Manganese levels varied at P≤0.05 between 601µg/g in cowpea vegetable samples for Lake region to 46µg/g in sorghum cereal samples obtained from the eastern region. (601 µg/g) cowpea vegetable samples from the Lake region had the highest manganese concentration. Among fruit species, Grewia Kwa Zulu Natal rhus obtained from the Lake region had relatively higher levels of manganese than Jackfruit, Sycamore fig and baobab sample populations.

In maize, sorghum and pearl millet species manganese levels did not exceed 52µg/g. No significant variation was observed in all the sample species apart from finger millet populations obtained from Mt. Elgon and Lake Region whose levels varied between 109-146µg/g (Fig 16).

Manganese levels varied at P≤0.05 between 601μg/g in cowpea vegetable samples for Lake region to 46μg/g in sorghum cereal samples obtained from the eastern region. (601 μg/g) cowpea vegetable samples from the Lake region had the highest manganese concentration. Among fruit species, Grewia Kwa Zulu Natal rhus obtained from the Lake region had relatively higher levels of manganese than Jackfruit, Sycamore fig and baobab sample populations.

In maize, sorghum and pearl millet species manganese levels did not exceed 52μg/g. No significant variation was observed in all the sample species apart from finger millet populations obtained from Mt. Elgon and Lake Region whose levels varied between 109-146μg/g (Fig 16).

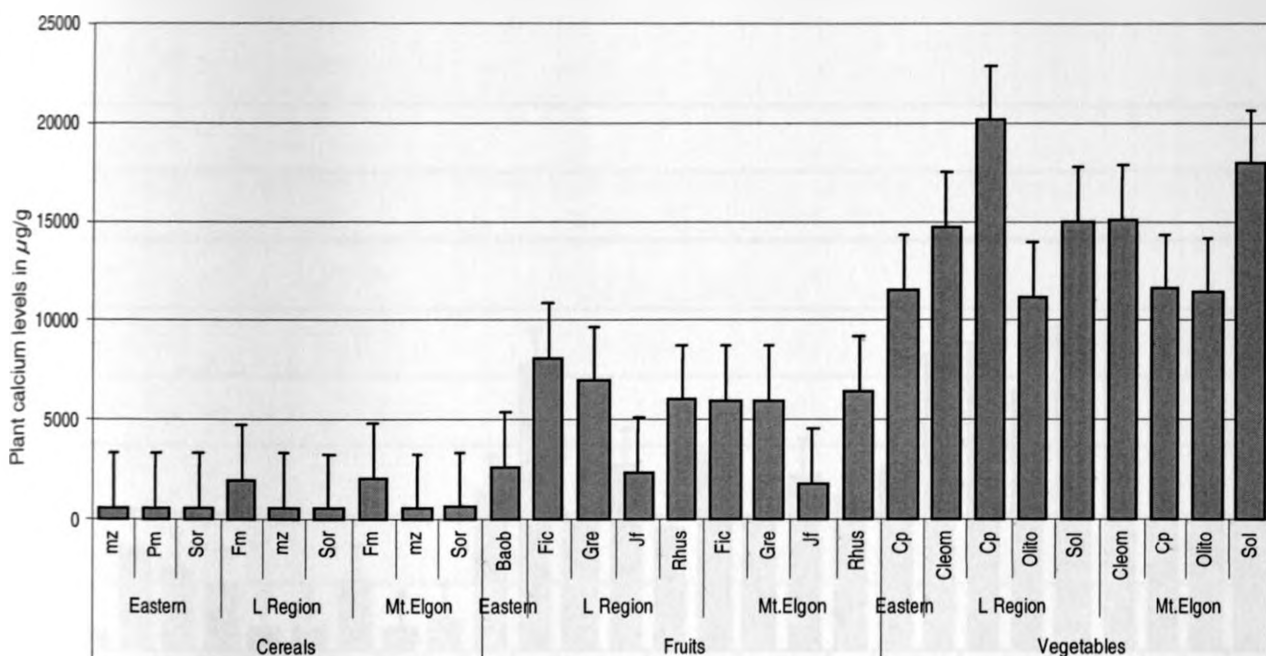**Figure 16:** **Manganese concentrations in on-farm populations of 13 plant species in the East- West Kenyan Nexus**

KEY: Mz=Maize, Pm=Pearl millet, Sor=Sorghum, Fm=Finger millet, (cereals) Gre=Grewia, Rhus =Kwa Zulu Natal rhus, Jf=Jackfruit, Fic=Sycamore fig, Bao=baobab, (Fruits) Sol=African nightshades, Olito=Jute mallow Cp=cowpea and Cleo=Spider plant (vegetables).
Vertical bars are standard error bars at p ≤0.05

4.8.5   Total micro nutrient health elements (MIE=Fe+Zn+Cu+Mn)

Plant species, from any one given region varied significantly at P≤0.05 in trace-nutrient levels between 1826µg/g in spider plant samples and to 59µg/g in Kwa Zulu Natal rhus samples from Lake region (Fig 17).
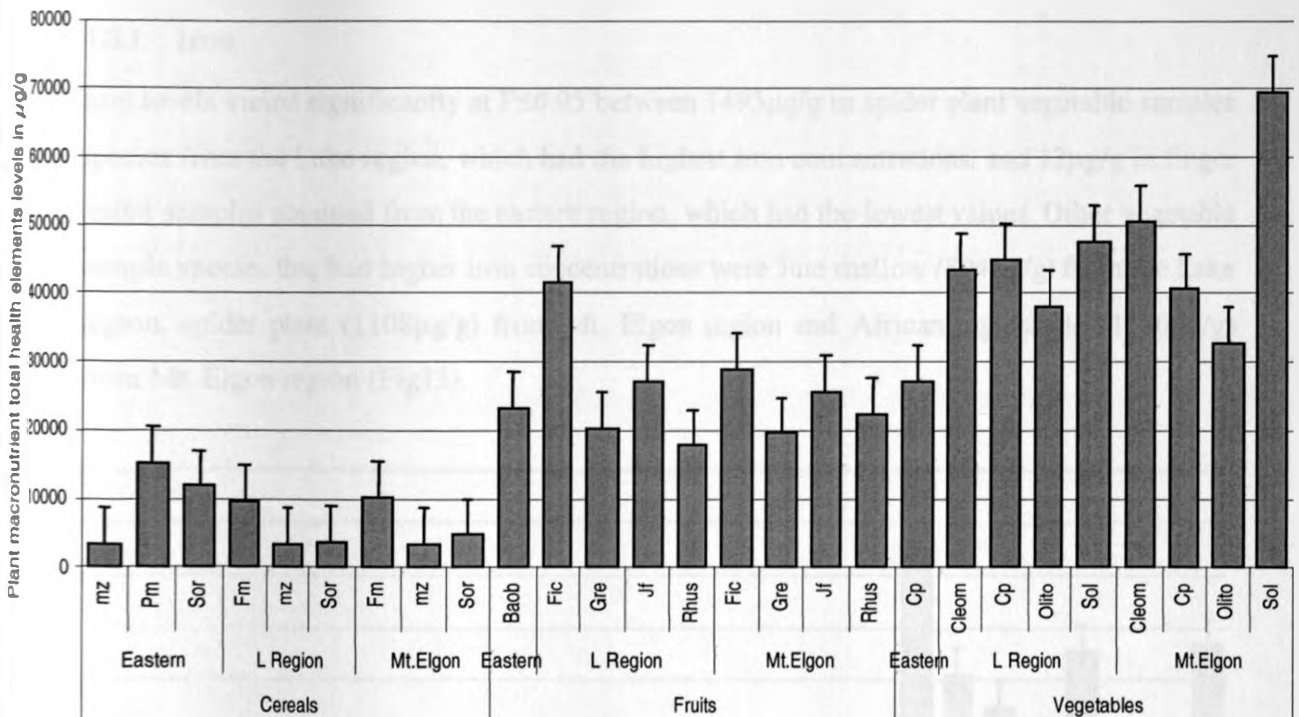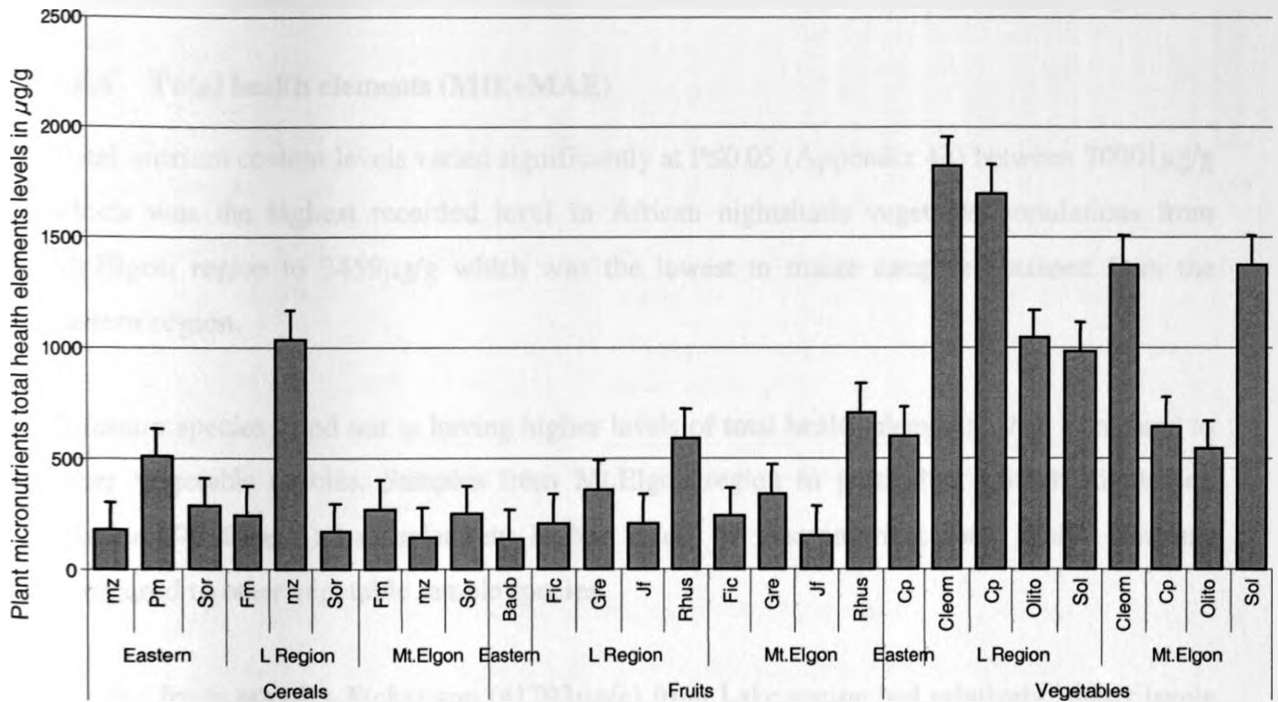

Figure 17:   Total micronutrients (MIE) concentrations in on-farm populations of 13 plant species in the East- West Kenyan Nexus

KEY: Mz=Maize, Pm=Pearl millet, Sor=Sorghum, Fm=Finger millet, (cereals) Gre=Grewia, Rhus =Kwa Zulu Natal rhus, Jf=Jackfruit, Fic=Sycamore fig, Bao=baobab, (Fruits) Sol=African nightshades, Olito=Jute mallow Cp=cowpea and Cleo=Spider plant (vegetables).
Vertical bars are standard error bars at p ≤0.05

Spider plant, cowpea, and African nightshade populations had relatively higher micronutrient concentrations in any given region sampled compared to maize and sorghum, which had the lowest concentrations. Spider plant (1826µg/g) and cowpea (1695µg/g) vegetable sample species from the Lake region in particular had the highest microelement concentrations compared to other regions.

Kwa Zulu Natal rhus and Grewia fruit populations, although differing slightly, had relatively higher microelement concentrations compared to other fruit populations (Fig.17).

The cereals samples generally had low levels of micronutrients nutrient element contents for the Lake region as well. There was a slight increase in micronutrients nutrient element content of pearl millet (506μg/g) sample species in the eastern region as to when compared to finger millet and sorghum. Maize had the lowest micronutrients nutrient element content (Fig.17).

4.8.6   Total health elements (MIE+MAE)

Total nutrient content levels varied significantly at P≤0.05 (Appendix 4b) between 70901μg/g which was the highest recorded level in African nightshade vegetable populations from Mt.Elgon region to 3459μg/g which was the lowest in maize samples obtained from the eastern region.

Solanum species stand out as having higher levels of total health elements when compared to other vegetable species. Samples from Mt.Elgon region in particular, African nightshade species (70901μg/g) had relatively higher levels of macronutrient total health elements compared to other vegetable sample species.

For the fruits samples *Fichus* spp (41793μg/g) from Lake region had relatively higher levels of total health elements followed by Jackfruit and baobab samples. When compared to the vegetables and fruits samples the cereals samples, the cereals had the lowest levels of macronutrient element content (Fig.18). In this study, the highest levels of major nutrient content in cereals were observed in pearl millet species (15663μg/g) from the eastern region while those of sorghum and maize from this same region were the lowest (Fig. 18).
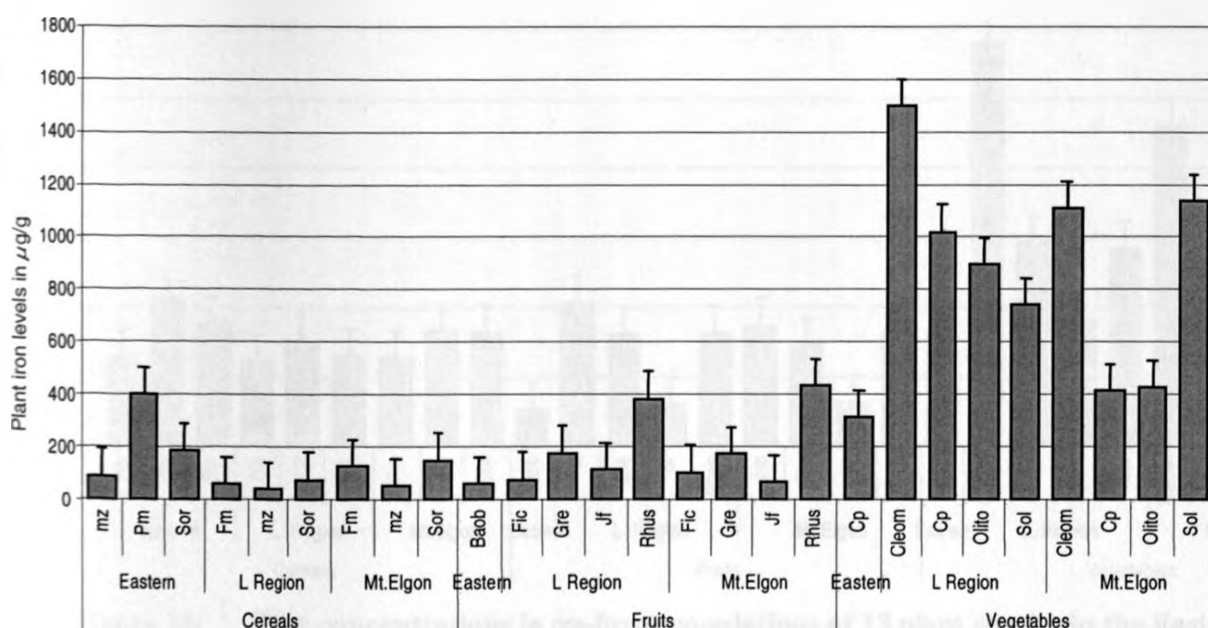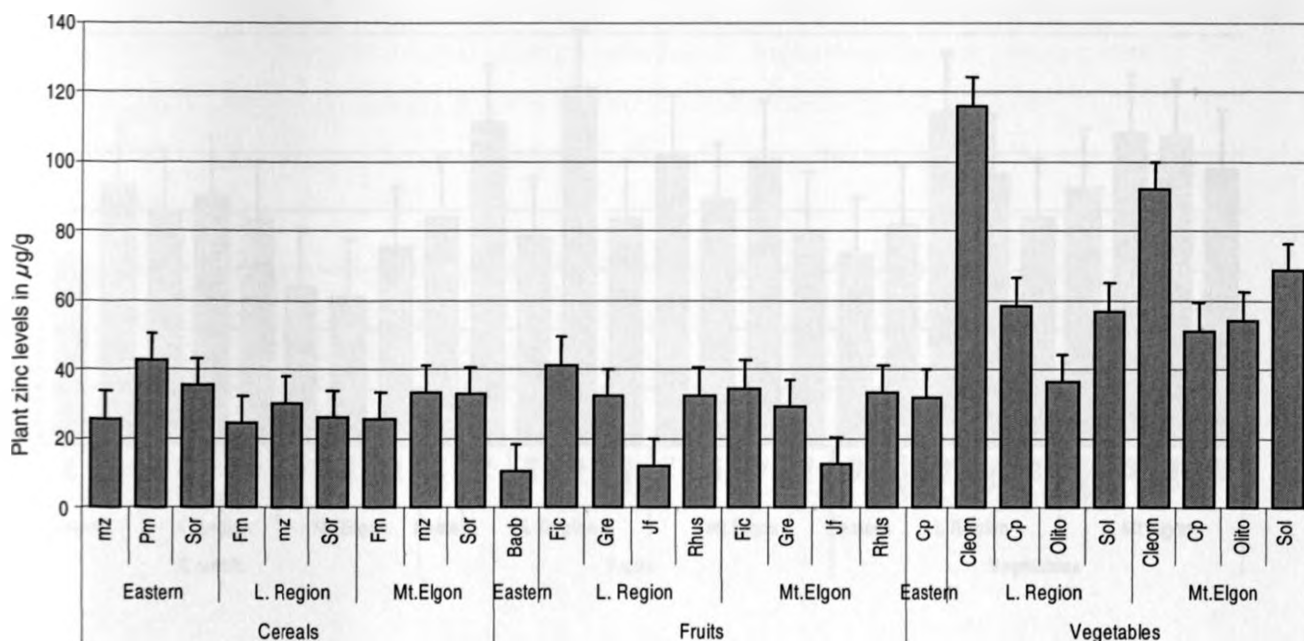
66
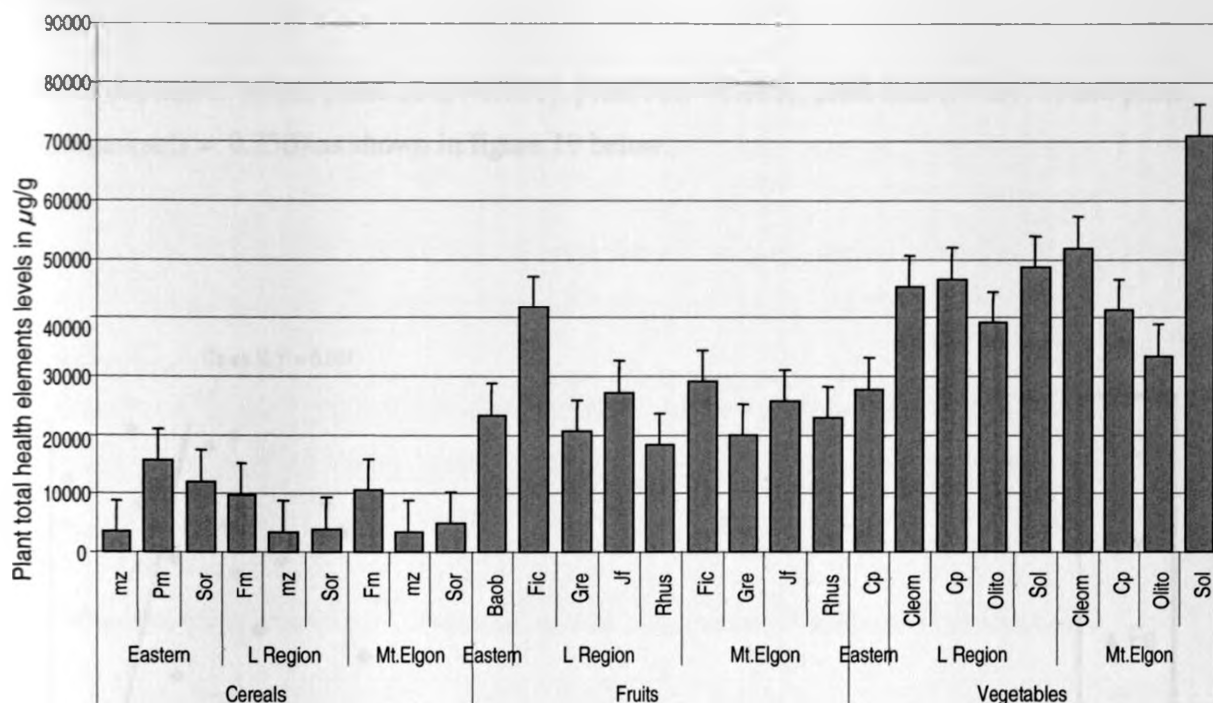
Figure 18: **Total nutrients (MAE+MIE) concentrations in on-farm populations of 13 plant species in the East- West Kenyan Nexus**

KEY: Mz=Maize, Pm=Pearl millet, Sor=Sorghum, Fm=Finger millet, (cereals) Gre=Grewia, Rhus =Kwa Zulu Natal rhus, Jf=Jackfruit, Fic=Sycamore fig, Bao=baobab, (Fruits) Sol=African nightshades, Olito=Jute mallow Cp=cowpea and Cleo=Spider plant (vegetables).
Vertical bars are standard error bars at p ≤0.05

IV: Plant – Soil macro and micronutrient element correlations

Table 25: Overall Plant – Soil macro and micronutrient element correlations

	Plant K	Soil K	Plant Ca	Soil Ca	Plant Fe	Soil Fe	Plant Zn	Soil Zn	Plant Mn	Soil Mn	Plant Cu	Soil Cu
Plant K	1.000	n.s	0.661**	n.s	0.600**	n.s	0.437**	n.s	0.250**	n.s	n.s	0.185**
Soil K		1.000	n.s	0.161**	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
Plant Ca			1.000	n.s	0.704**	0.274**	0.600**	n.s	0.410**	0.233**	n.s	0.232**
Soil Ca				1.000	-0.156*	n.s	-0.181**	n.s	-0.061**	n.s	n.s	0.247**
Plant Fe					1.000	0.275**	0.749**	n.s	0.422**	0.324**	n.s	0.155*
Soil Fe						1.000	n.s	0.731**	0.296**	0.859**	n.s	n.s
Plant Zn							1.000	n.s	0.368**	0.132*	n.s	n.s
Soil Zn								1.000	0.208**	0.723**	n.s	0.329**
Plant Mn									1.000	0.278**	n.s	0.185**
Soil Mn										1.000	n.s	0.362**
Plant Cu											1.000	n.s
Soil Cu												1.000

** Correlations significant at the 0.01level (2-tailed)
*Correlations significant at 0.05 level (2-tailed)

Significant positive linear relationships (P ≤ 0.05) for plants obtained using Pearson's 'r' are

those of plant K versus plant Ca (r =0.661), plant Fe(r =0.600), plant zinc (r =0.473) and plant manganese(r =. 0.250) as shown in figure 19 below.
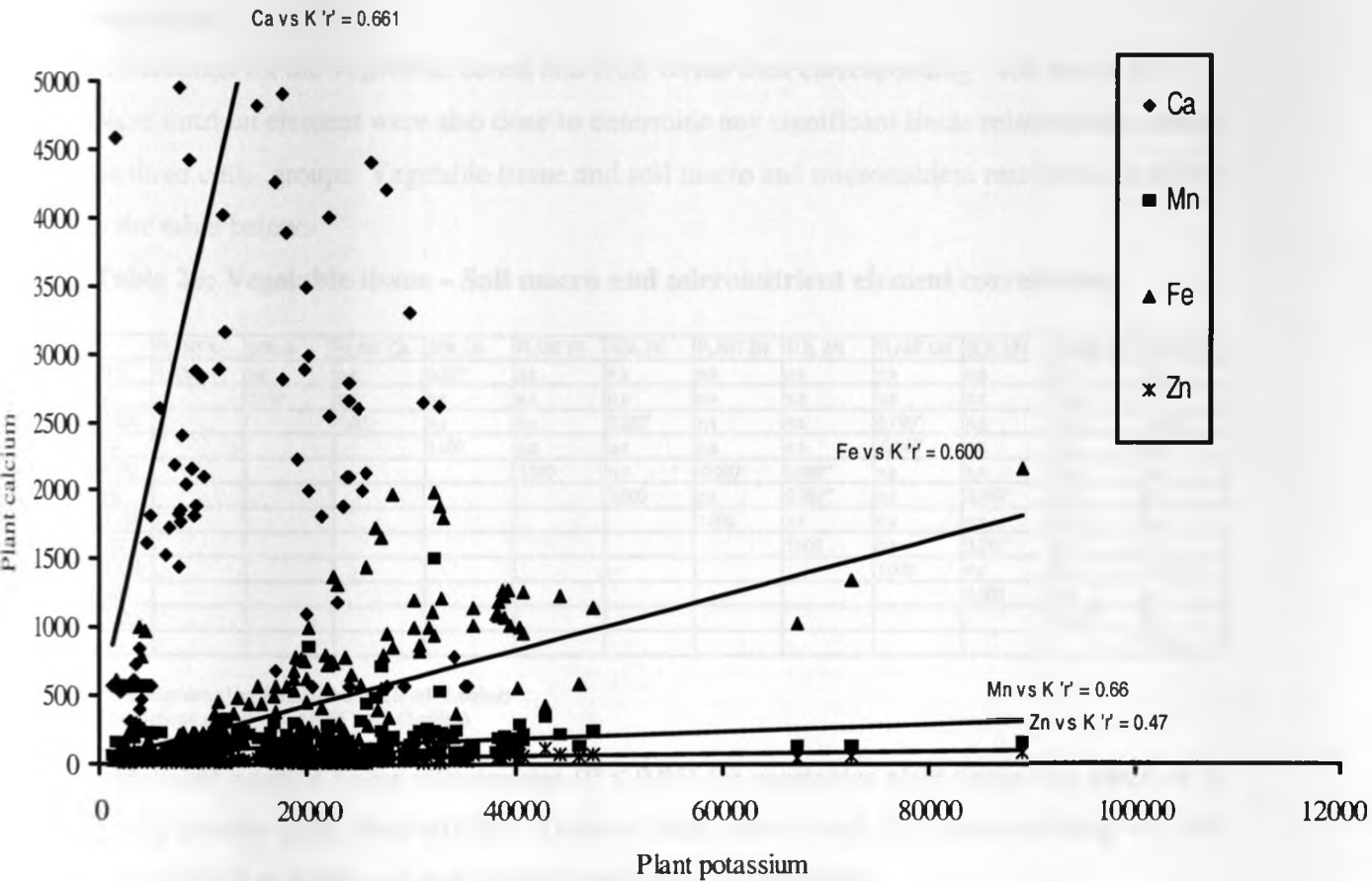
Fig. 19 Graph of overall plant macro and micronutrient element correlations

Plant Ca was correlated with plant Fe (r = 0.704), plant Zn (r = 0.600), plant Mn (r = 0.410) and plant Cu (r = 0.232). (Figure 19)

Plant Fe was also positively correlated with plant Zn (r = 0.749) and plant Mn (r = 0.422) with Plant Zn was only significantly positively correlated to plant Mn with (r = 0.368).

For the soils, Pearson's 'r' of 0.731 and 0.859 between soil Fe soil Zn and soil Mn showed that soil Fe had a significant positive linear relationship ($P \leq 0.05$) with Zn and Mn. Soil Cu was also positively correlated to Zn (r = 0.329) and Mn (r = 0.362) although somewhat

weakly.

Overall plant – soil relationships observed in this study were between plant Mn and soil Fe (r = 0.296), soil Mn (r = 0.278), soil Zn(r = 0.208) and soil Cu (r = 0.185). A Pearson's 'r'of 0.324 and 0.132 showed that soil Mn is correlated with plant Fe and plant Zn . Plant Fe was also correlated with soil Zn with Pearson's 'r' of, and 0.132 (Table 25)

Vegetable

Correlations for the vegetable, cereal and fruit versus their corresponding soil macro and micro nutrient element were also done to determine any significant linear relationships among the three culti- groups. Vegetable tissue and soil macro and micronutrient results are as shown in the table below.

Table 26: Vegetable tissue – Soil macro and micronutrient element correlations

	PLANT K	SOIL K	PLANT CA	SOIL CA	PLANT FE	SOIL FE	PLANT ZN	SOIL ZN	PLANT MN	SOIL MN	PLANT CU	SOIL CU
PLANT K	1.000	n.s	n.s	0.227*	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOIL K		1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
PLANT CA			1.000	n.s	n.s	0.232*	n.s	n.s	0.765**	n.s	n.s	-0.323*
SOIL CA				1.000	n.s	n.s	n.s	n.s	-0.244*	n.s	n.s	n.s
PLANT FE					1.000	n.s	-0.290*	0.689**	n.s	n.s	n.s	n.s
SOIL FE						1.000	n.s	0.689**	n.s	0.749**	n.s	n.s
PLANT ZN							1.000	n.s	n.s	n.s	n.s	n.s
SOIL ZN								1.000	n.s	0.741**	n.s	n.s
PLANT MN									1.000	n.s	n.s	-0.304*
SOIL MN										1.000	n.s	n.s
PLANT CU											1.000	n.s
SOIL CU												1.000

** Correlations significant at the 0.01level (2-tailed)
*Correlations significant at 0.05 level (2-tailed)

Significant positive linear relationships (P ≤ 0.05) for vegetables plant tissue was observed in plant Ca versus plant Mn(r = 0.765). Those of soils were for soil Mn versus soil Fe (r = 0.749) and soil Zn (r = 0.741) and that of soil Fe and soil Zn (r = 0.689).

Vegetable tissue macro and micronutrient element versus soil macro and soil micronutrient element correlations were only significant in plant Fe versus soil Zn (r = 0.689) and plant K versus soil Ca (r = 0.227).

In soils, significant linear relationships (P ≤ 0.05) were found between soil Fe versus soil Zn (r = 0.749) and Mn (r = 0.741)(Table 26)

Correlations for different specific vegetable species are shown in table 27, 28, 29 and 30

Table 27: Spider plant tissue – soil macro and micronutrient element correlations

Spider plant correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	n.s	n.s	n.s	n.s	n.s	-.627**	n.s	n.s	n.s	n.s	-.714**
SOILK		1.000	n.s	n.s	n.s	n.s	.480*	n.s	n.s	n.s	n.s	n.s
PLANTCA			1.000	n.s	n.s	n.s	.568*	n.s	n.s	n.s	n.s	n.s
SOILCA				1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
PLANTFE					1.000	n.s	n.s	n.s	.492*	n.s	n.s	.653**
SOILFE						1.000	n.s	.778**	n.s	.962**	n.s	.512*
PLANTZN							1.000	n.s	n.s	n.s	n.s	.482*
SOILZN								1.000	.557*	.777**	n.s	.677**
PLANTMN									1.000	n.s	n.s	.538*
SOILMN										1.000	n.s	n.s
PLANTCU											1.000	-.489*
SOILCU												1.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 28: Cowpea plant tissue – soil macro and micronutrient element correlations

Vegetable cowpea correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	n.s	n.s	n.s	n.s	n.s	-.627**	n.s	n.s	n.s	n.s	-.714**
SOILK		1.000	n.s	n.s	n.s	n.s	.480*	n.s	n.s	n.s	n.s	n.s
PLANTCA			1.000	n.s	n.s	n.s	.568*	n.s	n.s	n.s	n.s	n.s
SOILCA				1.000	n.s	n.s	n.s	n.s	-.488*	n.s	n.s	n.s
PLANTFE					1.000	n.s	n.s	n.s	.492*	n.s	n.s	.653**
SOILFE						1.000	n.s	.778**	n.s	.962**	n.s	.512*
PLANTZN							1.000	n.s	n.s	n.s	n.s	.482*
SOILZN								1.000	.557*	.777**	n.s	.677**
PLANTMN									1.000	n.s	n.s	.538*
SOILMN										1.000	n.s	n.s
PLANTCU											1.000	-.489*
SOILCU												1.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 29: African nightshade plant tissue – soil macro and micronutrient element correlations

African nightshade correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	n.s	n.s	n.s	n.s	n.s	-.627**	n.s	n.s	n.s	n.s	-.714**
SOILK		1.000	n.s	n.s	n.s	n.s	.480*	n.s	n.s	n.s	n.s	n.s
PLANTCA			1.000	n.s	n.s	n.s	.568*	n.s	n.s	n.s	n.s	n.s
SOILCA				1.000	n.s	n.s	n.s	n.s	-.488*	n.s	n.s	n.s
PLANTFE					1.000	n.s	n.s	n.s	.492*	n.s	n.s	.653**
SOILFE						1.000	n.s	.778**	n.s	.962**	n.s	.512*
PLANTZN							1.000	n.s	n.s	n.s	n.s	.482*
SOILZN								1.000	.567*	.777**	n.s	.677**
PLANTMN									1.000	n.s	n.s	.538*
SOILMN										1.000	n.s	n.s
PLANTCU											1.000	-.488*
SOILCU												1.000

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table 30: Jute mallow plant tissue – soil macro and micronutrient element correlations

Jute mallow correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	n.s	n.s	n.s	n.s	n.s	-.627**	n.s	n.s	n.s	n.s	-.714**
SOILK		1.000	n.s	n.s	n.s	n.s	.480*	n.s	n.s	n.s	n.s	n.s
PLANTCA			1.000	n.s	n.s	n.s	.568*	n.s	n.s	n.s	n.s	n.s
SOILCA				1.000	n.s	n.s	n.s	n.s	-.488*	n.s	n.s	n.s
PLANTFE					1.000	n.s	n.s	n.s	.492*	n.s	n.s	.653**
SOILFE						1.000	n.s	.778**	n.s	.962**	n.s	.512*
PLANTZN							1.000	n.s	n.s	.010	n.s	.482*
SOILZN								1.000	.567*	.777**	n.s	.677**
PLANTMN									1.000	.391	n.s	.538*
SOILMN										1.000	n.s	n.s
PLANTCU											1.000	-.480*
SOILCU												1.000

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Cereal

Similarly, just like in vegetable tissue, significant linear relationships ($P \leq 0.05$) for cereal grain were observed in plant Ca versus plant Mn (r = 0.765). Pearson's 'r' of 0.399 also showed that plant Mn was correlated to plant K.

Soil K was negatively correlated to plant and soil Zn(r = -0.261 and -0.228), soil Mn (r = 0.221) and plant Cu(r= 0.368). Soil Mn was also correlated to soil soil Fe (r = 0.749) and soil Zn (r = 0.741)(Table 31).

Table 31: Cereal grain – Soil macro and micronutrient element correlations

	PLANT K	SOIL K	PLANT CA	SOIL CA	PLANT FE	SOIL FE	PLANT ZN	SOIL ZN	PLANT MN	SOIL MN	PLANT CU	SOIL CU
PLANT K	1.000	n.s	n.s	0.227*	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOIL K		1.000	n.s	n.s	n.s	n.s	-0.261*	-0.226*	0.399**	-0.221*	-0.368**	n.s
PLANT CA			1.000	n.s	n.s	0.232*	-0.273*	n.s	0.785**	n.s	n.s	-0.323*
SOIL CA				1.000	n.s	n.s	n.s	n.s	-0.244*	n.s	n.s	0.258*
PLANT FE					1.000	n.s	0.499**	n.s	n.s	n.s	n.s	n.s
SOIL FE						1.000	-0.290*	0.689**	n.s	0.749**	n.s	n.s
PLANT ZN							1.000	n.s	n.s	n.s	n.s	n.s
SOIL ZN								1.000	n.s	0.741**	n.s	n.s
PLANT MN									1.000	n.s	n.s	-0.304*
SOIL MN										1.000	n.s	n.s
PLANT CU											1.000	n.s
SOIL CU												1.000

** Correlations significant at the 0.01 level (2-tailed)
* Correlations significant at 0.05 level (2-tailed)

Correlations for different specific cereal species are shown in table 32, 33, 34and 35

Table 32: Maize grain – Soil macro and micronutrient element correlations

Maize correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOILK	.126	1.000	n.s	n.s	-.415*	-.509**	n.s	-.484*	n.s	-.517**	-.402*	-.414*
PLANTCA			1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOILCA				1.000	.769**	n.s	-.582**	n.s	n.s	n.s	n.s	n.s
PLANTFE					1.000	n.s	n.s	n.s	n.s	n.s	n.s	.421*
SOILFE						1.000	n.s	.820**	n.s	.842**	.519**	n.s
PLANTZN							1.000	n.s	.397*	n.s	n.s	n.s
SOILZN								1.000	n.s	.782**	.600**	n.s
PLANTMN									1.000	n.s	n.s	n.s
SOILMN										1.000	.746**	.408*
PLANTCU											1.000	.481*
SOILCU												1.000

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 33: Finger millet grain – Soil macro and micronutrient element correlations

Finger millet correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	-.586*	.483*	n.s	n.s	n.s	n.s	n.s	-.516*	n.s	n.s	n.s
SOILK		1.000	n.s	n.s	n.s	n.s	n.s	n.s	.707**	n.s	n.s	n.s
PLANTCA			1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOILCA				1.000	n.s	n.s	n.s	.497*	-.517*	n.s	n.s	n.s
PLANTFE					1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOILFE						1.000	n.s	.695**	n.s	.680**	n.s	-.726**
PLANTZN							1.000	n.s	n.s	n.s	n.s	n.s
SOILZN								1.000	n.s	n.s	n.s	n.s
PLANTMN									1.000	n.s	.975**	-.495*
SOILMN										1.000	n.s	n.s
PLANTCU											1.000	-.633*
SOILCU												1.000

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 34: Sorghum grain – Soil macro and micronutrient element correlations

Sorghum correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s	-.987**	n.s	n.s	n.s
SOILK		1.000	-.467*	n.s	n.s	n.s	-.403*	n.s	n.s	n.s	.434*	-.546**
PLANTCA			1.000	n.s	.442*	n.s	.445*	n.s	n.s	n.s	n.s	n.s
SOILCA				1.000	n.s	n.s	n.s	.512**	n.s	.642**	n.s	n.s
PLANTFE					1.000	n.s	.571**	-.436*	n.s	n.s	n.s	n.s
SOILFE						1.000	n.s	.819**	n.s	.816**	-.440*	n.s
PLANTZN							1.000	-.454*	n.s	-.432*	n.s	n.s
SOILZN								1.000	n.s	.961**	n.s	n.s
PLANTMN									1.000	n.s	n.s	n.s
SOILMN										1.000	n.s	n.s
PLANTCU											1.000	n.s
SOILCU												1.000

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table 35: Pearl millet grain – Soil macro and micronutrient element correlations

Pearl millet correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	n.s	n.s	.885**	n.s	n.s	-.902**	n.s	n.s	n.s	n.s	.888*
SOILK		1.000	n.s	.901**	n.s	n.s	-.701*	-.949**	n.s	n.s	n.s	.735*
PLANTCA			1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOILCA				1.000	n.s	n.s	-.907**	-.815**	n.s	n.s	n.s	.703*
PLANTFE					1.000	n.s	n.s	n.s	n.s	.963**	n.s	n.s
SOILFE						1.000	n.s	n.s	n.s	n.s	n.s	n.s
PLANTZN							1.000	n.s	n.s	n.s	n.s	n.s
SOILZN								1.000	n.s	n.s	n.s	n.s
PLANTMN									1.000	n.s	n.s	n.s
SOILMN										1.000	n.s	n.s
PLANTCU											1.000	n.s
SOILCU												1.000

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table 36: Fruit tissue – soil macro and micronutrient element correlations

	PLANT K	SOIL K	PLANT CA	SOIL CA	PLANT FE	SOIL FE	PLANT ZN	SOIL ZN	PLANT MN	SOIL MN	PLANT CU	SOIL CU
PLANT K	1.000	n.s	n.s	0.227*	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOIL K		1.000	n.s	n.s	n.s	n.s	-0.261*	-0.228*	0.399**	-0.221*	-0.368**	n.s
PLANT CA			1.000	n.s	n.s	0.232*	-0.273*	n.s	0.765**	n.s	n.s	-0.323*
SOIL CA				1.000	n.s	n.s	n.s	n.s	-0.244*	n.s	n.s	0.0258*
PLANT FE					1.000	n.s	0.499**	n.s	n.s	n.s	n.s	n.s
SOIL FE						1.000	-0.290*	0.689**	n.s	0.749**	n.s	n.s
PLANT ZN							1.000	n.s	n.s	n.s	n.s	n.s
SOIL ZN								1.000	n.s	0.741**	n.s	n.s
PLANT MN									1.000	n.s	n.s	-0.304*
SOIL MN										1.000	n.s	n.s
PLANT CU											1.000	n.s
SOIL CU												1.000

** Correlations significant at the 0.01level (2-tailed)
*Correlations significant at 0.05 level (2-tailed)

Fruit tissue

The cereal and fruit tissue had similar trends in their correlations with the overall fruit tissue correlations showing no difference from the overall cereal grain –soil macro and micronutrient element correlations although different plant species had different correlations when analysed individually(Table 36)

Correlations for different specific fruit species are shown in table 37, 38, 39, 40 and 41

Table 37: Sycamore fig tissue – soil macro and micronutrient element correlations

Sycamore fig correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	.554*	n.s	.728**	n.s	.769**	.750**	.529*	n.s	.642**	n.s	.550*
SOILK		1.000	n.s	.956**	-.681*	.590*	n.s	n.s	n.s	.814**	.640*	.818**
PLANTCA			1.000	n.s	-.741**	.577*	n.s	.621*	-.536*	.663**	n.s	n.s
SOILCA				1.000	n.s	.679**	.625*	n.s	n.s	.819**	.659**	.813**
PLANTFE					1.000	-.658**	n.s	-.561*	n.s	-.780**	n.s	-.669*
SOILFE						1.000	n.s	.868**	n.s	.903**	n.s	.666**
PLANTZN							1.000	n.s	n.s	n.s	n.s	n.s
SOILZN								1.000	n.s	.700**	n.s	n.s
PLANTMN									1.000	n.s	n.s	n.s
SOILMN										1.000	n.s	.938**
PLANTCU											1.000	n.s
SOILCU												1.000

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

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Table 38: Kwa Zulu Natal rhus tissue – soil macro and micronutrient element correlations

Kwa Zulu Natal correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOILK		1.000	.560*	n.s	-.758**	.877**	n.s	n.s	n.s	.684**	n.s	n.s
PLANTCA			1.000	n.s	-.865**	n.s	n.s	n.s	n.s	n.s	-.722**	n.s
SOILCA				1.000	-.590*	n.s	n.s	.552*	n.s	n.s	n.s	n.s
PLANTFE					1.000	n.s	n.s	.546*	n.s	n.s	.740**	n.s
SOILFE						1.000	n.s	n.s	n.s	.762**	n.s	n.s
PLANTZN							1.000	n.s	n.s	n.s	n.s	n.s
SOILZN								1.000	n.s	.737**	n.s	n.s
PLANTMN									1.000	n.s	n.s	n.s
SOILMN										1.000	n.s	n.s
PLANTCU											1.000	n.s
SOILCU												1.000

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

Table 39: Grewia fruit tissue – soil macro and micronutrient element correlations

Grewia Correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	-.685**	.552*	n.s	n.s	n.s	n.s	n.s	.760**	n.s	.557*	n.s
SOILK		1.000	n.s	n.s	n.s	n.s	-.803*	n.s	n.s	n.s	n.s	n.s
PLANTCA			1.000	n.s	n.s	.724**	n.s	.725**	.824**	.782**	n.s	n.s
SOILCA				1.000	n.s	n.s	n.s	n.s	n.s	n.s	-.822*	n.s
PLANTFE					1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOILFE						1.000	n.s	.954**	.546*	.983**	n.s	.684**
PLANTZN							1.000	n.s	n.s	n.s	n.s	n.s
SOILZN								1.000	n.s	.971**	n.s	.747**
PLANTMN									1.000	.606*	n.s	n.s
SOILMN										1.000	n.s	.661**
PLANTCU											1.000	n.s
SOILCU												1.000

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Table 40: Jack fruit tissue – soil macro and micronutrient element correlations

Jack fruit correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	n.s	.703**	n.s	n.s	n.s	n.s	n.s	.520*	n.s	n.s	n.s
SOILK		1.000	.541*	.766**	n.s	n.s	n.s	.651**	n.s	n.s	.540*	.591*
PLANTCA			1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOILCA				1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
PLANTFE					1.000	.804**	n.s	n.s	-.523*	.697**	n.s	n.s
SOILFE						1.000	-.564*	n.s	n.s	.808**	n.s	n.s
PLANTZN							1.000	-.102	n.s	n.s	n.s	n.s
SOILZN								1.000	n.s	.635*	n.s	.705**
PLANTMN									1.000	n.s	n.s	n.s
SOILMN										1.000	n.s	n.s
PLANTCU											1.000	n.s
SOILCU												1.000

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Table 41: Baobab fruit tissue – soil macro and micronutrient element correlations

Baobab correlations

	PLANTK	SOILK	PLANTCA	SOILCA	PLANTFE	SOILFE	PLANTZN	SOILZN	PLANTMN	SOILMN	PLANTCU	SOILCU
PLANTK	1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOILK		1.000	n.s	n.s	.952**	n.s	n.s	n.s	n.s	n.s	n.s	n.s
PLANTCA			1.000	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SOILCA				1.000	.875*	.859**	n.s	.839**	n.s	.854**	n.s	.941**
PLANTFE					1.000	.700*	n.s	.685*	n.s	n.s	n.s	n.s
SOILFE						1.000	n.s	.965**	n.s	.985**	n.s	.825**
PLANTZN							1.000	n.s	n.s	n.s	n.s	n.s
SOILZN								1.000	n.s	.940**	.721*	.821**
PLANTMN									1.000	n.s	n.s	n.s
SOILMN										1.000	n.s	.849**
PLANTCU											1.000	n.s
SOILCU												1.000

**· Correlation is significant at the 0.01 level (2-tailed).

* · Correlation is significant at the 0.05 level (2-tailed).

CHAPTER FIVE

5.0   DISCUSSIONS

5.1   Mineral Nutrient Density ($\mu g/g$) variation on crop germplasm acquisitioned from farmers' fields

The ability of a plant to acquire, distribute, utilize and store micronutrient ions involves a number of specific transport processes at the membrane and organ level. At the same time, the quantity of minerals in the plants, including the amount deposited in cereal grains or other edible portions of crops is influenced by numerous, complex, dynamic and interacting factors. The variability that has been observed in a number of these processes has led to great variation in micronutrient density that is found within a plant (Grusak et al, 1999).

In this study, it was noted that farmer's populations were highly heterogeneous in micronutrient density. The heterogeneity was evident from the results of XRF determination on different plant species, which were obtained from various regions. The degree of variation was noted not only within similar species from the same region but also between different species from different regions. As earlier discussed in section 4.1.2 the significant variation in the various plant species were observed for the two limits of concentration ranges of XRF data into ranges such that there were two limits the highest range and the lowest range. This variation range is important in offering the breeder a source of genes for plant improvement. As earlier indicated in section 4.2, various germplasm that had the desired trait of high levels of micronutrient density were identified for selection.

Other workers have also reported variation in plant species when grown under similar conditions. Gupta (1992) working on micronutrient element on different crop species found out that crop species had different micronutrient density for grain samples even when grown under similar conditions. Shackette (1980) conducted a biogeochemical survey of mineral content of eight kinds of fruits and nine kinds of vegetables from different areas of commercial production in the United States; from which amounts of some of the elements in the plants varied from region to region.

5.1.1 Mineral nutrient density variation on cereal germplasm acquisitioned from farmers' fields in relation to hidden hunger alleviation

Thirteen species of useful African crop plants that were investigated fell in three culti-groups: the indigenous vegetables, cereals and fruits. After elemental determination on the seed of the cereal culti-group, it was found that elemental seed concentration in finger millet, sorghum, maize and pearl millet apart from sample MR 73 were low when compared to concentrations in the fruits and the vegetables samples.

Sample MR 45, maize germplasm accession from the Lake region had the highest micronutrient concentration when compared to maize germplasm from other sampled sites. This could possibly be due to population distinctiveness since maize materials did not necessarily come from the same source and /or the type of soil in relation to their ecology. Although sample MR 45 was considered as having the highest MAE within the maize populations, its elemental concentrations were still far much lower than the concentrations reported for most fruits and vegetables samples.

The low elemental concentration of cereals samples is of concern because they are largely considered major agronomic staple crops. The implication of thus is that communities that largely depend on them for food will be deficient in the nutrient elements that are important in fighting the ill effects related to hidden hunger. Cereals would therefore seem to contribute to micronutrient malnutrition rather than solving it unless their nutrient levels are enhanced through breeding processes for higher concentrations (Bio-fortification) or are eaten together with vegetables, which are rich in micronutrients and in amounts that would ensure that one gets the recommended dietary allowance. Shrikumar 1992, working on cereals samples in southern India explains that although wheat had higher concentration of zinc and iron than rice, zinc intake by people from that region was inadequate as a consequence of relatively small amounts of wheat in their diet.

5.1.2 Mineral nutrient density variation on leafy vegetable and fruit germplasm acquisitioned from farmers' fields in relation to hidden hunger alleviation

Leafy materials obtained from the vegetables and fleshy materials of the fruits samples appeared to accumulate high concentrations of nutrients in their tissues than those found in cereal seed. In this study, it was evident that traditional food plants particularly the indigenous vegetables had relatively high in micronutrient- element contents. Other literature quotes them as also being very high in β-carotene, and ascorbic acid.

The high micronutrient content in vegetables and fruits could be due to high phloem off-load into the fleshy tissues in part influenced by the evapo-traspiration stream (Kochian, 1991,Stephan et al, 1996,Scholz et al, 1987). Element flow, (Efflux) into seed tissues, by a process called phloem unloading is generated by influx (phloem loading) and the efflux of major solutes (sugars, amino acids and K ions) into phloem sink. Micronutrients – relatively phloem immobile – are often found in high concentrations within older leaves of plants with high transpiration rates, compared to new immature leaves suggesting that the flow (mobilization) from leaves to seed is phloem dependent (Grusak, et. al, 1995, 1999). The nature of micronutrient storage pool of a given species or genotype and the capacity for phloem loading in effect could explain the high leaf contents over those in seed. It is thus likely the leafy vegetables must be having high transpiration rates associated with active phloem loading.

Western Kenya, including the Lake region produced vegetables samples with comparatively higher micronutrient and macro element levels than the eastern Kenya possibly due to: Intense on farm pressure and /or consistent adaptability as the vegetable cultivars are more continuously cropped in that part of Kenya where *ugali* is the major preparation accompanied by indigenous vegetables more than anywhere else in Kenya. Consistent adaptability and continuous cropping of the vegetable species may have led through natural selection to possible agronomic micronutrient efficiency scenarios by way of how genotypes may take up minerals depending on the soil micronutrient status and genetic make up of the plant. The possible agronomic micronutrient efficiency scenario would be such that some vegetable genotypes would be able to take up micronutrients efficiently in soils, which are either high or

low in micronutrients

While others will be inefficient under similar circumstances. The uptake efficient genotypes may have evolved efficient uptake and storage mechanisms that enable them to take up minerals efficiently.

Type of soils in relation to their ecology. Soil micronutrient status, soil pH, soil moisture, soil type and soil micro organisms will greatly influence the ability of a plant to take up minerals and concentrate them in their tissues.

5.2   Variation in major and micronutrient-elements in indigenous plant species in relation to hidden hunger alleviation.

Potassium and calcium

Potassium and calcium are elements that are most abundant in the lithosphere. These elements are referred to as major because plants require them in relatively large amounts. Animals also require them in relatively larger amounts than the micronutrients for their dietary intake. Potassium and calcium content of most soils vary greatly with potassium showing significantly higher levels in plants than calcium. Potassium content of healthy leaf tissue is expected to be in the range of 1-4% in most plants. This is in agreement with what was found in this study. Potassium levels varied from 1% in cereals to 4.2% in vegetables.

Calcium on the other hand was however very low in cereals but significantly higher in vegetables. Calcium levels ranged from 600 μg/g in cereals to 1.4% in vegetables. Fish and other animal products are said to be the best sources of calcium. In areas where these products are unavailable, in view of vegetables having high macronutrients, vegetables become the next alternatives in providing these nutrients.

Zinc and Iron

Zinc content of plants varies considerably reflecting different factors of the ecosystems and of the genotypes (Fig. 15) (Graham and Welch 1996; Graham et. al, 1992; Ascher, 1987). However, zinc content of certain foodstuffs, cereal grains and pasture herbage from different countries do not differ widely. Zinc content ranged from 1.2-73μg/g in apple and lettuce leaves respectively while zinc content varied from 10-104μg/g in baobab and spider plant

species respectively in this study.

Compared to iron, zinc concentrations were lower both in plants and in soils. According to Akundabweni 2004(unpublished), zinc was somewhat present on Andosol, Nitisol and Luvisol and hardly present in Cambisol. He also indicated that zinc is known to be deficient in soils from Eastern, Southern and Central Africa. Zinc is of major nutritional importance. The RDA recommended for various groups of people range from 5mg for infants and 15mg for adults. The values for zinc obtained in germplasm analysed from this study ranged from $10\mu g/g$ in fruits where they were the lowest and $116\mu g/g$ in vegetables. Although still low, zinc levels in cereals was comparable to those found in fruits and that they did not differ significantly as compared to those found in vegetables.

The low levels of zinc however are of nutritional significance because as mentioned earlier in the section of literature review, animal products are known to be the best sources of zinc. However, animal products are expensive and hence outside the reach of most rural poor. Many communities in Kenya depend on the species sampled for food and this may imply that the levels of zinc intake would be insufficient unless breeding towards zinc dense cultivars is undertaken and soil management measures in relation to zinc levels are put in place. Zinc levels can be managed through micro fertilization. Soils type and fertilization will influence grain concentration (Rengel, et. al, 1999) added zinc increased grain yield in wheat (Graham, et. al, 1992). This would have to apply to any other nutrients that are found to be low in the plants and are of nutritional importance.

Copper

In all the elements that were analysed for this study, copper had the least variation in both the soils and the plants for any one given area and samples species. The vegetable species had relatively higher concentrations of copper compared to the other species. The copper levels even in vegetables did not exceed $14\mu g/g$. Shacklette and others in 1978 reported that copper in ash of a variety of plant species ranged from $5-1500\mu g/g$. He found that in several species sampled under widely ranging environments, copper contents of whole plant shoots did not often exceed $20\mu g/g$. This value is most often considered the threshold of excessive contents (Kabata and Pendias, 1984).

The relative immobility of copper in soils, its great ability to chemically interact with mineral

and organic components of the soil, and its ability to precipitate with various anions such as sulphide hydroxide may explain the little variation found in copper concentrations in plants and soils. Other workers have also reported findings similar to these. Nambiar and Montiramani, (1983), noted that while five 'desi' and five 'Kabuli' *Cicer arientium* cultivars differed in zinc and iron concentration in grain (50% difference between the lowest and the highest concentrations) no difference in copper concentrations was noted.

Manganese

Unlike copper, manganese showed a particularly wide variation among plant species sampled from different regions in this study other than in cereals. Despite manganese being essential in plant nutrition, manganese compounds are very important as soil constituents because this element control behaviour of several other micronutrients and has considerable effects on some soil properties (Kabata and Pendias, 1984). Loneagran (1975) stated that manganese levels were found to range from an average of 30-500μg/g in *Medicago trunculata* and *Lupinatus albus* respectively. Plant foodstuffs are also reported to contain variable amounts of manganese highest being in beetroots (36-113μg/g) and the lowest in tree fruits (1.3-1.5μg/g).

Manganese varied from 52μg/g in maize to 350μg/g in cowpea vegetable.

Fruit samples were low in both macro and micronutrient elements (section 4.4.5). They could however be important sources of vitamins. For instance, Baobab is known to have exceptionally high levels of vitamin C (Levine, et al, 1999).

Selenium and Iodine

Selenium is of physiological importance as it may perform the same role as iodine. Its levels however, were very low beyond detection limit. Absence of iodine detection in this respect is of concern. For one, iodine may have not been detected because of ineffective XRF instrumentation and the limitation of the technique used for analysis. Two, it may be totally absent in all the species sampled for analysis. If the latter were the case, then the nutritional implications would be serious. This would mean that the affected population would have to rely on other iodine sources such as iodised table salt for intake. Salt in Kenya is iodised at the rate of 100mg of potassium iodate per one kilogram of salt (Venkalesh and John, 1995). Iodised salt when not protected from certain conditions, in particular heat, moisture, or direct sunlight, will lose iodine but if packaged in polyethylene bags, it may retain iodine for up to a year. However, if removed from the original container and left outdoors exposed to moisture, salt losses iodine rapidly sometimes in as little time as half an hour (UNICEF, 1995).

Iodine ions are oxidized by sunlight into elemental iodine in the atmosphere and returned to the soil by rain. In this way the cycle is completed. However, the return of iodine to the soil is slow and small in amount compared to the original loss of iodine. Normally, natural correction of iodine content of the soil does not always take place. Crops grown in iodine-deficient soil are therefore also iodine deficient.

Nanyaro et al, 1984, noted that no data were known to exist for iodine concentrations in Tanzanian ground waters and that goiter has been reported in the Engari Nanyuki area; east of Mount Meru where he attributed to goiter prevalence in the area to drinking water, soils and crops that are deficient in iodine. Low iodine concentrations in groundwater are most likely to occur in the interior of the country, away from influences of maritime (iodine-enriched) rainfall.

Crops grown inland, away from the ocean, are usually low in iodine, whereas crops grown near the ocean may be adequate in iodine. For example, it is estimated that 20-50 mg of iodine per acre fall annually in rain along the Atlantic coastal plain, but only 0.7 mg iodine per acre falls in rain in the Great Lakes region of the U.S. The Midwest and Great Lakes region are among the areas where iodine deficiency is most common. Supplemental iodine provided by iodized salt is recommended for use in most countries because of the uncertainty of origin of foods (Salt Institute, 2001). The low levels or lack of iodine in plants can also be attributed to continuous cropping where the soils are depleted of iodine and the exhausted crop soils can no longer supply it to the plants (Keith Addison, 1983).

5.3 Soil as a basis for plant concentration

Based on results of XRF analysis, variations of micronutrients in plants and especially for iron in western Kenya seem to suggest that there is some possible relationship in low soil pH and micronutrients solubility. This relationship may be attributed to the genotype x environment interaction component where soils influences the levels found in plants depending on the efficiency of the plant species/ genotype to take up those minerals. Therefore, more uptake under the moist ecology of west Kenya where soils have low pH than the more alkaline pH of the Eastern Kenya. Soil pH strongly influences solubility of certain elements in the soil and the rate at which they are absorbed by plants. Iron, zinc, and manganese are less soluble in alkaline than acidic soils because they precipitate as hydroxides at high pH (Salisbury and

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Ross, 1991). Leaching in high rainfall areas such as the western Kenya may remove these ions from the upper soil layers, leaving a more acid soil. By contrast, the weathering of rock in arid regions releases K^+, Mg^{2+}, Ca^{2+}, and Mn^{2+} to the soil, but because of the low rainfall, these ions do not leach from the upper soil layers, and the soil remains alkaline as is in the case of Eastern Kenya. The soil pH is therefore an important factor in plant nutrient uptake. The high pH in Nitisols should be part of a process likely to help increase Fe solubility besides assisting in the reduction of Fe+++ to Fe++ state. Since iron is more soluble at low pH, many plants are able to chelate and solubilize iron. Johnston 1997 indicated that where iron is more soluble, plants might take up very large amounts of iron. This seems to be the case in the Lake region where high iron contents were found in the soil and consequently, high concentrations in plants. In this study, it was found out that coincidentally, the areas for highest iron were also highest for zinc and manganese (section 4.5.1.2). Grusak, et. al, 1999, noted that the same processes that influences solubility of iron could also increase the solubility of other micronutrient ions. Changing soil pH will also affect other minerals (Mitchell, 1957)

In light of the relationship that exists between the soil and the plant, breeding environments could be strategized such that areas with high micronutrient elements in soils are better testing grounds than areas with low micronutrient elements. Subsequently, uptake efficient genotypes would be better testing subjects than uptake inefficient genotypes.

The high nutrient content in west Kenya and in particular the Lake region (section 4.5.1) suggests that the Lake basin area could be an important site for micronutrient density characterization in plants in light of their relatively better levels. This statement however presupposes that solubility and availability conditions for micronutrient elements uptake are ambient. The site (edaphic) differences imply that:

i.   Any micronutrient screening needs to be multi locational so that micronutrient stability can be factored into the selection procedures.

ii.   Ecological appropriateness can maximize genotypic response in micronutrients.

iii. Appropriate micronutrient density breeding environments can be strategized for example, the Lake Basin area being a better testing ground than eastern.

iv.   Eco-geographic biodiversity is likely to be underpinned by the edaphic factors.

v.   There are possibilities for development of precision vegetable farming as a function of known edaphic differentiation.

5.4   EDXRF as a characterization and pre-breeding tool

EDXRF is recommended for large collections of germplasm since it is fast, and non-destructive in approach. It saved costs, yielded practical results useful in for developing a pre-breeding tool. The ease of sample preparation and the fact that the same sample could be used to determine many elements made EDXRF a useful tool for multielement survey for both major and minor elements. The procedure made it possible to determine micro, macro and total health elements in both plant and soil samples.

5.5   Plant – Soil macro and micronutrient element correlations

From the plant soil correlations (sec. 4 part IV) it is evident that plant macro and micronutrient correlations are likely to be independent of the soil macro and micronutrient correlations although the plant nutrient correlations significantly differed with plant – soil systems.

Soil calcium was found to be negatively correlated with most elements in the soil and in particular soil manganese in most plant species. Calcium is known to be a major antagonistic element and has been found to be antagonistic against Al, Cu, Zn and Mn among others. Antagonistic reactions have also been found observed for Fe, Mn, Cu and Zn, which are some of the key elements in plant physiology (Kabata and Pendias, 1984).

Soil Fe was positively correlated with soil Zn and soil Mn in most plant species. Fe, Zn and Mn solubility in the soil are pH dependent. At low pH iron is more soluble and plants are able to take up more Fe (Johnston, 1997) and since soil Zn and Mn are also pH dependant and positively correlated to soil Fe, it means then an increase in Fe solubility will also mean an increase in Zn and Mn solubility and hence an increased uptake of those micronutrient elements. The practical implication therefore is that when plant selection is done on a soil high in Fe then saliently high Zn and Mn will be selected for. However interactions observed within plants between trace elements have also indicated that these processes are quite complex, being at times both antagonistic and synergistic in nature and occasionally are involved in the metabolism of more than two elements. They are also found to differ depending on the specific reaction of the plant genotype or species (Kabata and Pendias, 1984).

CHAPTER SIX

6.0   CONCLUSIONS AND RECOMMENDATIONS

6.1   Conclusions

X –fluorescence spectroscopy locally available at the Institute of Nuclear Science at the University of Nairobi has the capacity for characterizing micronutrient density in germplasm. It proved to be an essential tool in determining variation in both major and minor elements in soils and plant species. In light of the above, EDXRF would therefore provide a novel tool for characterization; screening, evaluation and breeding. It could also be an important tool for developing a basis for agro-biodiversity management.

According to the study, based on XRF values and literature review, Farmers' populations appear to posses' adequate variation in both macro and micronutrient-trace elements for exploitation toward the prospects for germplasm enhancement, line development by use of convectional and biotechnology procedures and line evaluation.

The seed of some of the genotypes that contain high micro and/or macro elements could be multiplied and used by the farmers directly.

There is an indication that the leafy tissues of the vegetables contain relatively higher amounts of nutrients than seed material of cereals and fleshy parts of the fruits. The indigenous type may be even more superior in terms of nutrition than the fruits and cereals. High nutritional value of traditional vegetables has been reported by other workers: Sreeramulu (1983), Watson (1975), Oomen and Grubben (1976). Other literature quotes them as also being high in β carotene and vitamin C. Indigenous vegetables may therefore have potential to alleviate malnutrition in view of the fact that they are relatively high in nutritional value compared to cereals.

During the study, it was also noted that wild fruits were not high in micronutrient elements but could possibly be important sources for vitamins rather than minerals.

The low levels of seed micronutrient densities in the cereals than those of the leaf fraction in the leafy vegetables are attributed to the filters through which the minerals proceed namely,

i.   The soil status in relation to root micronutrient acquisition.

ii. Transport in the plant.

iii. The whole plant portioning.

iv. The proportion of the source material that is deposited and stored in the seed as result of the filtering points.

6.2 Recommendations

Based on the findings it is recommended that:

Any breeding efforts towards high micronutrient density in plants, should take into account the genotype x environment interaction component where there is need to separate the genotype from the edaphic connection in order to target the genetic potential for improving the farmer-preferred populations.

In light of the interaction component a standardization procedure should be formulated in order to offer more information with regard to the specific genotypic macro and micronutrient element contribution to hidden hunger.

a) The soil plant interaction suggests the need to consider soil macro and micronutrient element management in farming with the plant indigenous resources.

b) The XRF results suggest the need to investigate the genetic background in order to get a genetic basis on which to base plant selection for genetic improvement.

Future research would therefore require also looking into:

a. Role of biotechnology in accelerating genetic advance.

b. Nutrient bioavailability studies involving the consuming subjects.

APPENDICES

APPENDIX1: Bungoma rainfall and temperature data during the experimental period year 2002

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
R/fall in mm	61	73	141	240	237	134	108	131	125	165	128	78
Temp °C Max	26.8	27.8	27.6	26.2	24.9	24.8	23.5	22.8	25.2	25.6	25.0	25.6
Min	12.9	13.4	13.7	14.6	13.8	12.7	13.1	13.3	12.1	13.5	13.7	13.3
Mean	19.9	20.6	20.7	20.4	19.4	18.8	18.3	18.1	18.7	19.6	19.4	19.5

Source: Bungoma agricultural department.

APPENDIX 2: Lake Region rainfall and temperature data during the experimental period year 2002

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
R/fall in mm	56	99	148	236	174	73	64	88	87	88	143	98
Temp °C Max	30.2	30.1	29.7	28.3	27.7	27.5	27.3	27.9	28.9	29.9	29.7	29.4
Min	17.5	17.7	18.1	18.1	17.6	16.9	16.6	16.5	16.7	17.4	17.6	17.4
Mean	23.9	23.9	23.2	22.8	22.2	22.0	22.2	22.8	23.7	23.7	23.4	23.1

Source: Kisumu Veterinary Station.

APPENDIX 3: Eastern rainfall and temperature data during the experimental period year 2002

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
R/fall in mm	37	30	93	123	25	5	1	2	4	22	161	140
Temp °C Max	26.0	26.8	26.2	25.1	24.4	23.1	22	22.8	25.5	26.4	24.3	24.4
Min	14.0	14.2	15.8	15.6	14.8	12.5	12.0	11.8	12.4	41.0	15.8	41.4
Mean	20.0	20.5	21.0	20.3	19.6	17.8	17.0	17.3	18.9	20.2	20.0	19.4

Source: Kibwezi DWA plants Ltd

APPENDIX 4 (a): Analysis of variance table for major nutrient element content in various plant species from various regions

		Elements		
		K	Ca	M.A.E
Source	d.f.	Mean square	Mean square	Mean square
Rep	2	9899000n.s	3057000n.s	9660000n.s
Spp	12	2349000000**	674000000**	5135000000**
Site	8	407400000**	37470000**	441900000**
Spp.Site	55	267900000**	39520000**	385300000**
Residual	150	1.22E+07	7.55E+06	2.80E+07
Total	227	2.12E+08	5.15E+07	3.99E+08
cv%		18.5	40.6	20.6
se		3493	2748	5288

APPENDIX 4 (b): Analysis of variance table for trace nutrient element content in various species from various regions

		Elements					
		Fe	Zn	Cu	Mn	M.I.E	M.I.E+M.A.E
Source	d.f.	Mean square	Mean square	Mean square	Mean square	Mean square	Mean square
Rep	2	22828n.s	29.87n.s	2.531n.s	1941n.s	25576n.s	13460000n.s
Spp	12	2797290**	9711.86**	38.61**	156416**	3999812**	814400000**
Site	8	130472**	314.03**	14.776*	34122**	265039**	6481000000**
Spp.Site	55	205707**	558.07**	17.706**	33698**	301187**	402300000**
Residual	150	10459	70.68	5.255	2911	17536	2.81E+07
Total	227	209426	706.65	10.347	19577	305572	4.82E+08
cv%		25.9	20.7	27	42	23	20.4
se		102	8	2	53	132	5356

* * Significant at 0.01 level.
* Significant at 0.05 level.
n.s. Not significant

APPENDIX 5: Table of means of nutrient composition of various plants from sampled regions in µg/g.

Species	Elements								
	Ca	K	M.A.E	Fe	Zn	Cu	Mn	M.I.E	MIE+MAE
Vegetables									
Cowpea	14780	24100	38880	463	49	9.8	346.7	1026.4	34982
Jute mallow	11287	24172	35460	336	45	9.8	72.6	792.7	36252
Spider plant	14883	32100	46983	338	104	8.1	184.1	1603.3	48586
African nightshade	16428	42177	58606	428	62	8.6	164.0	1180.6	59787
Fruits									
Grewia	6347	13466	19813	53	30	7.8	128.8	348.2	20161
Kwa Zulu Natal rhus	6282	14172	20454	177	32	7.5	200.2	659.2	21113
Sycamore fig	6829	27113	33942	20	37	10.3	79.9	226.1	34168
Jack fruit	2027	24093	26120	43	12	10.7	66.5	178.7	26299
Baobab	2629	20566	23196	12	10	7.7	52	134.0	3172
Cereals									
Maize	570	5041	5612	30	29	6.3	52.0	153.5	7669
Finger millet	2031	7854	9886	64	24	6.7	127.9	258.0	10144
Sorghum	581	6171	6753	78	31	7.8	49.9	232.9	5353
Pearl millet	601	14555	15157	396	42	6.4	52	533.1	11068
cv%	40.6	18.5	20.6	25.9	20.7	27	42	23	20.4
se	2748	3493	5288	102	8	2	53	132	5356

APPENDIX 6(a): Analysis of variance table for major nutrient element content in soils from various regions.

		Elements		
		K	Ca	M.A.E
Source	d.f.	Mean squares	Mean squares	Mean squares
Rep	2	387100n.s	323892n.s	1400000n.s
Spp	12	80810000**	9351074**	61540000**
Site	8	576200000**	27927215**	678000000**
Spp. Site	55	61260000**	5725533**	76730000**
Residual	150	7.47E+06	700507	8.81E+06
Total	227	4.44E+07	3331536	5.16E+07
cv%		25.9	26.3	21.64
s e		2733	837	2968

APPENDIX 6(b): Analysis of variance table for trace nutrient element content in soils from various regions.

		Elements					
		Fe	Zn	Cu	Mn	M.I.E	M.I.E+M.A.E
Source	d.f.	Mean squares	Mean squares	Mean squares	Mean squares	Mean squares	Mean squares
Rep	2	1609000n.s	181.84n.s	9.35n.s	18369n.s	1690000n.s	1440000n.s
Spp	12	911100000**	2033.11**	80.486**	5860479**	1034000000**	1292000000**
Site	8	6921000000**	19804.22**	169.272**	59491285**	8245000000**	8458000000**
Spp. Site	55	417400000**	1698.5**	52.11**	5004028**	487600000**	64270000**
Residual	150	7.88E+06	68.18	8.101	42606	8151000**	1.88E+07
Total	227	3.98E+08	1263.61	28.281	3647159	4.69E+08	5.35E+08
cv%		9.399	14.85	30.5	17.55	9.17	9.66
se		2807	8.25	2.84	206.4	2855	4332

** Significant at 0.01 level.

* Significant at 0.05 level.
n.s. Not significant

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