UPTAKE OF MICRONUTRIENTS BY *ACACIA SENEGAL* VARIETIES AND ITS POSSIBLE EFFECT ON GUM ARABIC QUALITY

BY

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DECLARATION

1. I declare that this thesis is of my own composition and apart from acknowledged assistance, is a record of my own research. The material has never been presented before to the University of Nairobi or any other establishment for academic award.

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DEDICATION

This thesis is dedicated to my children, Grace Rirenet, David Kipkemoi Bartilol, Michael Kiprotich and my wife Magdaline W. Lelon for their support during the entire period.

My late father and mother, Lelon Cheptum Chepkener and Kabilo Lelon Cheptum Sei for their sacrifice to educate me. Without them I could not have come this far.

ABSTRACT

A study was conducted to establish the uptake of micronutrients by two *Acacia senegal* varieties established under arid and semi-arid conditions, and its subsequent effect on the quality of gum arabic exudates. Soil and gum arabic samples from the experimental sites at Solit, Kapkun, Kimorok and Maoi in Marigat division, Baringo district, were collected, dried and analysed to establish their baseline physical and chemical characteristics. Glasshouse pot experiments were conducted using the same soil and vermiculite media to determine uptake of copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) by *Acacia senegal* seedlings. A randomized, split-plot design that simulated the environmental conditions in the field was used in treatments varying from normal, low and high concentrations of the micronutrients applied.

The soil types varied significantly ($P < 0.05$) in the level of calcium (17.3, 5.7, 6.4 and 5.0 cmol. $(^{+})$/kg) and magnesium (6.1, 3.3, 4.0 and 2.7 cmol. $(^{+})$/kg), respectively, at the study sites. The average copper uptake (103 ppm) by *Acacia senegal* variety *senegal* in Solit on dry matter (DM) basis was significantly higher ($P < 0.05$) than that at Maoi (41 ppm), Kimorok (33 ppm) and Kapkun (30 ppm). Gum arabic from *Acacia senegal* variety *senegal* in Kapkun and Solit had concentrations of 45 and 40 ppm Cu, which reveal that *Acacia senegal* variety *senegal* tends to take higher Cu levels (108 and 156 ppm) from the soils than that of *Acacia senegal* variety *kerensis* at Kimorok and Maoi (38 and 32 ppm). Iron and manganese uptake by the variety (654 and 638 ppm) at Kapkun was significantly higher ($P < 0.05$) than that of the variety at Kimorok (366 ppm Fe and 307 Mn), respectively.

Zinc uptake by *Acacia senegal* variety *kerensis* at Kimorok (533 ppm) was significantly higher ($P < 0.05$) than in Maoi (233 ppm), Kapkun (224 ppm) and Solit (141 ppm). The gum arabic had ash content of 2.88%. Analysis showed that the ash content had a concentration of Zn (124 ppm) which indicated that *Acacia senegal* variety *kerensis* tend to take higher concentrations of Zn (533 ppm) from the soils than that of *Acacia senegal* variety *senegal* (141 ppm).

Moisture, ash and volatile matter contents in gum arabic from *Acacia senegal* variety *senegal* were 14.9%, 3.16% and 64.24%, while *Acacia senegal* variety *kerensis* had 15.2%, 2.88% and 63.8%, respectively. Gum arabic obtained from *Acacia senegal* variety *senegal* had higher levels of copper (45 ppm), iron (1415 ppm) and manganese (109 ppm) compared to variety *kerensis* which by contrast had higher levels of zinc (124 ppm) and nitrogen (0.34 %), respectively. All these levels however fell within the ranges quoted in the International Standard Specifications (0.26% - 0.39% N, iron (730 – 2490 ppm), manganese (69 – 117 ppm), zinc (45 – 111 ppm), ash 2 - 4% and moisture 13 - 15%, respectively). The quality parameters of gum arabic may partly depend on soil characteristics, climate, and availability of the nutrients in the soils.

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CONTENTS

List of Tables

List of Figures

List of Plates

List of Abbreviations

ADI	Acceptable daily intake
ANOVA	Analysis of variance
ASALs	Arid and Semi arid lands
cmol ($^{+}$)/kg	Centimoles of ions per kilogram
Dgl	Diameter at ground level
FAO	Food and Agricultural Organization
GOK	Government of Kenya
Ht	Heights
IPAL	Integrated Project in Arid Lands
JECFA	Joint Expert Committee on Food Additives (FAO/WHO)
KARI	Kenya Agricultural Research Institute
KEFRI	Kenya Forestry Research Institute
KK	Kimorok
KN	Kapkun

LSM	Least Significant Means
MI	Maoi
MTD	Maximum tolerated dose
mS/cm	millisiemens per centimetre
NARL	National Agricultural Research Laboratories
NAS	National Academy of Sciences (U S A)
PPM	Parts per million
S.E.	Standard error
SOM	Soil organic matter
ST	Solit
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.0 Introduction and Background

Kenya's total land surface area is approximately 590,000 square kilometres. About 80% of this area is arid and semi-arid lands (ASALs), which support 20% of human population with over 50% livestock population and significant proportion of wildlife (KEFRI, 1992; GOK, 1993). The remaining 20% of the land surface sustains 80% of Kenya's population and is being extensively exploited for agricultural production and plantation forestry. This reflects an imbalance since the area cannot sustain such a high population and its requirements of fuelwood, shelter and food production (Republic of Kenya, 1989a, b). In addition, the high population growth rate in the high and medium potential areas has exceeded the carrying capacity resulting into migration of people to the fragile ASAL ecosystem in search of settlement and farming (Lusigi, 1984).

The ASALs are characterised by low and erratic rainfall (150 - 750 mm annually), high potential evaporation rates (1900- 2500 mm/day), high mean annual temperatures (28^0C) and poor soils (Sombroek *et al.*, 1982). The soils are variable, shallow, rocky and low in organic matter, moisture content and water holding capacities which reduce infiltration rates thereby increasing water run-off and soil erosion (Sombroek *et al.*, 1982).

Pastoral and nomadic communities inhabit the ASALs and their livelihood greatly depends on livestock and small-scale agriculture. These communities are often subjected to various shocks and disruptions of drought, famine, lack of fodder, physical insecurity fuelled by ethnic conflict through livestock rustling, banditry, wildlife conflict, and pests and diseases,

resulting in great loss of livestock (Barrow, 1996). The high current movement of people from high and medium potential areas to the fragile ASAL areas in search of settlement has led to widespread over-exploitation of plant resources (Herlocker, 1999). The adverse effects of deforestation include loss of soil structure, decrease in soil fertility that leads to reduced crop yields, soil erosion and low livestock production (Sanchez, 1976; Brady and Weil, 1999). As a result, the ASAL communities remain vulnerable to scarcity of resources and their future survival is uncertain (Barrow, 1996; Herlocker, 1999).

ASAL ecosystem is endowed with natural vegetation mainly of Acacia woodlands, thorny trees, shrubs and bushy grasslands that are being over exploited for fuel wood, charcoal, medicines and building poles, food and fodder. This has led to loss of biodiversity resources, serious land degradation and negative impact on gum producing trees. Among the most exploited tree species, is the *Acacia senegal,* a multipurpose agro forestry tree belonging to (subfamily *Mimosoideae*, family *Leguminosae*), whose product is the gum arabic exudate, an article of commerce internationally (Green Way *et al.,* 1961).

In Kenya, *Acacia senegal* and other closely related species (*A. tortilis, A. elatior, A. nilotica, A. mellifera* and *A. seyal* var. *fistula, Commiphora* and *Boswellia* species) are found in abundance in the dry land areas of northern districts of Rift Valley and Eastern provinces (Chikamai and Gachathi, 1994). *Acacia senegal* is an important multipurpose tree for gum arabic production in the Sudan gum gardens (Bekele-Tesemma *et al.,* 1993). The tree prefers to grow at altitudes of 100 - 1700 metres above sea level (A.S.L) in coarse texture soils, sandy loams, slightly loamy sands and clay loam soils with annual rainfall mainly between 300- 400 mm. *Acacia senegal* is a drought resistant tree which can tolerate high daily temperatures over 45^0C and plays key role in rehabilitation of degraded areas, restores soil stabilization and

nutrient holding capacity and improves the turnover of soil organic matter pools (Bekele-Tesemma *et al.,* 1993). Gum arabic yielding trees are potential species suitable for afforestation of ASAL areas in combating the process of desertification, land degradation and restoring soil fertility.

Gum arabic exudate is a pale orange brown coloured natural product obtained from the stems of *Acacia senegal* var. *senegal* and *A. seyal* var. *fistula* and other closely related Acacia species. Gum arabic is used as a binder, emulsifier, stabilizer and protective agent in food, pharmaceutical and technical industries (FAO, 1995). Gum arabic is also edible and in addition, the tree is an important fodder species as the pods and leaves are palatable to livestock especially goats (Kokwaro, 1976).

The Joint Expert Committee on Food Additives (FAO/WHO) international revised specifications states that the quality parameters of gum arabic must conform to the characteristics of the Sudan gum from Kordofan gum belt region. The specifications of quality of gum arabic must be obtained from the branches and stems of *Acacia senegal* var. *senegal*, with moisture content of 13 to 15 % at 105^0C, total ash of less than 4% after ashing at 550^0C, specific rotation of -26^0 to -34^0, and nitrogen content of 0.26 to 0.39 %. The average cationic composition of total ash is usually 52 ppm Cu, 730 ppm Fe, 69 ppm Mn and 45 ppm Zn (FAO, 1990).

Gum arabic is produced in the dry land districts of northern Kenya, namely; Isiolo, Samburu, Marsabit, Wajir, Mandera and Turkana. In some areas pure stands of *Acacia Senegal* and other closely related Acacia species form extensive vegetations covering several square kilometers (Chikamai and Gachathi, 1994). Production of gum arabic has increased gradually with time from a few tonnes in 1990 to 400 tonnes in 1994 (Chikamai, 1997). Gum arabic is

gathered at random by uncoordinated group of pastoralists from regenerated natural stands of *Acacia senegal* and closely related species, over wider areas in different locations at different seasons. The harvested gums are mixed and sold to middle businessmen, usually operating other kinds of trades at local trading centres. These merchants export the gums without standard quality control to world market.

Kenya has emerged as a new supplier of gum arabic in the world market, but the country does not meet the competitiveness and adequate supply of the commodity to the world market (FAO, 1995). The Kenyan gum is of low quality when compared with the Sudan gum in the world market according to JECFA specifications (FAO, 1990). The quality of Kenyan gum has not been investigated adequately to allow its improvement. High quality gum will help to improve production of better-priced gums locally and internationally. It is anticipated that the quality of gum arabic from regenerated natural stands of *Acacia senegal* in a particular locality may be influenced by differences from one variety to the other, variation in soil types and compositions, specific habitats, climate, altitude and social factors. It can be speculated that micronutrient uptake may be limiting in some varieties of *Acacia senegal* and the seasonal factors influence the quality of gums. It is imperative therefore to postulate that if quality of gum is improved the ASAL communities would benefit from higher prices and this could be another source of income to supplement dependence on livestock production.

Gum arabic resources if efficiently, effectively and sustainably exploited in the ASAL areas may become the best alternative source of livelihoods for millions of ASAL people for a long time to come. These resources may be the benchmark of rural industrial revolution for the future of ASAL people. This can assist the ASAL communities in diversifying unsustainable farming practices to sustainable income generating activities where climatic conditions are

not favourable for rainfed agriculture. It is hoped that the findings and recommendations of this project may be used to encourage farmers in the ASAL areas to plant, maintain, protect, sustain and manage *Acacia senegal* varieties and other closely related species in their farming systems for high quality gum arabic production.

1.1 Rationale

Efforts to establish tree planting in the ASAL environments are often difficult due to variations in climatic and edaphic factors. The major challenge is that the pastoral and nomadic communities find no immediate reward in tree planting in arid and semi-arid lands. To reduce and reverse the trends of the alarming rate of deforestation and associated problems of environmental degradation, afforestation programmes are being initiated to promote tree planting of more indigenous species to increase stand density of the vegetation cover. Appropriate technologies for raising mass production of *Acacia senegal* seedlings deserve a priority in dry land afforestation programmes (Darkoh, 1991).

For successful afforestation programmes in the ASAL, research areas should include studies on soil and plant nutrition, inter-relationship between and among the macronutrients (e.g. nitrogen (N), phosphorus (P), potassium (K) and organic carbon (C), as well as micronutrients (e.g. copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) uptake by tree species. This would supplement the work that has been done on effect of irrigation on soil nutrient status in a forestry plantation at Bura Irrigation Scheme (Mwendwa *et al.*, 1993).

Macronutrients are needed in large quantities while micronutrients are taken in small (trace) quantities by plants. The functions of macro and micronutrients vary but they are very important to plant growth as they facilitate the catalytic enzyme reactions or stimulants in regulating the various physico-chemical processes in plant metabolism. Each element performs definite

functions within the plant and no single element can be completely substituted for another. Ideally, all elements are needed in their normal concentrations (i.e., "balanced nutrients level") to play their role in plant growth. Any other quantity may result in deficiency and/or toxicity of that particular element by manifesting visible symptoms such as growth retardation, foliage colour and other irregular plant metabolic functions.

Mineral nutrition of indigenous trees in these fragile ecosystems, especially trace metals such as Cu, Fe, and Mn etc. uptake has not been studied. Presently, there is limited knowledge on the mineral nutrient levels in the soils of ASAL and their uptake by the *Acacia* species. It is postulated that in certain tree species, trace metals may enhance moisture retention, by limiting the rate of trans evaporation in trees growing in the ASAL areas. These are important parameters that need evaluation, since trees require supplies of certain chemical elements from the soils in the form of ions for growth and development (Evans, 1992).

1.2 Problem Statement

Gum arabic is collected from natural stands of *Acacia senegal* and other closely related species by pastoralists involved in herding activities during the dry seasons in northern Kenya. Gums are faced with several constraints such as inadequate seeds for tree propagation technologies for raising mass production of tree nursery seedlings, potting media, quantity, quality, agronomic studies, management, demand, lack of standard harvesting methods and processing, poor prices and marketing. Studies on site characterization of factors such as site-to-site variations, soil types, humidity, temperature, altitude, physiological state of Acacia gum trees and seasonal difference in relation to gum arabic quality and quantity per tree from a specific variety need to be investigated. These factors influence quality of gum arabic. This study therefore attempts to establish the effect of micronutrients uptake by *Acacia senegal*

varieties on gum arabic quality, levels of trace elements uptake by *Acacia senegal* var. *senegal* and *A. senegal* var. *kerensis* seedlings in glass house pot experiment, and factors that may influence the quality of gum arabic production under the ASAL conditions of Marigat division, Baringo district.

1.3 Objectives

The overall objective of this project was to establish the effect of micronutrients uptake by *Acacia senegal* varieties on gum arabic quality under arid and semi - arid conditions.

The specific objectives of this study were to:

1. Determine soil characteristics and fertility in the study area.
2. Quantify uptake of copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) by *Acacia senegal* varieties using; pot experiments in glasshouse simulating the arid and semi-arid conditions.
3. Evaluate the physiochemical properties of gum arabic between and within sites.
4. Elucidate effect of *Acacia senegal* varieties on the quality of gums produced in the study area.

1.4 Organisation of the Work presented

The description and discussion of the project undertaken in this thesis is preceded by review of literature in Chapter Two on the general overview of the physical and chemical properties of soils, and the functions of mineral nutrients in plants. In addition, the description, distribution and uses of gum arabic exudates and *Acacia senegal* trees are discussed. Harvesting and marketing of gum arabic and status of production in Kenya is reviewed. Chapter Three deals with materials and the experimental methods used throughout the study; including the detailed description of study area, selection and description of sites, soil sampling and pretreatment, and the methods of soil analysis used. Studies on micronutrient uptake by *Acacia senegal* varieties under glasshouse conditions are preceded by the experimental design used, preparations and applications of nutrient solutions to the potted plants. Data collection, plant sampling and tissue analysis, gum arabic harvesting and analysis and statistical methods of data analysis are also given. Chapter Four describes the results of soil characteristics and fertility status, while Chapter Five reports on studies on micronutrient uptake under the simulated arid and semi-arid conditions. Chapter Six discusses the effect of *Acacia senegal* variety differences in quality of gum arabic, followed by an Integrating Discussion in Chapter Seven, which uses the results of all previous Chapters to address the objectives of the project. The way forward for the establishment of the quality control of Kenyan gum and recommendations for further research are also given.

CHAPTER TWO

LITERATURE REVIEW

2.1 Physical properties of Soil

The physical properties of soils are texture, bulk density, particle density, porosity; percolation rate and moisture content which have close inter-relationship with the chemical properties (Lal and Greenland, 1979).

Soil Texture

Soil texture estimates the percentage sand, silt and clay contents of the soil and is often based on the proportions of different particle sizes bound into aggregates that require dispersion of the soil into individual particles as sand (2.00-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002 mm) fractions (Page, 1982). Soil texture determines soil workability, water-holding capacity, soil structure and nutrient retention. Clay soils have micro pores that hold more water and retain nutrients than sandy soils and are easily prone to erosion that may lead to loss of soil productivity. Sandy soils have macro pores that retain less water and nutrients and may have low soil organic matter (Landon, 1991).

Bulk Density

Bulk density is used to identify the problems of root penetration, soil aeration in different soil horizons and soil texture of uncultivated and cultivated soils (Landon, 1991). Bulk density values vary considerably with moisture content, and determined by porosity of the given soil. Bulk densities of soils influence soil organic matter levels, and determine the supply of nutrients for growth of plants. They also play important role in storage of water

for root uptake (Lal and Greenland, 1979). For instance, soils with high organic matter have lower bulk densities than soils low in organic matter.

Particle Density

Particle density is used together with the bulk density and water content to calculate the airspace and percentage of water saturation. Particle density is the ratio of the total mass of a given soil to its volume and varies between narrow limits of 2.60 and 2.75 g/cm^3 per 100 cm^3 (Blake, 1965).

Porosity

Total porosity is the ratio of pore empty space within a soil to the bulk volume (V_b) the soil sample (Lal and Greenland, 1979). Porosity influences aeration, water movement and root penetration in soils. Compacted soils reduce total pore space; hence increases bulk density which may hinder moisture availability to crops.

Percolation

Percolation is the downward movement of water that will drain freely from the soil in response to the force of gravity (Brown, 1987). When all the available pore spaces in the upper part of the soil are filled with water the soil is saturated and the rate of percolation is slow (Lal and Greenland, 1979). The amount of water percolating through the soil profile is determined by the amount of water supplied and the total moisture conductivity of the lower horizon together with the amount of water retained by the profile at its field capacity (Landon, 1991).

Moisture content

Moisture content is the maximum water content that the soil will retain following free drainage after saturation (Brown, 1987). It influences nutrient uptake by plants and the recycling of available nutrients either upwards from the plant roots to the upper leaves or downwards from the leaves to the root system. Moisture content is influenced by many factors such as soil texture, bulk density, porosity and organic matter (Anderson and Ingram, 1993).

2.1.2 Chemical properties of soils

The chemical properties of soils include soil pH, electrical conductivity, organic carbon, nitrogen, phosphorus, exchangeable cations (Ca, K, Mg and Na) and micronutrients (B, Cu, Fe, Mn, Mo and Zn). The properties are useful for determining the soil fertility status, maintenance of soil productivity in terms of physical, chemical and biological functions, and estimating and evaluating the amount of nutrient amendments needed for optimum plant growth, Anderson and Ingram (1993).

Soil pH

Soil pH is a measure of the acidity (pH< 7.05) or alkalinity (pH> 7.05) status of soil solutions. Most plants grow best in the soil pH range 5.5-7.05. The availability of many essential nutrients needed for plant growth is often dependent on the pH of the soil solution, which is closely identical to that of the roots of plants growing in that soil (Parker and Walker, 1986).

Electrical conductivity

Electrical conductivity is the measure of salinity or the level of soluble salts in a soil solution (McBride *et al.,* 1990). The total salt content of a soil can therefore be estimated from this measurement since it reflects the extent to which the soil is suitable for plant growth (Lund *et al.,* 1999). Muhammed (1996) and Brady and Weil (1999) reported that conductivity increases with the salt content but varies with the nature of the ions in soils.

Organic Carbon

Soil organic carbon is a measure of the organic matter content in a soil (Jones, 1991). The organic matter determines the soil fertility status following the decomposition process which leads to release of nutrients to the soil. Soil organic matter functions to promote aeration and soil moisture regimes (Nelson and Sommers, 1996).

Nitrogen

The organic-N fraction is a measure of the soil reserve of N or its capacity to release N required by plants through the process of mineralization (McGill and Figueiredo, 1993). Plants use forms of nitrogen as NH_4^+, NO_3^- and NO^-_2 ions through nitrification process. Thus, methods of N analysis for most soils must take into account the various fractions if present. The Kjeldahl procedure gives a good estimate of total soil N content.

Phosphorus

Phosphorus (P) is a major nutrient in soils that occurs in both inorganic and organic forms and is mainly taken by plants in form of orthophosphate anions (Bolland, 1992). Inorganic phosphorus exists as the phosphates of metals held by positive charges of clay soil particles in soil solutions (Day and Parker, 1985). Enzymes must first mineralise organic phosphorus

before being taken by plants. Since P compounds in soils are highly variable and are related to soil type or parent material, many extraction techniques for available phosphorus are used worldwide for evaluating soil fertility (Brown *et al.,* 1977). Using the method of Olsen *et al.* (1954), the soil is extracted with 0.5 M solution of sodium bicarbonate at pH 8.5 prior to measurement. This procedure is generally accepted as a suitable index of P "availability" a wide range of soil types, especially those with pH above 7.05. In the original procedure carbon black was added to the extraction reagent to eliminate the color (because of soil organic matter) in the extract. The use of carbon black has since been eliminated in subsequent modification by Murphy and Riley, (1962), Watanabe and Olsen, (1965), and Olsen and Sommers, (1982) where, a single solution reagent containing ammonium molybdate, ascorbic acid and a small amount of antimony is used for color development (Stevenson, 1998).

Exchangeable cations in Soils

Exchangeable cations are nutrients ions released from the soil by solutions of neutral salts (Bohn *et al.,* 1985). Inorganic and organic colloids (clay particles and soil organic matter, respectively) are negatively charged and consequently can attract and bind cations such as potassium (K^+), sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) (Bohn *et al.,* 1985). The availability of exchangeable cations in the soils depends on soil texture and organic matter and leaching effects. Thus, nutrients can be held in the soil and not lost through leaching, and can subsequently be released for plant uptake (Bremner and Mulvaney, 1982).

Micronutrients in Soils

Micronutrients play important metabolic roles in plants, particularly in enzyme systems associated with the synthesis. Solubility of micronutrient cations decreases with an increase

in soil pH and lead to nutritional deficiencies (Mascagni and Cox, 1985). The distribution of micronutrients is used for characterization of soil types and soil fertility. Soil test values serve to predict deficient conditions of soils and to indicate how much is required to improve a given situation.

2.1.3 Functions of Mineral Elements in Plants

2.1.3.1 Macronutrients

(a) Nitrogen

Nitrogen is the most abundant element in plants and plays an essential role as a constituent of proteins, nucleic acids, chlorophyll, vitamins, growth hormones, and ligands for metal complexation in heterocyclic ring of metalloprotein complexes and uptake of other nutrients (Reuter and Robinson 1997). The synthesis of various amino acids and amides needed to make proteins depends on the availability of nitrogen and carbon compounds in the leaves. Nitrogen requirement for optimal growth in plants is in the range between 2 and 5% of the plant dry weight (Stevenson, 1986). Plants suffering from nitrogen deficiency exhibit symptoms such as retarded growth, yellow or pale green leaves with small cells and thick walls, inhibition of root elongation and delay of flowering (Spiers, 1978).

(b) Phosphorus

Phosphorus as phosphate is a constituent of nucleic acids, nucleoproteins and phospholipids, including those of cytoplasmic membranes (Miller and Donahue, 1992). Phosphorus is responsible for strongly acidic nature of nucleic acids (DNA), the carrier of genetic information and ribonucleic acids (RNA), which carries genetic messages from DNA to transport specific amino acids to the ribosomes where they joint together to make proteins

(Marschner, 1986). It takes an active part in the synthesis of organic matter and formation of various plant tissues and in the transfer mechanism of genetic characteristics in plants (Munson and Nelson, 1990). Phosphate and other nutrient ions are essential for cell division and for the development of meristem tissue (Wild, 1988). Phosphorus requirement for optimal growth in plants is in the range of 0.3 to 0.5 % of dry weight during the vegetative stages of growth (McKeague, 1978). Plants suffering from phosphorus deficiency show retarded growth, stunted root system, and dying of leaves (Martin and Matocha, 1973). Other metabolic processes include; dull greyish - green leaf colour, red pigmentation as a result of accumulation of anthocyanins during respiration and photosynthesis (Terry and Ulrich, 1973). Phosphorus toxicity in plants has not been reported (Marschner, 1986).

(c) Potassium

Potassium is required in large amounts by plants (Marschner, 1986). It is the most abundant cellular cation and is involved in transport of acidic metabolites, neutralization of anionic groups of macromolecules, activation of many enzymes and the control of cellular osmotic potential (Kresge and Younts, 1962). Potassium also plays a specific role in the mechanism of opening and closing of stomata; it accumulates, with malate, in the guard cells when stomata are open and is released when they are closed, thereby contributing to the osmotic potential on which the turgor of the guard cells depends (Wild, 1988). Potassium is also involved in the transport of photosynthetic products from the leaves and as a result it can have an indirect effect on photosynthesis (Spiers, 1983).

Potassium can be substituted to some degree by sodium in its physiological roles, particularly in the maintenance of cell turgor (Tandon, 1991 and 1993). Nicholaides (1985) reported the symptoms of potassium deficiency are often seen when there is premature death of the older

leaves, because of its withdrawal to the young leaves. When nitrogen and potassium are simultaneously in short supply, the plants are stunted; their leaves are small and rather grey in colour and die prematurely, first at the tips and then along the outer edges. Fruits and seeds of K- deficient plants are usually small in quantity and size (Tisdale *et al.,* 1985).

(d) Calcium

Calcium is essential for the growth of meristems, and root tips (Loneragan and Snowball, 1969). It plays a key role in the maintenance of cell membranes, protecting root tips against leakiness due to ion imbalance, low pH and presence of toxic ions such as aluminium (Brown, 1987). A few enzymes, including amylase and some nucleases require calcium (Wild, 1988). It is the main cation associated with the middle lamella of cell walls. In seeds, it is present as the salt of phytic acid (Brown *et al.,* 1977). Calcium deficiency causes the growth of the root system to be stunted, and leaf margins to curl backwards (Loneragan *et al.,* 1968). Degeneration at the apex of the young fruit (blossom end rot) is a common symptom of deficiency in tomatoes.

(e) Magnesium

Magnesium is required in large amounts by plants (Wild, 1988). It plays a major role as a central metal ligand in chlorophyll (magnesium porphyrin) in which one atom of magnesium is bound to four pyrrole rings (Brown, 1987). As a cofactor of most of the enzymes that act on phosphorylated substrates, it is of great importance in the transfer of energy (Martens and Lindsay, 1990). It also activates certain other enzymes, including carboxylases and some dehydrogenases (Tekalign *et al.,* 1991). Because of its role as a cofactor of enzymes that act on phosphorylated substrates, the distribution of magnesium in plants is often similar to that of phosphorus (Hewitt, 1983). The symptoms of magnesium deficiency vary among plant

species, but the first symptom is always interveinal yellowing, or chlorosis, because of diminished levels of chlorophyll (Westerman, 1990). This is accompanied by a decreased rate of photosynthesis. Biosynthetic pathways are disrupted as a result of inhibition of phosphorylation processes and soluble nitrogenous compounds accumulate with concomitant decreases in the proportion of proteins (Stevenson, 1986). In acidic and sandy soils, high levels of potassium or ammonium ions in the root medium similarly inhibit the uptake of magnesium.

(f) Sulphur

Sulphur is absorbed from the soil solution as sulphate ions (Stevenson, 1986), and can also be assimilated from the sulphur dioxide present in the atmosphere (Allaway, 1992). A large proportion of sulphate is reduced to sulphide, which is then incorporated in the amino acids such as cysteine, cystine and methionine (Verma, 1977). Normally these amino acids are present in the free state in very small quantities as they are rapidly converted to proteins (Stevenson, 1986). The sulphide is also present in some coenzymes, including biotin, thiamine and coenzyme A, which are essential for metabolism when attached to appropriate apoenzymes (Wild, 1988). The ferrodoxins, which are non-haem proteins involved in photosynthesis and other electron transfer process, contain sulphide and iron in equivalent amounts (Anderson and Evans, 1956). When the supply of sulphur is ample, the rate of uptake may exceed the rates of reduction and assimilation into proteins and other organic compounds and this leads to accumulation of sulphates in the plant tissues (Stevenson, 1986). Sulphur is essential for the synthesis of the sulphur-containing amino acids and proteins including enzymes (Williams and Steinbergs, 1959). Sulphur deficiency disrupts many biochemical reactions in plants leading to increased levels of amines, amides and since these substrates are not utilized for the synthesis of proteins. The level of carbohydrates is also reduced as a result

of diminished photosynthesis (Johnson and Fixen, 1990). Sulphur- deficient plants are stunted and weak with thin stems while the leaves remain small and distorted. A deficiency of either sulphur or nitrogen causes chlorosis, or yellowing, of the leaves as a result of diminished levels of chlorophyll (Wild, 1988).

(g) Sodium

Plants to a varying degree depending on the species absorb sodium (Spiers, 1983). It is not known to be essential except for some salt tolerant *Atripelex* species. Sodium can, however, sometimes have beneficial effects on plant growth (Landon, 1991). It can particularly replace potassium in osmotic roles and the maintenance of cell turgor and this effect is large when the supply of potassium is inadequate (Wild, 1988).

2.1.3.2 Micronutrients (Trace elements)

(a) Copper

Copper occurs in two oxidation states Cu^{+} and Cu^{2+} ions. The available species in soils is the Cu^{2+} (Wild, 1988; Reuter and Robinson 1997). Copper is an essential trace element absorbed by plant roots and translocated to the shoots predominantly in ionic form (Marschner, 1986). Copper is a constituent of a prosthetic group of oxidases in which molecular oxygen is used directly in the oxidation of substrate. These include cytochrome oxidase, phenol oxidase, laccase, ascorbic acid oxidase and amine oxidase (Marschner, 1986; Martens and Lindsay, 1990).

The catalytic activity of these enzymes depends on the ability of their copper to undergo reversible change from Cu^{+} to Cu^{2+} (Whitney, 1988). This is an oxidation-reduction process. In addition to the oxidases which cataylse the reduction of molecular oxygen, plants have

superoxide dismutase, an enzyme containing copper and zinc, which reacts with superoxide ions (O^{-}_{2}) to produce molecular oxygen and hydrogen peroxide (Stevenson, 1986). As the superoxide ion is toxic and readily produced from molecular oxygen, superoxide dismutase plays an important, protective role in plant growth and development. Copper also plays a role in photosynthesis as an essential constituent of plastocyanin. This protein is located in the chloroplasts and forms part of oxidative phosphorylation process that mediates the electron transport chain between the two photochemical systems of photosynthesis (Stevenson, 1986).

In cytochrome oxidase, copper acts as the terminal recipient of electrons from mitochondrial electron transport chain prior to transfer to oxygen (Reuter and Robinson 1997). The activity of the cytochrome oxidase is attributed to reversible change in oxidation state in photosynthesis (Wahle and Davies, 1977). Copper also plays a role in the catalytic activity of oxidation reactions of plant phenols in two distinct enzymes: phenolase and laccase. Phenolase catalyzes oxidation of monophenols to diphenols such as dihydroxyphenyl-alanine (Dopa) and also involved in the synthesis of lignin and alkaloids which protect wounded tissues from fungal attack. Laccase is found in thylakoid membrane of chloroplast and is required for the synthesis of plastoquinone, a constituent of the photosynthetic electron transport chain (Martens and Lindsay, 1990).

In ascorbic acid oxidase, copper catalyses the oxidation of ascorbic acid to L- dehydroascorbic acid. The enzyme occurs in the cell wall and cytoplasm (Reuter and Robinson 1997). In amine oxidase, copper catalyses oxidative deamination of polyamines which occur abundantly in legumes during the seedling stage (Walker and Webb, 1981). The normal concentrations of copper in soils and plants which are considered as adequate, range between 10 to 18 mg kg^{-1} and 7 to 30 mg kg^{-1} Cu, respectively (Mitchell, 1964).

The concentration depends on the type of soil and plant species and may fall outside these ranges. When the Cu concentration in plants is less than 3 ppm in the dry matter, deficiency symptoms are likely to occur (Jones, 1972). These symptoms often depend on plant species or variety, and the stage of growth (Graham *et al.,* 1981). Reuter *et al.* (1981) reported that copper deficiency was responsible for delay in flowering and formation of fruits of *Chrysanthemums*, possibly because of induced phenolase activity and consequent interference in auxin oxidase system. Copper deficiency has no effect on chloroplasts of spinach or maize but affects the chloroplasts of oats even when the white tip symptom is evident (De Kock *et al.,* 1979). In general, many plant species display chlorosis, necrosis, leaf distortion and terminal dieback in young shoot tissues (Lindsay and Norvell, 1978).

Copper toxicity is reported to be rare in field grown plants, except in areas where high copper containing pesticides have been applied. When Cu levels exceed 20 ppm in mature leaves, toxicities may occur (Reuter and Robinson 1997). The common symptoms of copper toxicity in many plants are: reduced shoot vigour, poorly developed and discoloured root systems, and leaf chlorosis. They develop in a manner regarded as characteristic for phloem immobile nutrients (Loneragan, 1968); affecting those meristems which are active when external copper supply is high.

(b) Iron

The functions of iron in plants include chlorophyll formation and activation of some enzymes (Whitney, 1988). Iron is taken by plant roots as Fe^{3+} and plant roots first reduce it to Fe^{2+}, which is then translocated to the shoots where it is again oxidized back to Fe^{3+} (Tiffin, 1970; Tisdale, 1985). Some of the iron can be stored in the leaves as phyto-ferritin, which is essential for developing plastids during the process of photosynthesis (Hewitt, 1983).

The active iron occurs in numerous enzyme systems either as a structural component of prosthetic groups or as a constituent of the protein itself (Wallace, 1980). The best-known prosthetic groups are the iron porphyrins which, when attached to specific proteins, are known as haem proteins (Rains, 1976). These include peroxidase, catalase and some dehydrogenase enzymes, as well as cytochromes that function as electron carriers during photosynthesis and respiration. The reduction of nitrate to ammonia requires iron, since the enzyme nitrite reductase itself comprises a haem protein, called sirohaem and a non-haem component containing iron and sulphur (Anderson and Evans, 1956). Leghaemoglobin, another haemprotein, is required for the fixation of dinitrogen in legume root nodules. Through reversible oxygenation, it regulates the supply of oxygen to nitrogenase that is highly sensitive. The most important non-haem protein is ferredoxin that has a very high negative redox potential and acts as an electron carrier in photophosphorylation, in the photosynthetic reduction of nicotinamide adenine dinucleotide phosphate (NADP), and in the reduction of nitrite. In legume root nodules and other biological nitrogen fixing systems, either ferredin or flavodoxin acts as an electron carrier to nitrogenase, which comprises a non-haem protein with molybdenum as an essential constituent and an iron-sulphur protein (Rains, 1976).

The normal concentrations of iron in soils and plants which are considered as adequate range between 1 and 10% and 25 to 500 mg kg^{-1} Fe, respectively, (Mitchell, 1964). Fe is an immobile element in plants and the Fe content in plants can vary considerably with a critical level of 20 ppm in grasses and corn (Jones *et al.*, 1991). Fe deficiency is likely to occur when the concentration in leaves is 50 ppm or less and very difficult to correct in some crops (Ponnamperuma *et al.*, 1981). Foliar applications of Fe have been found to be effective in correcting Fe deficiencies in plants such as turf grasses (Mitchell, 1964).

(c) Manganese

Manganese is absorbed in its biologically active form of Mn^{2+} by an energy-linked process that is negatively influenced by the presence of Mg^{2+} and Ca^{2+} (Peverill *et al.*, 1999). Manganese, like magnesium, can act as a cofactor of many enzymes that act on phosphorylated substrates (Mascagni and Cox, 1985). Some of the enzymes in the Kreb's cycle, notably decarboxylases and dehydrogenases, are also activated by manganese, although it can be substituted by magnesium.

Manganese is present in the chloroplasts in a complex that oxidizes water to produce molecular oxygen, hydrogen ions and electrons (photolysis) in photosynthesis. The role of manganese in the photosynthetic evolution of oxygen is reflected in gross changes in structure of the chloroplasts in manganese deficient plants. Manganese also plays a role in regulating the levels of auxin in plant tissues through activation of the auxin oxidase system. Manganese deficiency in plants varies considerably depending on soil types and plant species (Miller and Donahue, 1992).

Manganese differs from other micronutrients in that both deficiency and toxicity are widespread in agricultural practice. Manganese deficiency normally occurs when the leaf tissue concentration is less than 15 ppm. Plants which are sensitive to Mn deficiency are equally sensitive to excessive Mn. Growth of soybeans, which are particularly sensitive to Mn deficiency, is reduced when leaf Mn levels approach 200 ppm (Ohki, 1976).

Morgan *et al.* (1966) found that Mn toxicity is associated with the destruction of indole acetic acid (IAA). Meudt (1971) reported that Mn enhances the sulphate-induced chain reaction during the enzyme auto-oxidation of IAA. Manganese ions are believed to mediate in electron

transfer between sulphite ions and IAA free radicals. Symptoms of manganese toxicity are likely to occur in acid soils (as a result of the reduction of manganese oxides). Induced iron deficiency is another well known symptom (called "Crinkly leaf") induced by manganese toxicity in dicotyledons such as cotton and beans (Foy *et al.,* 1981). Excessive uptake of manganese in acid soils of East Africa has been established to be a principal problem (Chamberlain and Seale, 1963).

(d) Zinc

Zinc is absorbed by plants as Zn^{2+} and translocated to the shoots primarily as the free ion. Zinc is known to be an essential constituent of a number of plant enzymes such as carbonic anhydrase, alcohol dehydrogenase, auxin oxidase, superoxide dismutase, DNA and RNA polymerases, peptidases, proteinases and cytochromes (Stevenson, 1986). All these enzymes play varied, but significant roles (Whitney, 1988). The function of carbonic anhydrase is to catalyze the hydration of CO_2 in plants during photosynthesis. The catalytic action of the enzyme is both in the cytoplasm and the chloroplasts. Reuter and Robinson (1997) reported that alcohol dehydrogenase catalyses the reduction of acetaldehyde to ethanol in meristematic zones of roots in higher plants. Superoxide dismutase (a zinc-copper containing enzyme) acts in the reaction mechanisms involving the detoxification of molecular oxygen during the reduction of superoxide ion in the chloroplasts (Marschner, 1986). Zinc is required for the synthesis of tryptophan, a precursor for the synthesis of I.A.A. in plants.

Zinc deficiency produces leaf malformation, and is often characterised by irregular mottling, with yellow ivory interveinal areas. Extreme resetting of terminal and lateral shoots in woody species and multiple branching are also a common feature. Mitchell (1964)

reported that the normal concentrations of zinc in soils and plants considered as adequate are in the range of 10 to 300 and 21 to 70 mg kg^{-1} zinc, respectively.

Stunting is a frequent symptom associated with Zn deficiency (Boyle and Smith, 1985). Low levels of zinc that result in deficiencies have been reported in coffee, sisal leaves and tea in various parts of East Africa and in soils of some parts of Kenya (Chamberlain, 1961). The critical Zn value for apple is about 14 ppm with the first symptom of the deficiency being small fruit size. Zinc deficiency in pecans occurs when the Zn leaf level is 30 ppm or less (Whitney, 1988).

Zinc interacts with phosphorus when large amounts of phosphorus fertilizers are applied to soils low in zinc (Martens and Lindsay, 1990; McBride, 1994). The excess phosphorus enhances zinc adsorption, thereby maintaining the availability of zinc (Jones *et al.*, 1991). The phosphorus-zinc interactions in plants minimize the inhibition of zinc uptake and zinc translocation from the roots to the shoots by calcium cations (Loneragan, 1968).

Zinc is relatively non-toxic to many crops and a concentration of 500 mg kg^{-1} Zn in soil is often needed before zinc toxicity is observed (Jones, 1972; Walsh and Beaton, 1973). Zinc toxicity can readily induce iron deficiency, resulting in chlorosis in young leaves as well as inhibition of root elongation. This may be as a result of the isoelectric nature of the two hydrated Zn^{2+} and Fe^{2+} ions (Woolhouse, 1983).

(e) Boron

Boron (B) is absorbed by plants as undissociated boric acid and follows the flow of water into the roots (Bell, 1997). Boron requirements vary considerably among crops and certain plant

species show toxicity symptoms if the level exceeds 200 ppm B (Watson and Brown, 1998). The optimum range in leaf tissue of most crops is 20 to 100 ppm. Some crops are particularly sensitive to B and can be injured when the B level in the leaf is too high. For example, B levels in excess of 50 ppm have been associated with B toxicity in peaches (Johnson and Fixen, 1990). The B critical level for corn is about 4 ppm, while lucerne, cotton, peanut, and soybeans have critical levels of 20 ppm.

Boron in plants is not a very mobile element because uptake from the roots to the shoot is confined to the xylem. Uptake and translocation are closely related not only to the mass flow of water to the root surface but also to the xylem water flow (Gaines and Mitchell, 1979). It acts as a substrate in carbohydrate metabolism for the synthesis of phenolic acids and hemicelulose (cell wall material). Boron is involved in transport of sugars and also regulates the flux of substrate in lignin biosynthesis via the formation of stable phenolic borate complexes, particularly with caffeic acid, and maintains IAA oxidase activities during cell division and root elongation (Hewitt, 1983).

Dicotyledons are more susceptible to boron deficiency than monocotyledons, with the exception of maize and sorghum (Keren and Bingham, 1985). Boron deficiency symptoms in plants occur in the newly emerging tissues and show disorganized meristems leading to early death of stem tips (Shuman *et al.,* 1992). Leaves may become crinkled and misshapen while stems and petioles thicken and crack. Flowering may be totally suppressed while fruit and seed formation, if it occurs, is abnormal (Gupta, 1993). A very rapid effect of boron deficiency is a reduction in the level of RNA and cessation of cell division in root tip meristems, which make the roots become shortened and appear bumpy. The symptoms of boron toxicity on mature leaves are marginal and/or tip chlorosis and necrosis. Corn whose B

requirement is low, is also sensitive to excess B. Toxicities may occur when the B level in young corn leaf tissue exceeds 25 ppm (Watson and Brown, 1998). On young leaves there is yellowing of margins, crumpling, blackening and distortion (Rashid *et al.,* 1997).

(f) Molybdenum

Molybdenum (Mo) is absorbed from soils predominantly as the MoO_4^{2-} ion (Wild, 1988). The content of molybdenum in plants that is considered to be adequate for healthy growth is only 0.1 ppm Mo dry weight. Molybdenum is an essential constituent of two important enzymes involved in biological nitrogen fixation; namely nitrate reductase and nitrogenase (Reuter and Robinson, 1997). Nitrate reductase is a molybdoflavo-protein and is present in the cytoplasm of leaves and roots (Hewitt, 1983). Molybdenum is specifically required for the biological fixation of dinitrogen both in the symbiotic systems of legumes and certain non-legumes, and in free-living organisms (Munson and Nelson, 1990). Nitrogenase, the enzyme responsible for the reduction of dinitrogen, consists of two iron-sulphur proteins; one contains molybdenum while the other contains iron (Martens and Lindsay, 1990).

Molybdenum requirement of legumes is higher than that of other plants since Mo is essential for the fixation of atmospheric N by the symbiotic bacteria (Lowe and Massey, 1965). Molybdenum is essential for the conversion of nitrate to ammonium ions in plants. The symptoms of molybdenum deficiency include proliferation of small nodules on the roots, and reduction in levels of amino acids, amides and amines (Possingham and Brown, 1957). Molybdenum toxicity in young leaves causes malformation and golden yellow discoloration of the shoot tissues. In mature leaves it causes mottling over whole leaf but little pigmentation, cupping and distortion of stems. Molybdenum is quite toxic to animals if the forage being consumed contains more than 15 ppm Mo (Reuter and Robinson, 1997).

2.1.3.3 Soil Fertility Status under Arid and Semi-arid Conditions

Soil fertility may be defined in terms of soil productivity, as the capacity of a soil to supply essential nutrients in adequate and right proportions for optimum growth of plants (Sanchez *et al.*, 1996). Soil degradation is the main cause of low soil fertility and leads to poor vegetation cover and low crop yields in dryland agriculture. According to Lal (2000), soil degradation in the ASALs is often caused by neglect and misuse of soil over a long period of time. Soils in most of the arid and semi-arid areas have low organic matter, low cation exchange capacity, low nutrient reserves and low plant-available water holding capacity. They are highly fragile and easily degraded. Land degradation in the ASALs is likely to intensify in the future due to increase in population density, intensive cultivation of marginal lands, as well as the more escalating arid conditions caused by the effects climate change. Soil fertility replenishment in ASALs is often not feasible because it is too costly, risky and impractical for many farmers as a result of high potential evaporation rates, high temperatures that do not encourage bacterial activity especially in acid soils and leaching effects (Lal, 1996). In addition, there are no adequate fertility replenishment strategies and resources to improve soil productivity for sustained irrigated agriculture (Pereira, 1993).

Water run-off removes considerable quantities of soil organic matter and mineral nutrients. This consequently destabilizes soil structure and decreases the infiltration rate, in addition to reducing the available soil moisture for plant growth (Lal, 1996). Nutrient uptake by plants is influenced by soil moisture, the principal factor limiting the growth of plants in dry land environment. Organic matter influences soil stability, proneness to erosion, the quality of soil structure, water holding capacity, and nutrient storage and turnover. Soil structure regulates movement of water retention and nutrient transformations, faunal activity, species diversity, strength and rigidity of the rooting media (Lal, 1996). A decline in soil organic

matter levels may cause an increase in proneness to compaction, lower infiltration rates, increase run-off and hence enhance the likelihood of erosion.

Sanchez *et al.* (1996) reported that loss of organic matter and soil structure stability leads to severe land degradation with adverse consequences on physical, chemical, biological and nutrient status of soil. Loss of nutrients is often recognized as an increasing problem particularly in sub-tropical and tropical countries (Smaling, 1990; Smaling *et al.*, 1997).

2.1.4 Description and Distribution of *Acacia senegal* varieties in Kenya

The *Acacia senegal* tree is a widespread woody species. It is extremely variable in its habitat, from a bush of about 2 m to a tree of 15 m tall, with a flat to rounded crown (Bentje, 1994). The tree has many branches and erect twigs with small, grey-green spreading within the upright part. The bark is yellow/brown and smooth on younger trees, changing to dark grey, gnarled and cracked on older trees. The branchlets have thorns just below the nodes: three thorns with the central one hooked downwards and laterals curved upwards and the median one curved backwards (Gachathi, 1994). The tree produces white or cream colored flowers during the rainy season. *Acacia senegal has* four different varieties namely: *Acacia senegal* var. *senegal*, *A. senegal* var. *kerensis* Schweinf. *A. senegal* var. *rostrata* Brenan, and *A. senegal* var. *leiorhachis* Brenan (Chikamai and Gachathi, 1994).

2.1.4.1 Description, Uses of Gum arabic exudates and Acacia senegal

Gum arabic is water soluble, exudes naturally or in response to wounding of the stems of the *Acacia senegal* varieties. It is colloidal and insoluble in alcohol and ether. It contains high amount of sugar and is closely allied to the pectins. The gum from other *Acacia* species

(*A. seyal,* etc.) is available commercially as gum tahla and marketed for technological applications (FAO, 1990). Gum arabic has been used for over 4,000 years. Egyptians used gums as early as 2,000 B.C. in food, preparations of human and veterinary medicines, in crafts, and as a cosmetic. Sudan gum has been an article of commerce since 100 A.D (Anderson, 1987).

Gum arabic is used as a stabilizer, emulsifier, thickener, binder and protective agent in the food, pharmaceutical, and technical industries (FAO, 1995). FAO specification for gum arabic intended for food use stipulates that it should come from *Acacia senegal* or closely related species (FAO, 1990). The exudate is suitable for food purposes having been evaluated toxicologically as a safe food additive (Anderson and Morrison, 1990). In Europe, the legislative requirement for the food additive of gum arabic is the quality performance in bakery products. This makes gum arabic the material of choice in food industry (FAO, 1990). As an emulsifier, gum arabic is used in confectionery products, particularly to prevent crystallisation of sugars. In candy products it is also used as a glaze, means of encapsulating flavours (for example, spray-dried flavours and citrus oils), and in a range of dairy and bakery products it is used as a glaze. It is used either as a vehicle for flavouring or as a stabilizer or clouding agent in soft and alcoholic drinks.

In pharmaceutical industry, gum arabic is used in tablet manufacture as a binding agent, as soothing and softening agent for cough syrups, and as an emulsifying agent in cosmetics such as creams and lotions and sometimes in combination with other gums (FAO, 1995).

Gum arabic is used in the manufacture of adhesives and ink, and as a binding medium to suspend the colouring matter. It is also used to increase the viscosity of ink, or to make it flow well, to prevent it from feathering. It is also used as a protective agent to treat offset lithographic plates such as a protective coating to prevent oxidation in printing industry and

as a component of solutions to increase hydrophilicity and impart ink repellency to the plates, and as a base for photosensitive chemicals (FAO, 1995). Other technical uses include ceramics, where gum arabic helps to strengthen the clay, certain types of inks, and pyrotechnics. It is also used as a binding agent in textiles, paints and adhesives such as traditional office glue and postage stamps (FAO, 1995).

The tree is used in agro forestry systems in dry land farming for honeybee forage, fuel wood, charcoal making, fibres (ropes) and tool handles. It is a windbreaker and a nitrogen fixing tree, an important attribute in stabilizing soil structure and improving soil fertility (FAO, 1986; NAS, 1979).

2.1.4.2 Gum arabic Production, Harvesting and Marketing in Kenya

Gum arabic is collected by uncoordinated groups of women and herdsmen from pastoralist communities at different seasons over wider areas (Gachathi, 1994). The collected gum is marketed through middle businessmen usually operating other kinds of trades at local trading centres. These businessmen include hotelkeepers and shopkeepers who sell the same at a profit to local companies such as Semi arid lands for livestock (SALTLICK), Nalepo farmers, AfriGums, etc. for export to the world market. In the Sudan however, gum arabic is collected in an orderly manner and systematically from tapped *Acacia senegal* plantations. The gum is therefore uniform in most respects and is considered the best grade internationally (Gachathi, 1994). The grading and quality control yardstick for gum arabic on the international market is based on standards of the Sudan gum.

Gum arabic production in Kenya is faced with several problems and constraints. The major problems facing gum quality are inadequate tools and analytical procedures on timing of tapping and harvesting, cleaning, sorting, handling, packaging and storage. These factors

affect the grading of Kenyan gum arabic in the world market. When the Kenyan gum is tested in the world market, it is rated of low quality according to the strict regulations of JECFA specifications (FAO, 1990). There is inadequate information on data in terms of harvesting techniques, cleaning, sorting, handling, packaging, storage and transportation all of which affect quality of gum arabic. *Acacia senegal* varieties as well as seasonal factors may also influence quality of gum arabic. It is also possible that variation in soil type, humidity and rainfall or even vegetative or physiological state of the species influence the quality. It is imperative therefore to postulate that if quality of gum is improved the local communities would benefit from higher prices and this could be another source of income to supplement dependence on livestock production in the ASALs. There is need therefore to investigate factors that influence the quality and production of gum arabic and to determine variability in physicochemical characteristics of Kenyan gum arabic and their relationship with variables such as soil types, altitude and seasons. This would be in addition to establishing a Kenyan system quality control for grading of gum arabic based on physical and chemical properties of soils.

CHAPTER THREE

MATERIALS AND METHODS

3.1 The Study Area

3.1.1 Introduction

Baringo district is situated in the Rift Valley province of Kenya. It covers an area of 8,655 square kilometers. It lies between latitudes $0^0 15'$ and $1^0 45'$ N and longitudes $35^0 30'$ and $36^0 15'$ E.

Figure 3.1: Location of the Study Sites – Baringo District

It borders Turkana district to the north, Samburu and Laikipia districts to the east, Koibatek to the south, and Keiyo, Marakwet and West Pokot districts to the west (Figure 3.1). The district has three main agro ecological zones: lowlands, medium highlands and the highlands (GOK, 1993). The lowlands comprise the northern plateau, Lake Baringo and Kerio Valley basins. The medium highlands extend from Kimose to Mugurin while the highlands comprise the Tugen hills, which start from Tenges, Lembus forest, Kabarnet through Kabartonjo with an elevation of 1800 - 2300 metres above sea level.

The district experiences two seasons of rainfall. The long rains start from the end of March to July and short rains from September to November. The average annual rainfall varies from 1000-1500 mm in the highlands to less than 500 mm in the lowlands around Nginyang and Lake Baringo basin. The soils of the district east of Kerio river are predominantly saline, sodic calcareous, while those of Tugen hills are developed on undifferentiated volcanic rocks and ashes of older volcanoes, mainly of basic igneous rocks (GOK, 1993).

About 46% of Baringo district comprises the arid and semi-arid lands (ASALs), with low and erratic rainfall, high potential evaporation rates, high temperatures and poor soils (Sombroek *et al.*, 1982). This area is predominantly a lowland dry zone. The only activities are livestock, sorghum and millet farming.

Marigat division, one of the 12 divisions in the district, receives an average annual rainfall of less than 500 mm. Annual temperatures average 30^0C in dry seasons and 26^0C during wet seasons. The annual potential evaporation rate is about 2000 mm. The topography of the area comprises mainly plain, undulating, rolling and hilly features. The soils are

variable, shallow, stony and rocky with loose lava boulders of igneous rock rich in calcium carbonate (Sombroek *et al.*, 1982).

The division is endowed with natural vegetation mainly of Acacia woodlands consisting of *Acacia mellifera, A. tortilis, A. senegal* var. *kerensis, A. senegal* var. *senegal, A. nilotica,* A. *reficiens, A. seyal* var. *fistula* and *A. hockii.* It is the dominant Acacia vegetation that made Marigat division a choice study site for gum quality investigations. The division is faced with serious land degradation problems caused by deforestation of trees and shrub species capable of producing various essential products, such as gums, tannins, herbal medicines, essential oils, fodder, honey, charcoal and food for domestic and commercial uses.

3.1.2 Selection and Description of Study Sites

The study sites were Solit (ST), Kimorok (KK), Kapkun (KN) and Maoi (MI), and selection was based on survey of high stand density, occurrence and wide distribution of *Acacia senegal* and its varieties in their habitats.

(a) Solit

Solit is located about 9 kilometres south of Koriema centre along Marigat-Kabarnet road in Sabor sub location, Kimalel location. It lies at latitude 0^0 25′ N and longitude 35^0 53′ E. The topography is 3% slope with an altitude of 1300 metres above sea level.

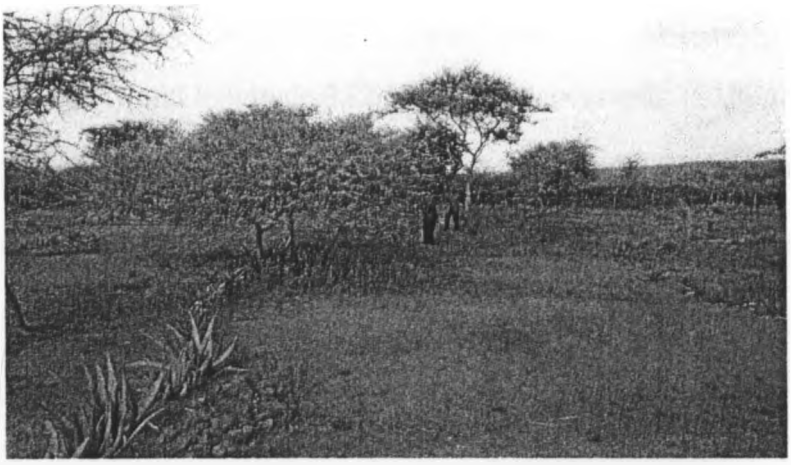

Plate 3.1: Solit Site - *Acacia senegal var. senegal* and other closely related species

The soils are shallow with moderate erosion on the upper part to severe erosion on the lower part of the site by water run off during rainy seasons. The study site covered 0.5 hectare and was dominated by moderate stands of *Acacia senegal* var. *senegal* and other closely related species (Plate 3.1).

(b) Kimorok

Kimorok is located about 5 kilometres from Marigat town along Marigat-Kabarnet road in Kimalel sub-location, Kimalel location (Plate 3.2).

Plate 3.2: Kimorok Site - *Acacia senegal var. kerensis* and other closely related species

It lies at latitude 0^0 28′ N and longitude $35^0$55′ E. The topography is 1% gradient with an altitude of 1200 meters above sea level. The soils are shallow, stony and rocky and moderately swept by gully erosion during rainy seasons. The site was 0.8 hectare, dominated by high stand density of *Acacia senegal* var. *kerensis* and other closely related species with sparse distribution of grass cover, bushes and shrubs.

(c) Kapkun

Kapkun is located about 12 kilometres to the south of Marigat-Kabarnet road in Sabor sub-location, Kimalel location (Plate 3.3). It lies at latitude 0^0 23′ N and longitude 35^0 54′ E.

Plate 3.3: Kapkun Site - Both *Acacia senegal* variety *senegal and kerensis* with other closely related species

The topography is moderately plain but slants from east to west with 2% gradient and an altitude of 1300 metres above sea level. The site was 1.0 hectare, dominated by *A. senegal* var. *senegal*, and *A. senegal* var. *kerensis* and other closely related species.

(d) Maoi

Maoi is located about 2 kilometres east of Maoi centre along Marigat-Nakuru road in Kaplelwo sub-location, Kaibosoi location (Plate 3.4). It lies at latitude 0^0 24′ N and longitude $35^0$56′ E.

Plate 3.4: Maoi Site - *Acacia senegal* var. *kerensis* and other closely related species

The topography is mainly plain with a gentle slope on the eastern part of about 1% gradient with an elevation of 1200 metres above sea level. The soils are shallow and rocky with moderate erosion by water run-off during rainy seasons. The site was 1.0 hectare, dominated by high stand density of *A. senegal* var. *kerensis* and other closely related species.

3.2.1 Soil Sampling and Pretreatment

Soil samples were dug at a depth of 15-25 cm with a mattock, from five different holes and mixed in a basin to give one representative sample in all the four study sites. Thirty samples of about 600 g each were collected and put in labelled polythene bags. A soil pit of about 60 to 100 cm deep was dug in each site and horizon boundaries identified, marked

and measured to provide the soil profile. Samples in each pit were taken from each horizon for determination of bulk density, particle density and porosity (Plate 3.5).

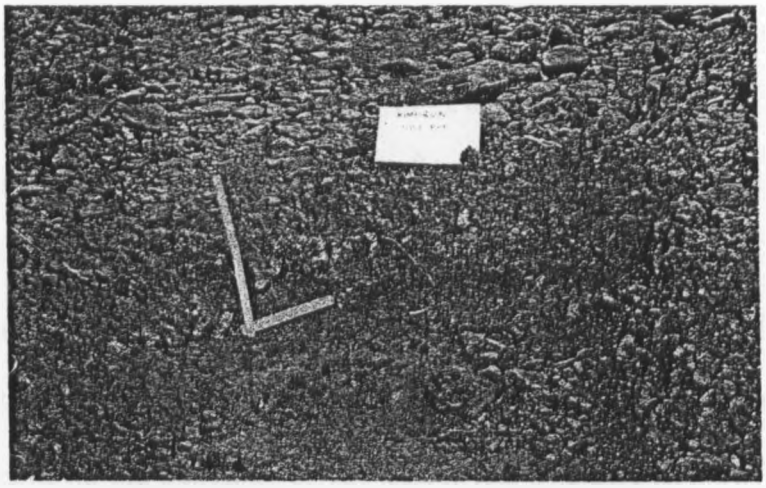

Plate 3.5: Soil sampling in the Study sites

Soil samples were air-dried, ground in a mortar and sieved through 2 mm sieve mesh to remove gravel and plant materials for analysis of physical and chemical properties and for glasshouse pot experiments.

3.3 Soil Analysis

3.3.1 Physical properties of Soils

(a) Soil texture

Mechanical analysis was used to determine soil texture based on the difference in velocity of settling particles between coarse and fine fractions within a water column. Soil was shaken in a dilute alkaline solution of 10 % sodium hexametaphosphate (dispersing agent) to disperse the coarse and fine colloids in the soil aggregates. The dispersing agent removes oxides of iron and aluminium, calcium carbonate ($CaCO_3$) and organic matter that have a cementing action on the particles. The effectiveness of this dispersing agent depends upon

the adsorption of sodium in exchange for other cations, and the resultant development of strong electrical repulsion forces between the soil particles.

Soil texture analysis (particle size analysis) was determined by the hydrometer method of Bouyoucos (1962). Air-dried sample (50g) portions were weighed into 500 ml bottles and placed in a mechanical shaker. Aqueous sodium hexametaphosphate (10%) dispersing agent (50 ml) and 300 ml of distilled water were added and the bottles tightly stoppered and shaken over night. The contents were quantitatively transferred into a 1000 ml graduated measuring cylinder and made to the mark with distilled water. The procedure used to treat the blank was similar to the treatment of the sample (suspension mixture). The suspension was mixed thoroughly with a plunger. The hydrometer was lowered gently into it and the reading taken at the upper edge of the meniscus surrounding the stem. The suspension mixture was stirred thoroughly again with a plunger for one minute, and time was recorded when the stirring ceased. The hydrometer was carefully lowered into the suspension again and the reading and temperature recorded 40 seconds after the previous timing. This reading was used to determine silt and clay.

Two hours following the previous reading, the second hydrometer reading and temperature were taken for both the soil suspension and blank. This reading was used for the determination of clay fraction (Hinga *et al.*, 1980).

(b) Bulk density, Particle density, Porosity, Percolation Rate and Soil moisture content

Bulk density, particle density and porosity were determined by methods of Blake (1965) and Hinga *et al.* (1980), while percolation rate and soil moisture content were determined by methods of Anderson and Ingram (1993) and Okalebo *et al.* (2002). For bulk density,

coring of cylindrical metal samplers of 5 cm diameter of known volume were driven to 5 cm deep into the soil surface in each field site. The core sampler was filled with the soil and then carefully dug out with its contents so as to obtain a core sample in a natural soil condition. The soil sample was carefully removed, trimmed around the cylinder with a small shovel on both ends and tightly closed with caps on top and bottom of the cylinder. Core samples were oven dried at 105^0 C and weighed for determination of bulk density.

Particle density was measured by weighing clean, dry pyknometer in air and filled about one third full with 2 mm air-dry soil in duplicate. It was heated gently for a few minutes to remove entrapped air and was cooled with its content to room temperature, carefully stoppered and the outside wiped with a clean, dry cloth. The contents were weighed and temperature of the suspension was measured for particle density, taken as the ratio of the total mass (weight) of solid particles to their volume, excluding pore spaces.

Porosity was determined by core method according to (Blake, 1965) as the bulk density, where the core samples were saturated with water and all the pores filled. Core soil samples were oven dried at 105^0C to a constant weight. The volume of the water was obtained by converting the weight lost on drying at 105^0C on the basis of density of water (D_W = gcm^{-3}), the same as the bulk volume of the core sample. Then porosity was calculated from the dry bulk density and particle density given by the expression as a volume percentage equal to the volume percent water content at saturation.

Percolation rate was determined by filling a large and small-diameter steel cylinder with water. Water in the large steel cylinder was allowed to drop to the same level as in the small cylinder and time was recorded at intervals of 5 minutes, and then refilled up to its original level. The height of water in the small diameter cylinder was allowed to fall for about 15

minutes and then refilled up to its original level. The height of water in the outer ring was adjusted throughout the measurements until a constant rate was obtained. Percolation rates were measured from the water level at predetermined time intervals and the rate of inflow dropped with time and the experiment was stopped when the rate remained constant after three hours of percolation.

Soil moisture was determined by weighing air-dried soil sample in a clean dry bottle and placed in an oven at 105^0C for 6 hours, removed and allowed to cool in a desiccator for 30 minutes and then re-weighed to obtain an oven-dry weight.

3. 4 Determination of Chemical properties of Soils

Organic carbon, total nitrogen, soil pH water (1:2), soil pH calcium chloride (0.01M $CaCl_2$), electrical conductivity, available phosphorus, exchangeable cations (potassium, magnesium, calcium and sodium) and micronutrients (copper, iron, manganese and zinc) were determined by the procedures described in the subsequent sections.

3.4.1 Organic carbon

Organic carbon was determined by the method of Okalebo *et al.* (2002). An air-dry soil sample (0.5g) was weighed in a 500 ml conical flask and 5 ml of 1.0 M potassium dichromate solution and 7.5 ml of concentrated sulphuric acid added. The contents were placed in a heated block at 145-155^0C for 30 minutes, removed and cooled to room temperature. The digested sample was transferred to a 100 ml conical flask and 0.3 ml of ferroin indicator solution added before titrating with 0.2 M ferrous ammonium sulphate solution. All the titres were corrected for blank and recorded as a measure of unused potassium dichromate.

3.4.2 Total Nitrogen by Kjeldhal Method

Total nitrogen by Kjeldhal method was determined according to the methods of Anderson and Ingram (1993) and Okalebo *et al.* (2002). A soil sample (0.3 g) was weighed and transferred to labeled clean digestion tubes and 2.5 ml digestion mixture (prepared by dissolving 3.5 g of selenium powder and 72 g of salicylic acid in 1 litre of concentrated sulphuric acid) was added, mixed well and placed in a block digester (Skalar Block Digester System, Model SA 5640).

The digestion tubes were heated to 110^0C for 1 hour and removed to cool for 30 minutes before adding three 1 ml aliquots of hydrogen peroxide (30%) in succession. The contents were returned to the block digester and heated at 330^0C for two hours to obtain clear, colourless digests. The contents were removed and allowed to cool, mixed with 25 ml of distilled water and then transferred into a 50 ml volumetric flask and made up to the mark with distilled water. An aliquot of 5 ml solution was transferred to the distillation apparatus and 10 ml of 40% sodium hydroxide added. 5 ml of 1% boric acid and 4 drops of mixed indicator (a reagent used to indicate the end point in a titration procedure) were added to the distillate and then distilled till the indicator turned from red to green. The distillate was titrated with 0.05 M HCl till the colour changed from green to grey.

3.5 Soil pH and Electrical conductivity

Soil pH and electrical conductivity were measured according to the procedures of Anderson and Ingram (1993) and Okalebo *et al.* (2002), respectively. A 20g sample was weighed into 100 ml plastic bottles and 50 ml distilled water added. The contents were shaken for 10 minutes, allowed to stand for 30 minutes, and shaken again for 2 minutes. The soil suspension was allowed to settle for one hour.

The pH and electrical conductivity were measured using a pH meter (Model 691) and conductivity meter (Model TOA Cm-20S), respectively.

3.5.1 Extractable Phosphorus

The available phosphorus was extracted using the procedure of Olsen *et al.* (1954) and analysed according to the method of Anderson and Ingram (1993). Air-dry soil (5 g) was weighed into a 250-ml shaking bottle and 100 ml of 0.5 M sodium bicarbonate solution added. The contents were shaken on a mechanical shaker for 30 minutes at 200-300 rpm.

The suspension was filtered through Whatman No. 42 filter paper and an aliquot of the filtrate (10 ml) pipetted into a 50-ml volumetric flask. To this was added 5 ml of 0.8 M boric acid and 10 ml of ascorbic acid reagent. The contents were diluted to the mark with distilled water, mixed well and let to stand for 1 hour to allow full colour development. A blank was made by substituting the sample with 5 ml of distilled water and carrying through the procedure. A standard series containing 0.0, 1.0, 2.5, 5.0, 7.5, 10, and 12 ppm P was complexed similarly and absorbance values of all the solutions were measured at 880 nm (Model UV Spectronic 21-Milton Roy Co.).

3.5.2 Soil Extractable Macronutrients

(a) Potassium and Sodium

Potassium and sodium were determined using a flame photometer (Corning M 410) (Anderson and Ingram, 1993). An air-dry soil sample (< 2-mm) of 5 g was weighed into a 250-ml clean plastic bottle and 100 ml of 1.0 M neutral ammonium acetate solution added and the contents were shaken on a mechanical shaker for 30 minutes (Neutral ammonium acetate was used to extract maximum cations that occupy exchange sites on the soil

surface). The contents were filtered (Whatman No. 42 filter paper). To 5 ml of the filtrate contained in a 50 ml volumetric flask was added 1 ml of 26.8 % Lanthanum chloride solution and the contents made to the mark with the ammonium acetate solution. Standards containing potassium and sodium at concentrations 0.0, 2.5, 5.0, 10, 15 and 20 ppm were prepared similarly (to fall within the measurable range of the calibrated flame photometer and atomic absorption spectrophotometer). The flame emission intensities were measured at 766 and 589 nm for potassium and sodium, respectively.

(b) Calcium and Magnesium

An air-dry soil sample (< 2-mm, 5 g) was weighed into a 250-ml clean plastic bottle and 100 ml of 1.0 M ammonium acetate solution (pH 7.0) added. The bottle was stoppered and shaken on a mechanical shaker for 30 minutes. The contents were filtered (Whatman No. 42) and 5 ml of soil extract pipetted into a 50 ml volumetric flask. To the aliquot 1 ml of 26.8 % Lanthanum chloride solution was added before making to volume with the ammonium acetate solution. Standards containing calcium and magnesium at concentrations 0.0, 2.5, 5.0, 10, 15 and 20 ppm Ca and 0.0, 0.4, 1.0, 2.0, 3.0, and 4.0 ppm Mg were prepared similarly (to fall within the measurable range of the calibrated flame photometer and atomic absorption spectrophotometer). The absorbance readings were taken at 422.7 and 285.2 nm, respectively for calcium and magnesium using a Shimadzu Model AA – 6410 F atomic absorption spectrophotometer (Anderson and Ingram, 1993).

3.5.3 Soil Extractable Micronutrients

Extractable micronutrients (iron, zinc, manganese and copper) in soils were determined at wavelengths of 248, 213, 279 and 324.8 nm, respectively, by Shimadzu Model AA – 6410 F atomic absorption spectrophotometer according to the method of Anderson and Ingram (1993). A 5 g air-dry soil sample (< 2-mm) was weighed into a 250 ml clean plastic bottle

and 50 ml of 1% EDTA extracting solution added. (EDTA, a chelating agent was used because of its capability to extract all forms of metal-chelate ionic complexes at low concentrations of available iron, zinc, manganese and copper in soils). The sample was shaken on a mechanical shaker for 1 hour. The suspension was filtered (Whatman No. 42) and 5 ml of the filtrate pipetted into a 50 ml volumetric flask. The contents were filled to the mark with 1% EDTA extracting solution. Standards were prepared containing 0.0, 0.5, 0.75, 1.0, 1.5 and 2.0 ppm of Cu and Zn, and 0.0, 2.0, 4.0, 6.0, 8.0, and 10.0 ppm of Fe and Mn, respectively, using the extracting solution.

In these methods of soil extractions, initial recovery tests in soils were valid for all the nutrients to achieve a significant recovery test. However, dilution effects of nutrients uptake inhibited the recovery tests over time because of soil heterogeneity. Standard methods of Okalebo *et al.* (2002) and Anderson and Ingram (1993) on recovery tests on soil nutrients amelioration were adopted in the study.

3.6 Micronutrients Uptake Studies

3.6.1 Seed Collection

A flowering survey was carried out from January to March 2002 to determine the proper time for seed collection in the study areas. About 200g of *Acacia senegal* seeds were collected randomly by hand from selected healthy trees in each site. The seeds were dried and stored in polythene bags for establishment in glasshouse pot experiments.

3.6.2 Seed Germination in the Controlled Growth Chamber

Seeds were sown in a plastic trough with sterilized pure sand. The germinated young seedlings were placed in the automated controlled growth chamber to prevent fungal attack.

Temperature was set at 28^0C, light (photoperiod) and air circulation were automatically controlled (Plate 1).

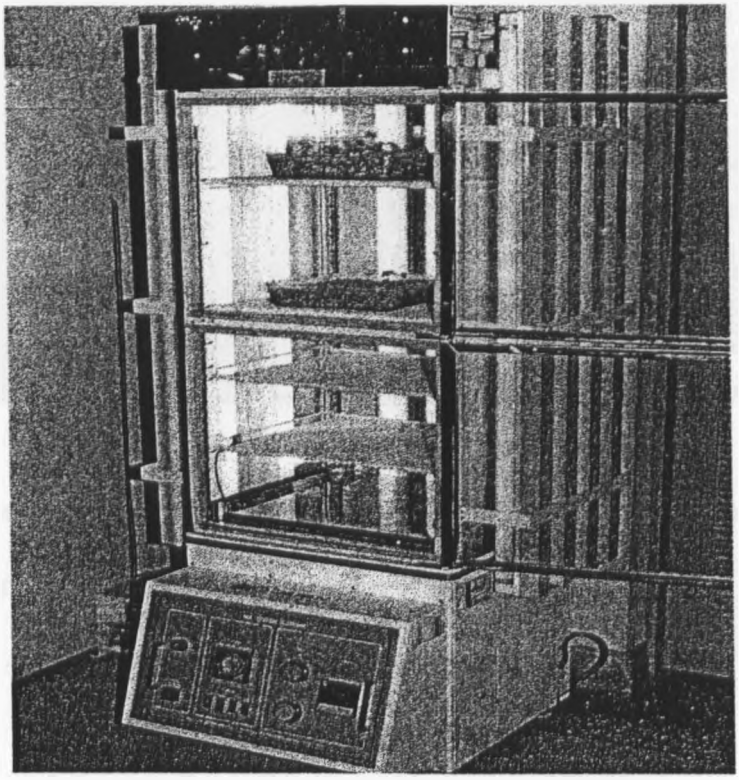

Plate 1 Controlled Growth Chamber for Seed Germination

The seeds were irrigated with distilled water after every four days to provide adequate moisture for germination. Tree seedlings were germinated and transplanted after 21 days into half-filled pots with soil and vermiculite media under glasshouse conditions that simulated the ASAL environment (Plate 2).

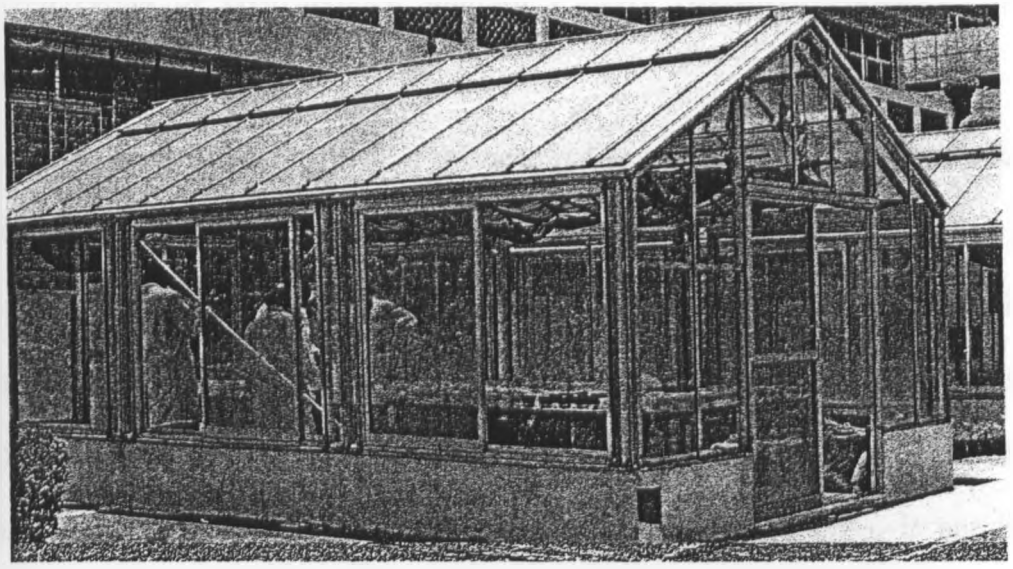

Plate 2 Glasshouse Experiment

The vermiculite, a solid inert aggregate, was added to provide a homogenous medium for raising tree seedlings in the glasshouse experiments (Stout, 1961).

3.6.3 Glasshouse Experimental Design

A Split-plot block design was used for this study. The layout comprised main plots, subplots and sub-subplots. The soil and vermiculite media were assigned to the main plots. Sites and micronutrient treatments were assigned to the subplots and sub-subplots, respectively, in two replicates. Table of random numbers was used to allocate media, sites and treatments randomisation in order to take care of interactions between and within treatments, sites and media. Hydroponics nutrient solution was used for micronutrient uptake by the seedlings in the glasshouse pot experiment (Stout, 1961).

3.6.4 Preparation of Hydroponics Solution Culture (Balanced Nutrient Solution Media)

Hydroponics normal solution culture, a balanced nutrient medium that contained adequate concentrations of all essential elements was prepared from reagent salts of analytical grade or equivalent. For preparation of nutrient solutions: nitrogen, phosphorus and potassium, a concentration of 2000 ppm of each element was made by dissolving 6.9989g $(NH_4)_2FeSO_4.6H_2O$ and 14.0711g potassium nitrate (KNO_3), 8.7872g potassium hydrogen phosphate (KH_2PO_4) and 5.1718g potassium nitrate (KNO_3) respectively, in one litre of distilled water. Calcium and magnesium at 8000 ppm and 1000 ppm, respectively, were prepared by dissolving 29.3440g calcium chloride ($CaCl_2.2H_2O$) and 10.1406 g magnesium sulphate ($MgSO_4.7H_2O$), in one litre of distilled water (Stout, 1961). For the micronutrients copper, iron, manganese and zinc, concentrations of 6 ppm, 100 ppm, 50 ppm and 20 ppm were prepared by dissolving 0.0235 g copper sulphate ($CuSO_4.5H_2O$), 0.4978 g ferrous sulphate ($FeSO_4.7H_2O$), 0.2030 g manganese sulphate ($MnSO_4.4H_2O$) and 0.0879 g zinc sulphate ($ZnSO_4.7H_2O$) in one litre of distilled water (Stout, 1961).

3.6.5 Preparation of Low Micronutrient Medium

Copper, iron, manganese and zinc concentrations of 2 ppm, 50 ppm, 25 ppm and 10 ppm were prepared by dissolving 0.0079 g $CuSO_4.5H_2O$, 0.2489 g $FeSO_4.7H_2O$, 0.1015 g $MnSO_4.7H_2O$ and 0.0440 g $ZnSO_4.7H_2O$ in one litre of distilled water (Stout, 1961).

3.6.6 Preparation of High Micronutrient Medium

Copper, iron, manganese and zinc concentrations of 10 ppm, 150 ppm, 100 ppm and 40 ppm were prepared by dissolving 0.0393 g $CuSO_4.5H_2O$, 0.7467 g $FeSO_4.7H_2O$, 0.4060 g $MnSO_4.7H_2O$ and 0.1759 g of $ZnSO_4.7H_2O$ in one litre of distilled water (Stout, 1961).

3.6.7 Application of Nutrient Solutions, Monitoring and Data Collection Procedure

The hydroponics balanced nutrient solutions were applied, drained and replaced with fresh solutions after every fourteen days to minimise depletion in nutrient levels during the growth of tree seedlings (Plate 3).

Plate 3 Application of dosage treatments to *Acacia senegal* seedlings

Because of potential fluctuations in pH during the process of nutrient uptake by the *Acacia senegal* seedlings, the concentration of each element in the nutrient solution was buffered with 1 ml of 1 M ammonium acetate solution at pH 7.0 in each media. The dose levels of the micronutrient media were applied in increasing order as low, normal (balanced) and high concentrations. The choice of these levels was based on balanced nutrient levels occurring in higher plants as suggested by Stout (1961).

There were a total of 144 pots. Seventy two were each filled with 500g of soil. The rest were filled with 500g of vermiculite. In each pot was planted one seedling. The experiment was replicated twice and each treatment was randomly allocated in a row (block). The position of blocks by soil or vermiculite per site was randomly allocated for one medium. There were 9 treatments randomized to either vermiculite or soil with micronutrient solutions (Cu, Fe, Mn, and Zn) in Table 3.1).

Table 3.1 Categorizations of Nutrient Treatments (Stout, 1961)

Nutrient Concentrations				
	Copper (Cu)	**Iron (Fe)**	**Manganese (Mn)**	**Zinc (Zn)**
Treatment Levels		**ppm**		
Normal concentration	6	100	50	20
Low concentration	2	50	25	10
High concentration	10	150	100	40

Footnote:

Normal concentrations represent treatment Number 1

Low concentrations represent treatment Numbers 2, 4, 6 and 8

High concentrations represent treatment Numbers 3, 5, 7 and 9

The seedlings were applied with normal treatments of 10 ml three times in a month for two hundred and forty days. This was to allow each seedling to attain stable growth before applications of low and high dosage treatments. Diameter at ground level (Dgl) and heights (ht) in millimetres were recorded once in thirty days during the period of study.

3.8 Gum arabic Analysis

Ninety gum arabic samples of about 200g were collected during the dry seasons from the two varieties of *Acacia senegal*: *senegal* and *kerensis*. The samples were air dried for fourteen days and ground using a pestle and mortar for analysis of moisture content, ash, volatile matter, internal energy, nitrogen and the trace elements; copper, iron, manganese and zinc.

3.8.1 Determination of the Moisture and Ash contents

A portion of sample (5 g) was weighed into a clean dry crucible of known weight and oven dried at 105°C for 6 hours, and cooled in a dessicator for 30 minutes. The crucibles were re-weighed to determine the moisture content as percent ratio of the change in weight to the original sample weight. The dry weight was then placed in a muffle furnace and temperature raised to 550^{0}C. After one hour, the crucibles were removed, cooled in a dessicator for 30 minutes and weighed. The contents were ignited at 900^{0}C for two hours, cooled in a dessicator for 30 minutes and weighed. The ash content was taken as the percent loss in weight after ignition that of the original sample.

3.8.2 Determination of Internal energy in gum arabic samples

Gum arabic (5 g) was weighed into a clean dry crucible of known weight and then placed in a muffle furnace and temperature raised to 550^{0}C to obtain optimum internal energy. The furnace was open to cool to 150 ^{0}C to eliminate moisture, before putting in a dessicator to cool to room temperature for 30 minutes and weighed. The contents were ignited at 850^{0}C for two hours, then cooled in a dessicator for 30 minutes and weighed. Internal energy was determined as the percent loss in weight after ignition of the original sample.

3.8.3 Determination of the Volatile matter in gum arabic samples

A clean dry crucible of known weight was weighed with 5 g of gum arabic sample and oven dried at 105°C for 6 hours and then removed and cooled in a dessicator for 30 minutes. The crucibles were re-weighed to determine the volatile matter as percent ratio of the change in weight to the original sample weight according to the methods of Anderson and Ingram (1993 and Okalebo *et al.* (2002).

3.8.4 Determination of Nitrogen content and Trace elements in gum arabic samples

The methods for determination of nitrogen content and trace elements in gum arabic samples are similar to the methods described earlier in sections 3.4.2 and 3.5.3.

3.9 Statistical Methods of Data Analysis

Statistical analysis of data was carried out using SPSS for windows Release 8.0.0 (1997), and Microsoft Excel (2003) computer software. The statistical method used was Analysis of Variance (ANOVA) using Generalized Linear Models Procedure (GLM). Generalized Linear Modelling equations for soil physical and chemical analysis:

$$y_{ijk} = \mu + S_i + \varepsilon_{ij}$$

Where,

μ = Overall mean,

S_i = effect of i^{th} site, i = 1, 2, 3, 4.

ε_{ij} = random error

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Where,

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ε_{ij} = random error

Analysis of micronutrients uptake:

$$y_{ijkl} = \mu + c_i + s_j + m_k + (s^x m)_{jk} + \varepsilon_{ijkl}$$

Where,

μ = Overall mean,

c_i = Covariate

S_i = effect of i^{th} site, i = 1, 2, 3, 4.

m^k = effect of the k^{th} medium, k = 1, 2;

$S^x m$ = interaction effect of k th medium in the i th site, i = 1, 2, 3, 4, k =1, 2,

ε_{ijklmn} = random error.

Generalized Linear Modelling equations for Analysis of heights and diameter at ground level (Dgl).

$$y_{ijkl} = \mu + s_i + m_j + t_k + (s^x m)_{ij} + (s^x t)_{ik} + (m^x t)_{jk} + \varepsilon_{ijkl}$$

Where,

μ = Overall mean,

S_i = effect of i th site, i = 1, 2, 3, 4.

m_j = effect of the m^{th} medium, j= 1, 2;

t_k = effect of the t th treatment, k = 1, 2, 3, 4, 5, 6, 7, 8, 9

$s^x m$ = interaction effect of the the i^{th} site and j^{th} treatment, i = 1, 2, 3, 4, j = 1, 2, 3, 4, 5, 6, 7, 8, 9.

$_{s}{}^{x}{}_{t}$ = interaction effect of i^{th} treatment in the k^{th} medium, l = 1, 2, 3, 4, 5, 6, 7, 8, 9, k = 1, 2.

$_{m}{}^{x}{}_{t}$ = interaction effect of j^{th} treatment in the k^{th} medium, where j =1, 2, 3, 4, 5, 6, 7, 8 and 9, k = 1, 2,

ε_{ijkl} = random error.

Analysis of variance was caried to test significant differences among the means of physical and chemical properties of soils, gum arabic, micronutrients concentration, diameter at ground level and heights in media (soils and vermiculite), sites, treatments and variety between and within sites in the experimental unit. Pearson correlation analysis was also used to correlate levels of soil chemical properties, gum chemical properties, low, normal and high dosage treatments of micronutrients uptake by seedlings of *Acacia senegal* variety *kerensis* and *Acacia senegal* variety *senegal* (Meredith and Stehman 1991).

CHAPTER FOUR

CHARACTERIZATION OF SOILS AND SOIL FERTILITY STATUS

4.1 Physical Properties of Soils

(a) Soil Texture

The physical properties of soils are given in Table 4.1. Soil texture in Solit and Maoi comprised 68.75 % sand, 16.69 % silt, and 14.56 % clay and 62.29 % sand, 27.23 % silt, and 10.49 % clay, respectively (Appendix I). Kimorok and Kapkun comprised 55.47 % sand, 27.60 % silt, and 16.27 % clay, and 57.60 % sand, 26.50 % silt, and 15.90 % clay, respectively.

Table 4.1: The Physical properties of Soils

		Solit (n=32)	Kapkun (n=32)	Kimorok(n=32)	Maoi (n=32)
Sand	%±SE	68.75±0.72	57.6±0.75	55.47±0.75	62.29±0.69
Clay	%±SE	14.56±0.62	15.9±0.64	16.27±0.64	10.49±0.59
Silt	%±SE	16.69±0.59	26.5±0.61	27.6±0.61	27.23±0.56
Bulk density	g cm^{-3} ±SE	1.24±0.04	1.19±0.04	1.22±0.04	1.17±0.04
Particle density	g cm^{-3}±SE	1.61±0.10	1.67±0.10	1.69±0.10	1.72±0.10
Porosity	%±SE	23±5.78	29±5.78	26.75±5.78	28.75±5.78
Percolation	ml min^{-1}±SE	33±11.83	11.5±11.83	40±11.83	27.5±11.83
Moisture	%±SE	8.50±1.66	3.50±1.66	13.5±1.66	11.5±1.66

Footnote:

n = number of samples analysed

S.E. = Standard error

Sand content in Solit and Maoi of 68.75 % and 62.28 % was significantly higher ($P < 0.05$) than 55.47 % and 57.60% in Kimorok and Kapkun, respectively. Silt content of 16.69 % in

Solit was significantly lower ($P < 0.05$) than 27.6%, 26.5 and 27.3% in Kimorok, Kapkun and Maoi, while 10.49 % clay in Maoi was significantly lower ($P < 0.05$) than 16.27%, 15.90% and 14.56% in Kimorok, Kapkun and Solit, respectively (Figure 4.1).

Soil texture in Solit and Maoi was sandy loam with high sand contents (68.75 % and 62.28 %) due to the fact that weathering of parent material into inorganic constituents of soil minerals formed sandy soils. These soils were low in clay and high sand contents with low soil organic matter of 0.78% and 1.15%, respectively (Table 4.2).

Sandy soils in Solit and Maoi had low soil moisture content (8.5 and 11.5%) which influenced decomposition process of low soil organic matter. Kimorok and Kapkun had sandy clay loam with clay contents (16.27 % and 15.90 %), respectively, which revealed that clay content had higher organic matter content (1.97% and 1.73%) than that of sandy soils.

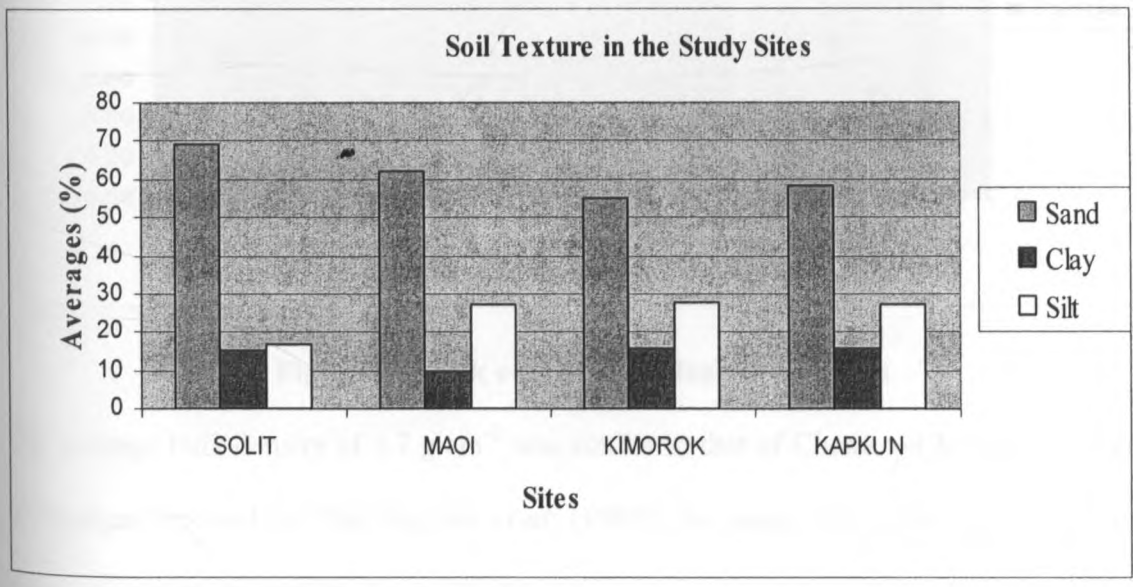

Figure 4.1 Soil Texture in the Study sites

The results of texture were similar to that of sandy soils reported by Landon (1991) that soils with high clay (20%) generally has high organic matter content (3.0%), because of slow decomposition of organic matter compared with sandy soils. Both texture had good drainage and aeration and may be susceptible to water erosion during wet seasons.

(b) Bulk and Particle Densities

The average bulk and particle densities were 1.21 and 1.66 g cm^{-3} in all the sites. The values were high because of high sand content which indicated that levels of soil organic matter and soil moisture characteristics were low in the study area (Table 4.1).

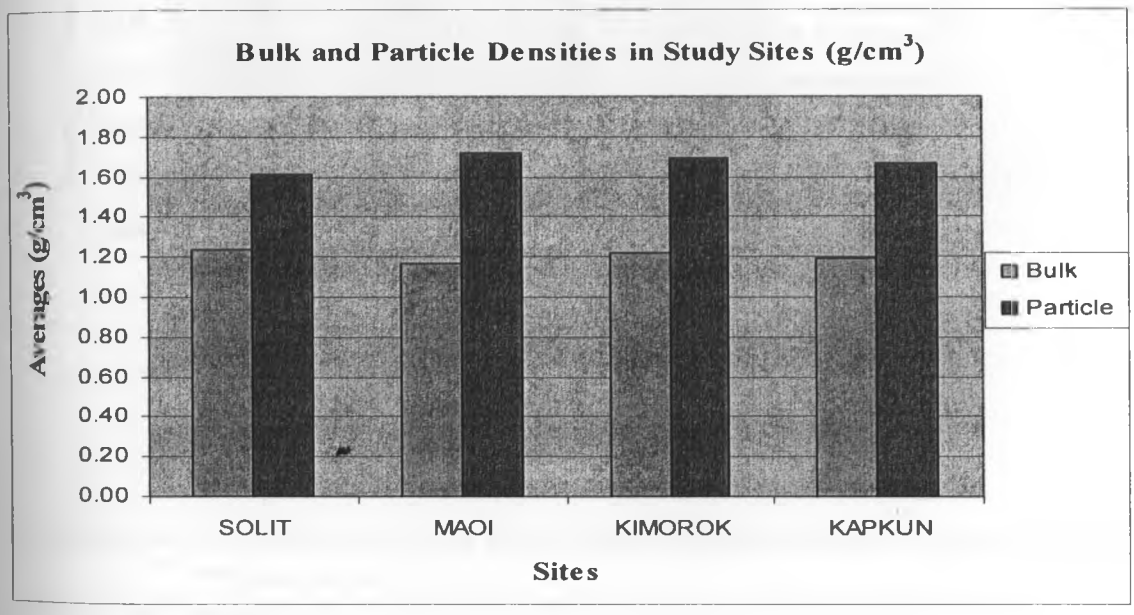

Figure 4.2 Bulk and Particle densities in Sites

The average bulk density of 1.2 g cm^{-3} was similar to that of Chemeron Irrigation Scheme in Marigat reported by Van Engelen *et al.* (1983); the range (1.2 g cm^{-3} and 1.3 g cm^{-3}) was within that reported by Anon (1991).

(c) Porosity and Percolation

Porosity in Kapkun, Kimorok and Maoi of 29%, 26.75% and 28.75% was high because of silt clay texture, while percolation rate in Kimorok, Solit and Maoi of 40, 33 and 27.5 ml/min was high as attested to influence of high levels of sand content, respectively (Table 4.1). Percolation rate of 40 ml/min in Kimorok was high because of influence of high levels of silt and clay contents of 27.60% and 16.27%, respectively.

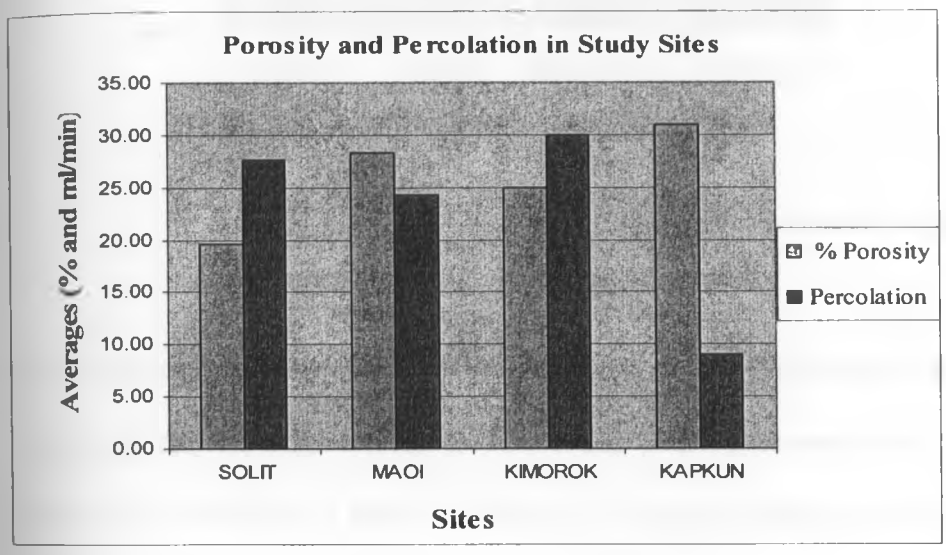

Figure 4.3 Porosity and Percolation in Sites

Percolation rate in Kapkun was lower than in Solit, Kimorok and Maoi because of high silt (26.50%) and low moisture which influences nutrient uptake and rainfall infiltration in the soil (Landon, 1991).

(c) Soil Moisture Content

Soil moisture (13.5 %) in Kimorok was significantly higher ($P < 0.05$) than 3.5 % in Kapkun, respectively (Figure 4.4).

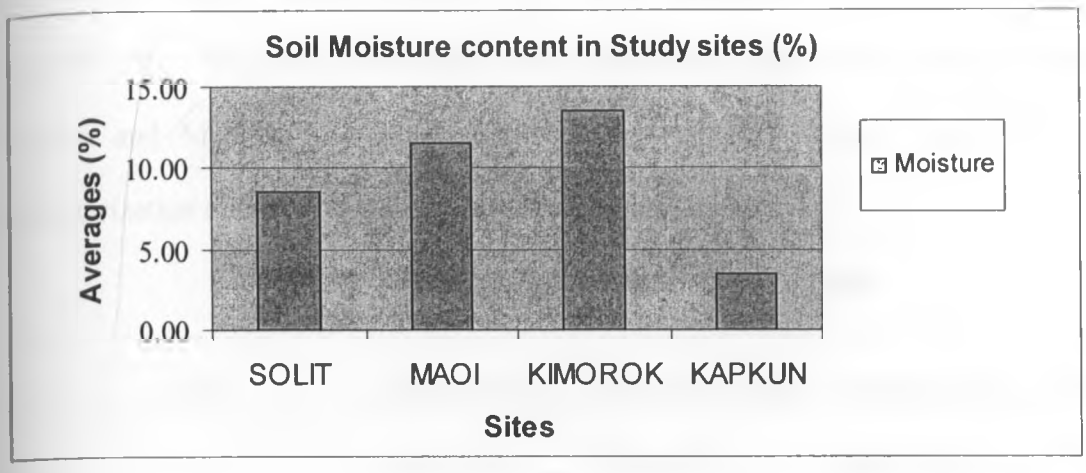

Figure 4.4 Soil Moisture content in Sites

Soil moisture of 13.5% in Kimorok was high as a result of influence of high levels of soil organic matter and clay content of 1.97% and 16.27%, respectively. Organic matter permits the infiltration of water and acts as a biological buffer ensuring that a balanced supply of nutrients is available to the plant roots, and clay particles contribute to the stability of soil aggregates.

Soil moisture in Kapkun was low due to the effect of soil texture (sandy clay loam) and low percolation of water (11.5 ml/min), in which clay soils are so finely textured that very little water penetrates to lower levels of soil horizon. The results of moisture content were low that revealed water stress limits the nutrient uptake by plants in all the sites. The effects of low moisture regime affect the physiological growth of plants and conditions of soil microorganisms in arid and semi-arid environments.

4.2 Chemical Properties of Soils

(i) Soil pH

The soil pH values were significantly different from each other in all the sites ($P < 0.05$, Appendix II). Soil pH 7.05 in Solit was significantly higher than those of Kimorok, Kapkun and Maoi (6.0, 5.9 and 6.19), respectively ($P < 0.05$, Table 4.2). The characterization criteria for soils are given in Table 4.2.

Table 4.2: Characterization Criteria for soils

	Site	Solit (n= 62)	Kimorok (n= 62)	Kapkun (n= 62)	Maoi (n= 62)
		Mean±S.E.	Mean±S.E.	Mean±S.E.	Mean±S.E.
pH		7.05±0.04	6.05±0.04	5.96±0.04	6.19±0.04
EC	mS/cm	0.06±0.00	0.05±0.00	0.04±0.00	0.04±0.00
C	%	0.46±0.03	1.15±0.03	1.01±0.03	0.67±0.03
C:N		2.99	9.37	4.82	4.25
SOM	%	0.78±0.06	1.97±0.06	1.73±0.06	1.15±0.06
N	%	0.18±0.02	0.14±0.02	0.30±0.02	0.17±0.02
PO_4^{3-}-P	ppm	11.54±1.00	14.60±1.01	14.10±1.02	13.91±0.99
K	cmol ($^+$)/kg	0.45±0.05	1.24±0.05	1.58±0.05	1.16±0.05
Ca	cmol ($^+$)/kg	17.33±1.27	5.74±1.28	6.40±1.30	4.97±1.26
Mg	cmol ($^+$)/kg	6.08±0.24	3.31±0.24	3.99±0.24	2.75±0.23
Na	cmol ($^+$)/kg	1.00±0.10	0.54±0.10	0.99±0.11	1.17±0.10
Cu	ppm	1.67±0.08	0.73±0.08	0.61±0.09	0.58±0.08
Fe	ppm	151±11	234±11	250±11	287±11
Mn	ppm	263±14	320 ±14	344±14	383±14
Zn	ppm	1.73±0.47	7.64±0.46	6.00±0.47	5.06±0.46

Footnote: n= number of samples analysed; S.E. = Standard error

The soils of Solit were neutral because of high levels of calcium and magnesium of 17.33 and 6.08 cmol ($^{+}$)/kg, respectively, while those of Kimorok, Kapkun and Maoi were acidic soils as a result of increased the levels of soil organic matter of 1.97%, 1.73% and 1.15%, respectively. pH values were similar to the values reported by Peverill *et al.*, (1999) on acidic and neutral soils that had a pH range of 5.5-7.05 which indicates adequate availability of calcium, potassium, nitrogen, phosphorus and micronutrients to most plants. The report also states that the soils of many arid and semi-arid areas have favourable pH range of about 6 and 7, but there is not enough precipitation to optimize the availability of nutrients for most plants. Brady and Weil (1999) reported that soil pH range in soils varied and the availability of nutrient uptake by plants is influenced by other factors such as texture, soil organic matter, soil moisture, leaching and erosive effects.

(ii) Electrical conductivity

Electrical conductivity of 0.06 mS/cm in Solit was significantly higher than those of Kimorok, Kapkun and Maoi (0.05, 0.04, and 0.04 mS/cm), respectively ($P < 0.05$, Table 4.2). This was because of sand content of 68.75%, soil pH 7.05, high levels of calcium and magnesium (17.33 and 6.08 cmol ($^{+}$)/kg) and Ca: Mg cation ratio of 3:1, which may have influenced the level of salinity in the soils and the availability of nutrient uptake by plants (Jaynes, 1996; Lund *et al.*, 1999).

The average level of salinity in all the sites was 0.05 mS/cm. This was low in view of the fact that moisture content averaged 9.3% aggravated by low and erratic rainfall in the study area. The low moisture limited the availability of nitrogen, phosphorus and micronutrients uptake by plants in the soils (Sudduth *et al.*, 1998).

(iii) Carbon and Carbon: Nitrogen ratio

Carbon content (1.15 and 1.01%) in Kapkun and Kimorok were significantly higher than those of Solit and Maoi (0.46% and 0.67%), respectively ($P < 0.05$, Table 4.2). The high levels of carbon in Kapkun and Kimorok was because of increased the levels of soil organic matter of 1.97% and 1.73%, respectively.

Carbon to nitrogen ratio (9.37:1.00) in Kimorok was significantly higher than the ratios for Kapkun, Maoi and Solit (4.82: 1, 4.25:1 and 2.99:1), respectively ($P < 0.05$, Table 4.2). This was ascribed to high soil moisture content 13.5%, which aids the oxidation of carbon in the decomposition of organic matter to release carbon dioxide in the soil. This oxidation process may have influenced the low carbon content as plants take in water and carbon dioxide in the presence of sunlight energy during photosynthesis.

Soil organic carbon also influences the decomposition of SOM by microorganisms through nitrification process (Landon, 1991). High C: N ratio of 8.21:1 was ascribed to increase in clay content of 16.27% which may have influenced the immobilization of nitrogen uptake by plants and fixing the ammonium ions in the exchange sites of SOM through mineralization during nitrification process (Jones, 1991)

(iv) Soil organic matter (SOM)

Soil organic matter of 1.73 and 1.97% in Kapkun and Kimorok were significantly higher than those of Solit and Maoi (0.78 and 1.15%), respectively ($P < 0.05$, Table 4.2 and Figure 4.5).

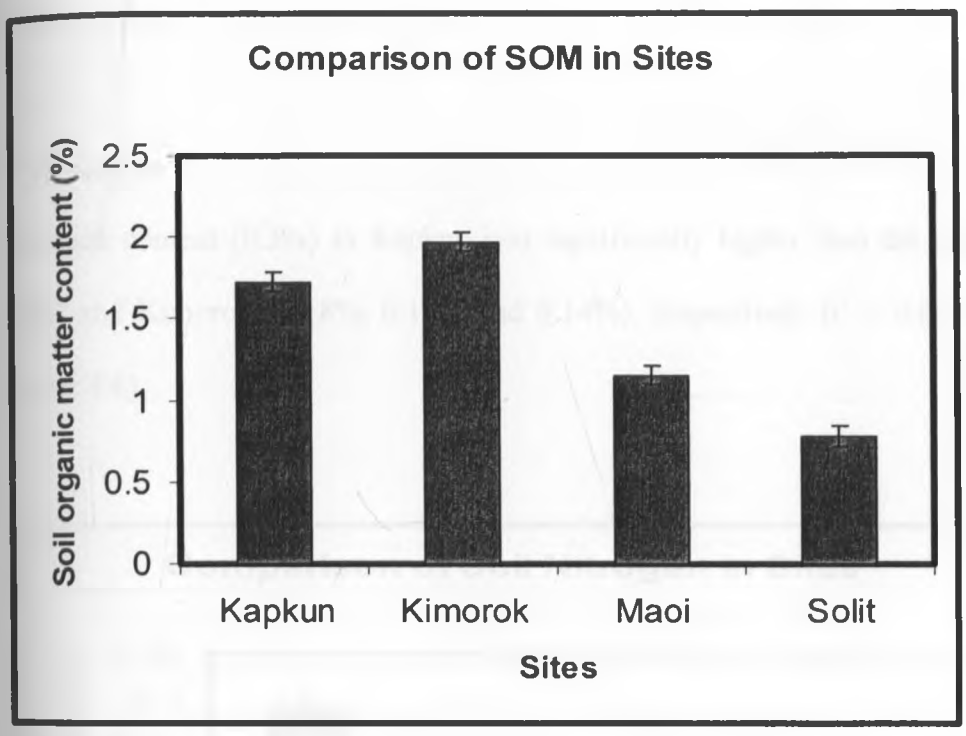

Figure 4.5 Comparison of SOM

This was attested to high clay content that enhanced the soil organic matter. Soil organic matter acts as store and supplies the plant nutrients and improves the biological functions of the soil. Maoi had higher SOM (1.15%) than 0.78% in Solit because the soils were acidic (pH 6.19), where in acid soils organic matter increases while it decreases in neutral soils (pH 7.05). These findings agree with the work by Donahue and Brann (1984), which reported that organic matter in neutral and basic soils (pH 7.0 – 7.8) decreases while it increases in acidic soils (pH 5.8 – 6.5).

Microorganisms influence the decomposition of Soil organic matter through nitrification process (Walker and Woodson, 1987; Donahue and Brann, 1984). SOM plays a key role in maintaining good physical conditions of soils including water holding capacity, provides a balanced supply of nutrients, protect nutrients against leaching by improving cation exchange capacity and greater recycling and supply of micronutrients (Vance *et al.*, 1987).

(v) Nitrogen

Nitrogen content (0.3%) in Kapkun was significantly higher than the contents at Solit, Maoi and Kimorok (0.18%, 0.17% and 0.14%), respectively ($P < 0.05$, Table 4.2 and Figure 4.6).

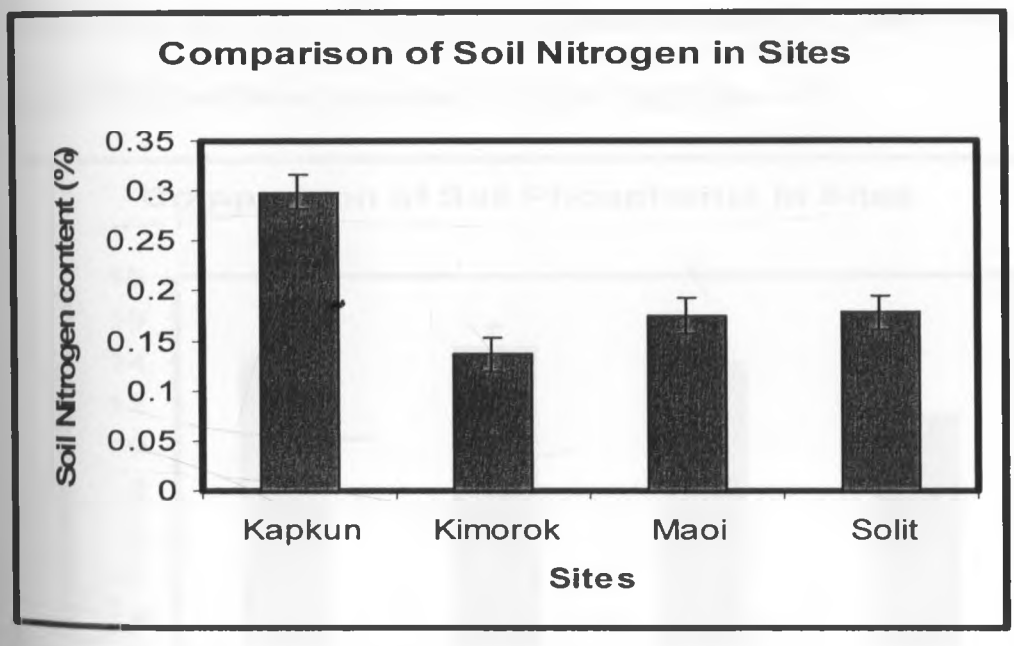

Figure 4.6 Comparison of Soil N

This was attributed to sandy clay loam with pH 5.96 which influenced the mineralization of soil organic matter by microorganisms to release oxidised ammonium ions (NH_4^+) to nitrite

and nitrate during the nitrification process (Jones, 1991). This may also be coupled with release of nitrate ions and phosphate ions that accumulated during the long period of dry season, where suddenly green plants spring up and grow rapidly within a very short time at the onset of the first rains in the drylands (Landon, 1991). Since climatic conditions play a key role in the formation of SOM content, some carbon dioxide that is released by microorganisms in the atmosphere dissolves in rainwater to form weak carbonic acid (H_2CO_3). This may react with soil minerals to form carbonates and hydrogen carbonates of calcium, magnesium and potassium within positive and negative surface charges of colloids in the soils in the wet seasons (Vance *et al.*, 1987).

(vi) Phosphorus

Phosphorus contents (11.54 ppm and 14.6 ppm) in Solit and Kimorok were significantly different from each other ($P < 0.05$), while Kapkun and Maoi (14.10 and 13.91 ppm), were not significantly different, respectively (Table 4.2 and Figure 4.7).

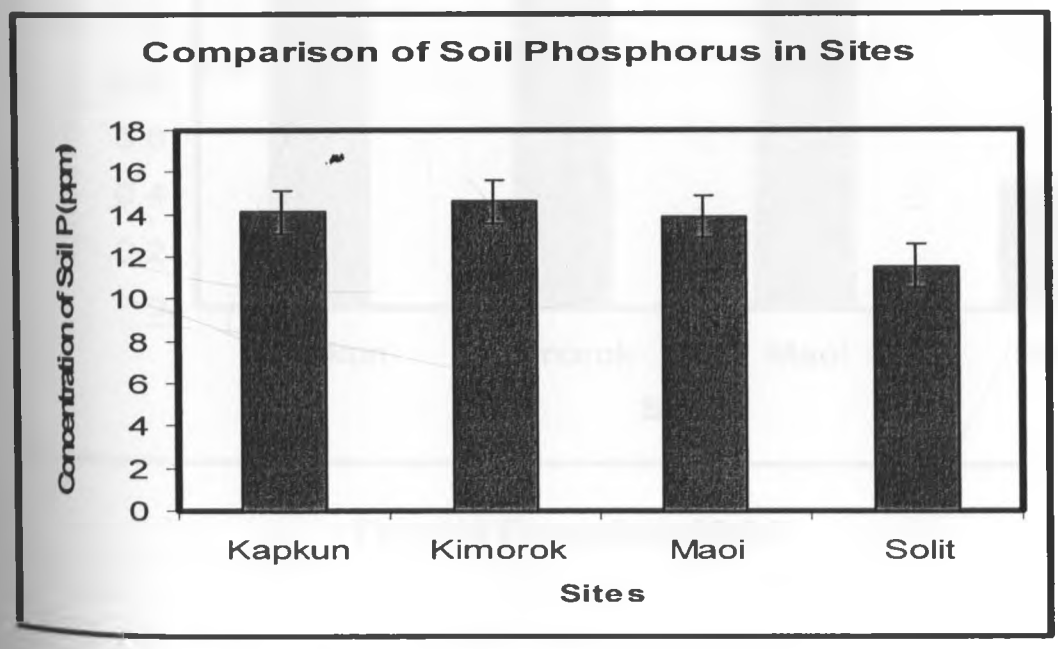

Figure 4.7 Comparison of Soil P

This was as a result of influence of calcium ions (17.33 cmol ($^+$)/kg) at soil pH 7.05 which interacted with phosphate ions to form precipitation of insoluble calcium phosphates and the solubility of phosphate ions is very dependent on soil pH that influences the availability of phosphate ions in soil solution (Tisdale *et al.*, 1985).

(vii) Potassium

Potassium of 1.57 cmol ($^+$)/kg in Kapkun was significantly higher ($P < 0.05$) than 1.24, 1.16 and 0.45 cmol ($^+$)/kg in Kimorok, Maoi and Solit, respectively (Table 4.2 and Figure 4.8).

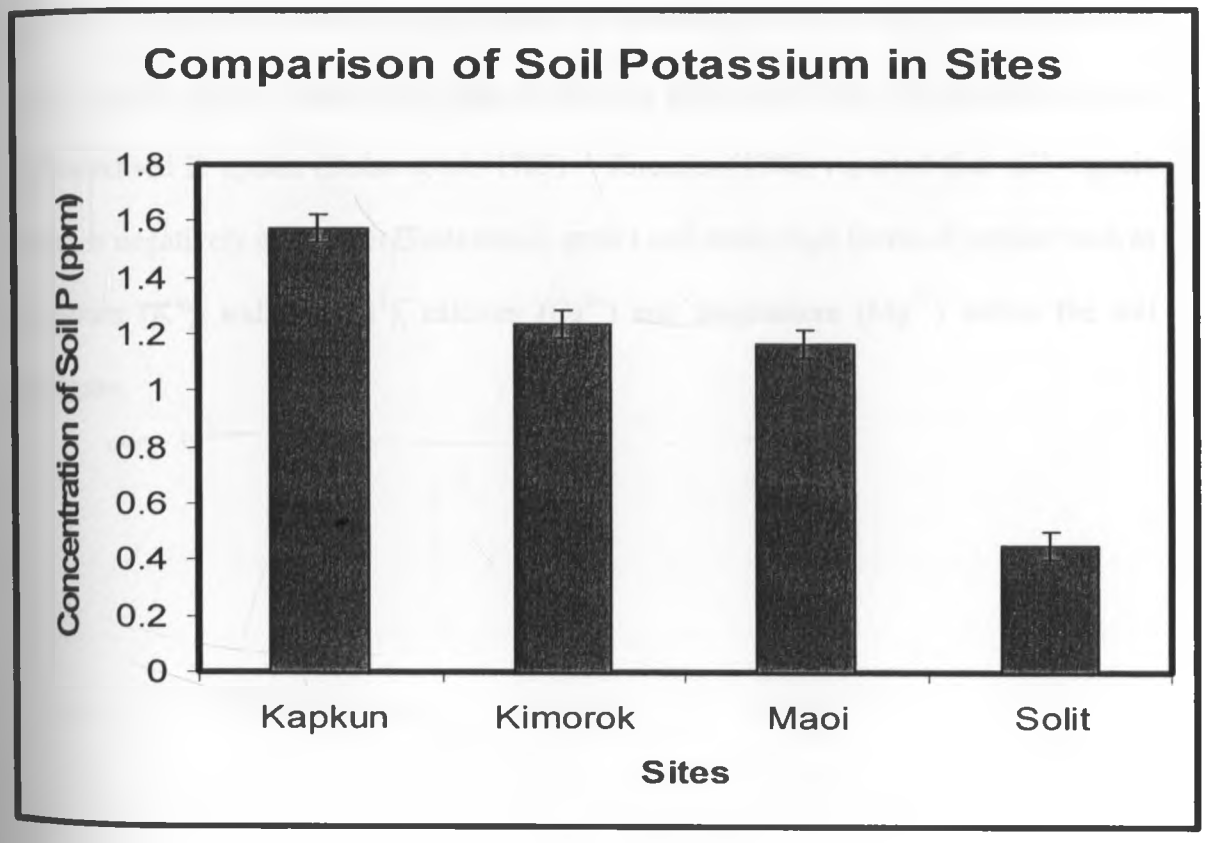

Figure 4.8 Comparison of Soil K

This was in view of the fact that clay content (15.9%) and SOM (1.73%) influenced the availability of potassium ions in soil solution (Tisdale *et al.*, 1985).

Potassium content (0.45 cmol ($^+$)/kg) in Solit was significantly lower than those of Kimorok, Kapkun and Maoi (1.25, 1.57 and 1.16 cmol ($^+$)/kg), respectively ($P < 0.05$).

Potassium content in Solit was low as a result of sandy loam texture with low soil moisture which K^+ ions were prone to leaching and interaction with other cations (Ca^{2+}, Mg^{2+} and Na^+) that reduced the concentrations of K^+ ions within the soil solution during the wet season. There were also high levels of calcium and magnesium (17.33 and 6.08 cmol ($^+$)/kg), respectively, which reduced the availability of K^+ions in the soil.

Kimorok, Kapkun and Maoi had high levels of potassium owing to sandy soils with high levels of soil organic matter that reduced leaching effects and high phosphorus contents that increased K uptake (Bohn *et al.,* 1985). Rhoades (1982) reported that soil organic matter is negatively charged colloids which attract and retain high levels of cations such as potassium (K^+), sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) within the soil aggregate.

(viii) Calcium

Calcium of 17.33 cmol ($^+$)/kg in Solit was significantly higher than those of Kimorok, Kapkun and Maoi (5.74, 6.4 and 4.97 cmol ($^+$)/kg), respectively ($P < 0.05$, Table 4.2 and Figure 4.9).

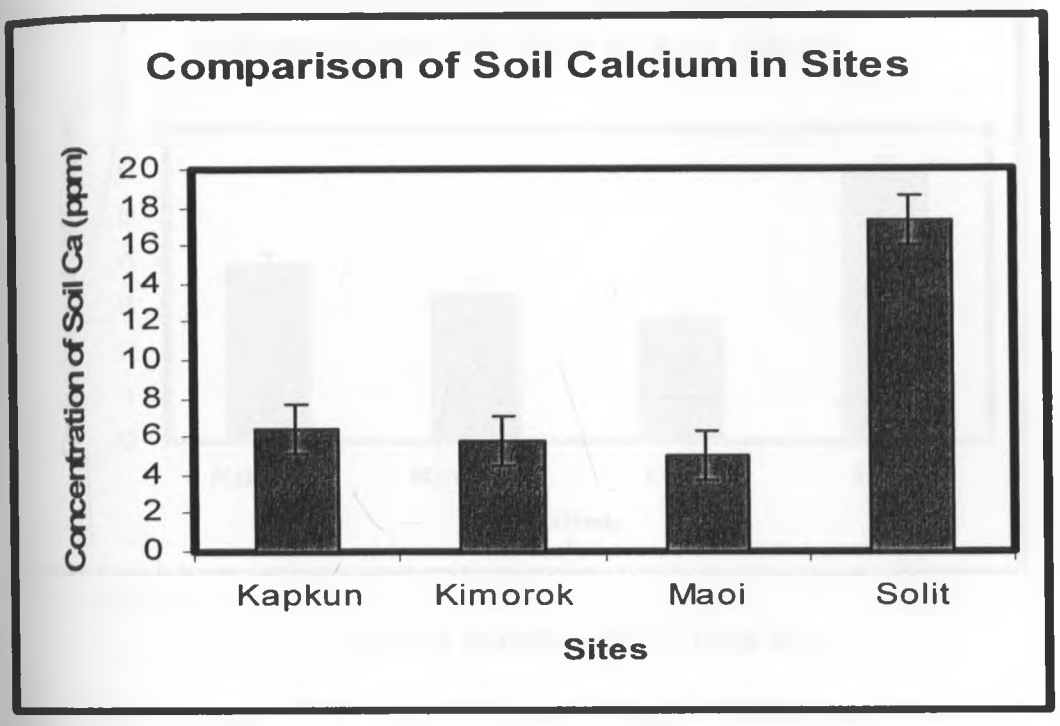

Figure 4.9 Comparison of Soil Ca

Calcium content (17.33 cmol ($^+$)/kg) in Solit was high as a result of soil pH (7.05) which influenced interaction of calcium ions in the soil solutions with phosphate ions to form precipitation of insoluble calcium phosphates. The precipitation of calcium phosphate is promoted at high soil pH which influences the fixation of phosphate ions (11.54 ppm) in the soil solution. The results of calcium levels in sandy soils of the study sites were similar to the results of Bremner and Mulvaney (1982) reported that interaction of Ca^{2+} with other cations (HPO_4^{2-}, Mg^{2+}, K^+ and Na^+) increased and protected the concentrations of Ca^{2+} ions against leaching by improving cation exchange capacity within the sandy soils.

(ix) Magnesium

Magnesium contents (6.08 and 2.75 cmol ($^+$)/kg) in Solit and Maoi were significantly different from each other as well as Kimorok and Kapkun (3.31 and 3.99 cmol ($^+$)/kg), respectively ($P < 0.05$, Table 4.2 and Figure 4.10).

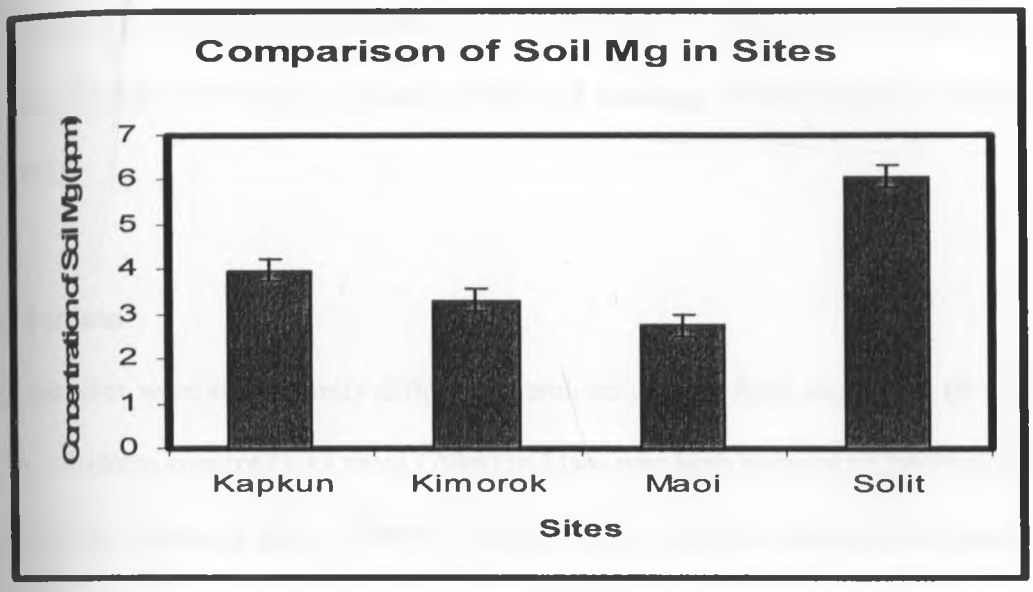

Figure 4.10 Comparison of Soil Mg

Magnesium contents (2.75 and 3.31 cmol ($^+$)/kg)) in Maoi and Kimorok were not significantly different from each other, respectively. In Solit, magnesium content (6.08 cmol ($^+$)/kg) was high in view of the fact that the high level of calcium (17.33 cmol ($^+$)/kg) may have influenced the adsorption of magnesium ions on negatively charged surfaces of soil colloids in SOM. This effect may have inhibited the leaching of Mg^{2+} under field conditions (Landon, 1991). Kapkun soils were more acidic than that of Maoi which had higher magnesium of 3.99 cmol ($^+$)/kg) than 2.75 cmol ($^+$)/kg. This was attested to high level of SOM (1.73%) compared with 1.15% of Maoi. This also agrees with the report on the work of Donahue and Brann (1984) that organic matter in neutral and basic soils (pH 7.0 – 7.8) decreases while it increases in acidic soils (pH 5.8 – 6.5). This reason applies to levels of SOM in Kimorok and Solit, respectively. Maoi had low level of magnesium

because of leaching effects in more acid sandy soils with Ca: Mg cation ratio of 3:1 on the exchange sites of soil organic matter. Rhoades (1982) reported that clay particles and soil organic matter are negatively charged colloids that may attract and retain cations such as potassium (K^+), sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}). Therefore, level of magnesium cation with high Ca: Mg cation ratio of greater than 5:1 may have influenced magnesium availability in the soil. The availability of exchangeable magnesium in soils also depends on texture, organic matter and leaching effects (Bremner and Mulvaney, 1982).

(x) Sodium

All the sites were significantly different in sodium content from each other ($P < 0.05$; Table 4.2). Sodium content (1.17 cmol ($^+$)/kg) in Maoi was high because of interaction of soluble salts in the exchange sites of SOM. This may have protected sodium ions against leaching by improving cation exchange capacity within the soil aggregates. Kapkun had low level of sodium as a result of acid sandy soils with low moisture and leaching effects that decreased sodium cations on the negative charge of the exchange sites of soil organic matter in the soil solution (Landon, 1991).

(xi) Copper

Copper content (1.67 ppm) in Solit was significantly higher than those of Kimorok, Kapkun and Maoi (0.73, 0.61 and 0.58 ppm), respectively, ($P < 0.05$, Table 4.2 and Figure 4.11).

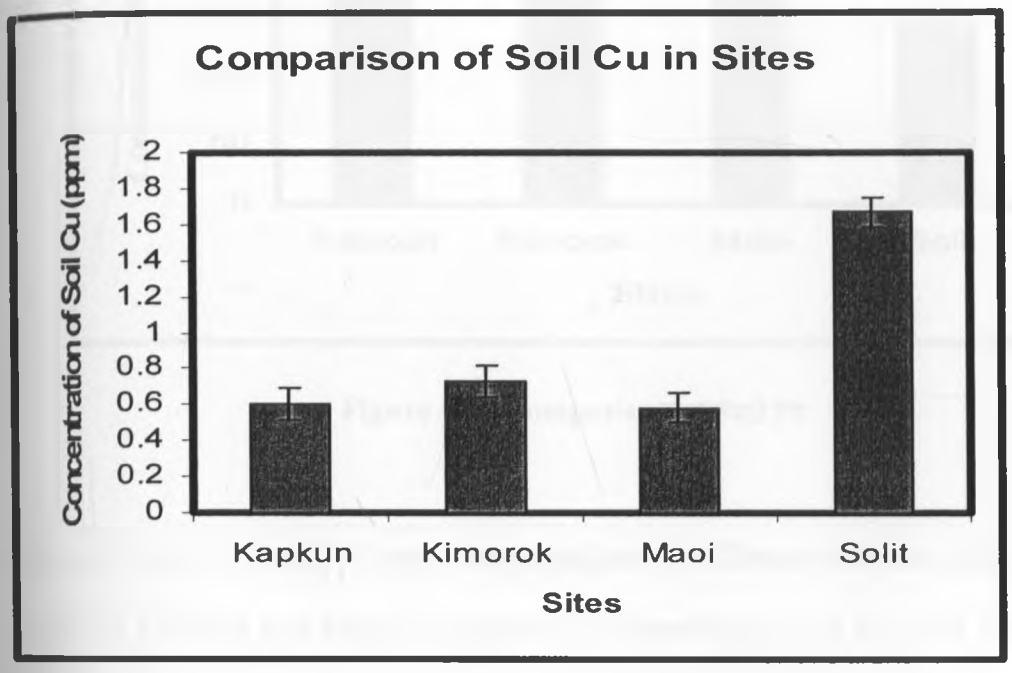

Figure 4.11 Comparison of Soil Cu

Available copper (1.67 ppm) in Solit was low because of influence of high calcium content (17.33 cmol ($^{+}$)/kg) which may have formed stable complexes with phosphates (11.4 ppm) in clay soils (14.56%) and (0.45% SOM) that inhibited copper ions by strong covalent bonding with organic matter in the soils (Tisdale *et al.*, 1985).

(xii) Iron

Available iron (287 ppm) in Maoi was significantly higher than those of Solit, Kimorok and Kapkun (151, 234 and 250 ppm), respectively ($P < 0.05$, Table 4.2 and Figure 4.12).

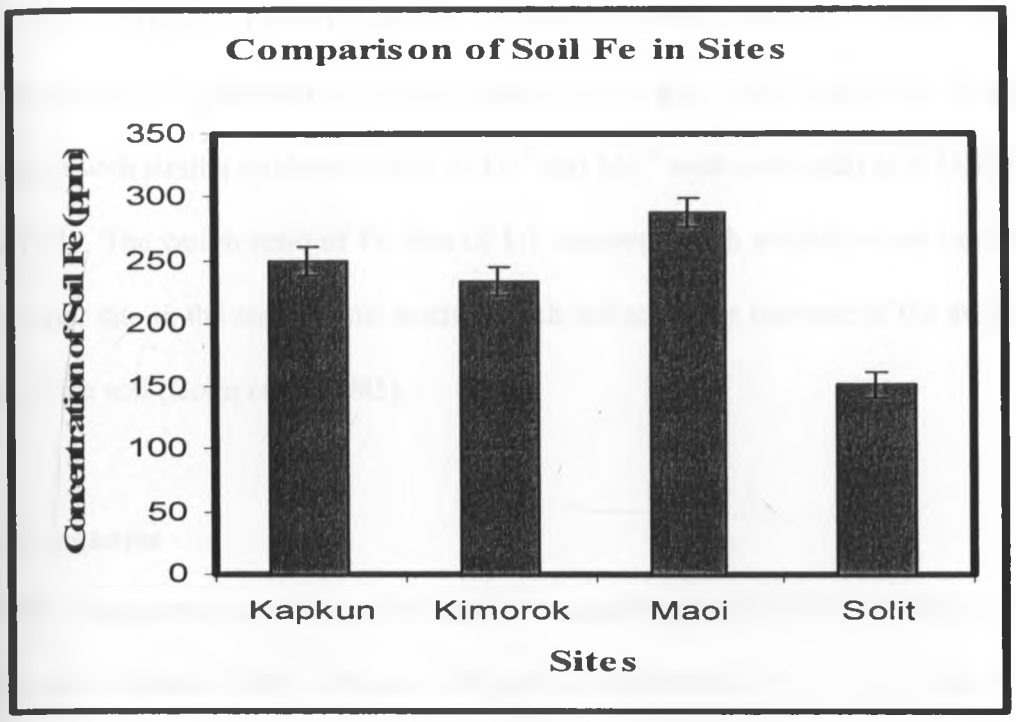

Figure 4.12 Comparison of Soil Fe

Solit and Maoi (151 and 287 ppm) were significantly different from each other ($P < 0.05$) as well as Kimorok and Kapkun, respectively while Kapkun and Kimorok (250 and 234 ppm) were not significantly different from each other. Available iron (250 and 234 ppm) in Kapkun and Kimorok were attested to soil pH given that by comparing pH of Kapkun with that of Kimorok, at pH 5.96, iron (250 ppm) increased while iron (234 ppm) at pH 6.05 had decreased. The level of iron (151 ppm) in Solit was low because of high soil pH 7.05; hence at soil pH 7.05 available Fe becomes less soluble in the soil. In view of the fact that the solubility of iron is highly dependent upon soil pH and its availability decreases at high pH in the soil solution (Parker and Walker, 1986). Increased soil pH reduces the availability of Fe^{+2} to plants through increased adsorption at negative charged exchange sites of SOM (Woolhouse, 1983).

High level of available iron in Maoi was ascribed to acidic soils (pH 6.19), as the soil becomes acidic the availability of iron increases at low pH. The interaction of iron and manganese with similar oxidation states of Fe^{+2} and Mn^{+2} with ionic radii of 0.73 and 0.75, respectively. The cation ratio of Fe: Mn of 1:1 competes with available iron ions for the same carrier site in the soil organic matter which influence the increase of the availability of iron in the soil (Bohn *et al.*, 1985).

(xiii) Manganese

Available manganese of 383 ppm in Maoi was significantly higher than those of Solit, Kapkun and Kimorok (263, 344 and 320 ppm), respectively ($P < 0.05$, Table 4.2 and Figure 4.13).

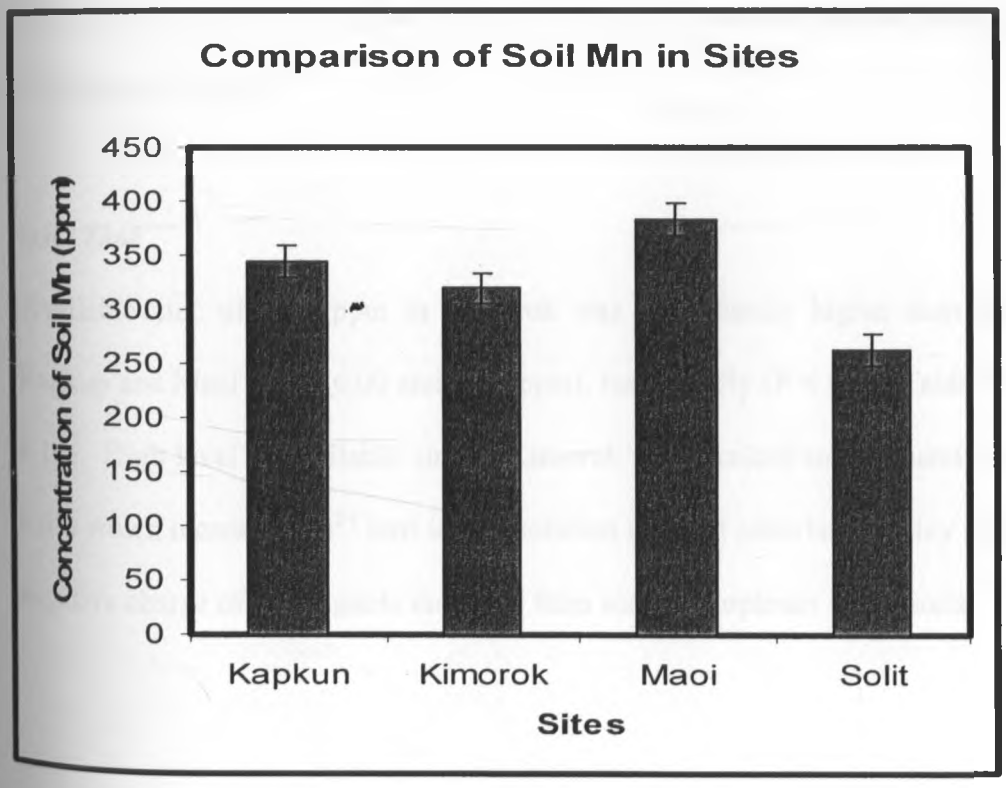

Figure 4.13 Comparison of Soil Mn

Available manganese in Maoi was high due to acid sandy soils (pH 6.19) and high soil moisture of 13.5% which aided the oxidation of manganese ions in the soil solution to enhance its availability at low pH. At soil pH 6.19, as the soil becomes acidic the availability of manganese increases, since the solubility of manganese is highly dependent upon soil pH and soil moisture during the decomposition of organic matter to release other cations (Cu^{2+}, Fe^{2+} and Zn^{2+}) in the soil.

In Solit, available manganese (263 ppm) was low by reason of high soil pH (7.05). As soil pH increases Mn^{+2} tends to precipitate, as MnO_2 thus is less available to plants. In addition, high levels of other cations (Fe^{2+} and Zn^{2+}) can reduce plant uptake of Mn^{+2}, probably through competition at binding sites of clay soils. Manganese interacts with other cations, particularly iron citrate when applied in acidic soils (pH 5.9) which increased the absorption of Mn in the roots of avocado tree which corrected Mn deficiency in clay soils (Tisdale *et al.,* 1985).

(xiv) Zinc

Available zinc of 7.64 ppm in Kimorok was significantly higher than those of Solit, Kapkun and Maoi (1.73, 6.00 and 5.06 ppm), respectively ($P < 0.05$, Table 4.2 and Figure 4.14). High level of available zinc in Kimorok was ascribed to acid sandy clay soils (pH 6.05) which increased Zn^{2+} ions in soil solution that had adsorbed on clay surfaces and the negative charge of soil organic matter to form stable complexes in the soils.

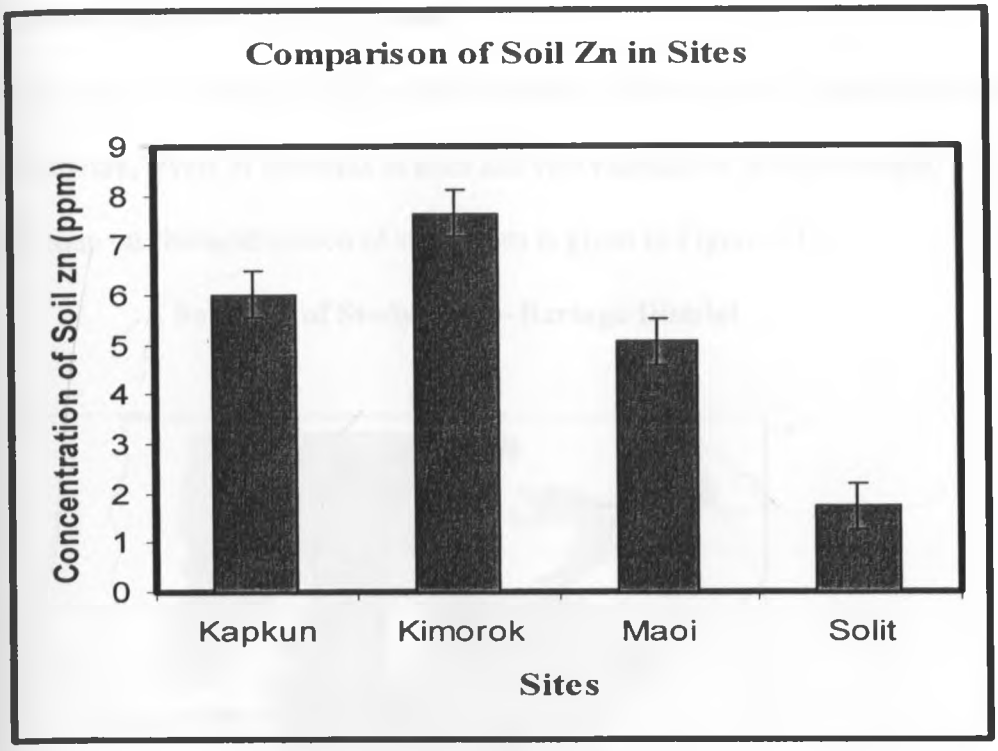

Figure 4.14 Comparison of Soil Zn

Available zinc in Kapkun and Maoi were 6.00 and 5.06 ppm, this was because of high levels of nitrogen and potassium (0.3% and 1.58 cmol (+)/kg) which inhibited the availability of zinc in the soils. The level of available zinc in Solit was low on the basis of soil pH (7.05). As soil pH increases, Zn^{+2} precipitates as $ZnFe_2O_4$ or $ZnSiO_4$ and is unavailable for plant uptake. High level of Mn (263 ppm) may also have interacted with Zn and other cations to form strong complexes on the exchange sites of soil organic matter in the soils (Jones, 1972). Available zinc was low in all the sites, as a result of high soil pH (6.0 – 7.05). At high pH, zinc precipitate to form insoluble complexes of zinc silicates in the soil, since the solubility of zinc is highly dependent upon soil pH and its availability decreases at high pH in the soil solution (Tisdale *et al.,* 1985).

4.2.1 Characterization Criteria for soils

The criteria used to characterise the soils of the study sites were soil types shown on the soil map, soil texture, levels of nutrients in soils and two varieties of *Acacia senegal.*

The soil map on characterization of study sites is given in Figure 4.15.

A Soil map of Study Sites – Baringo District

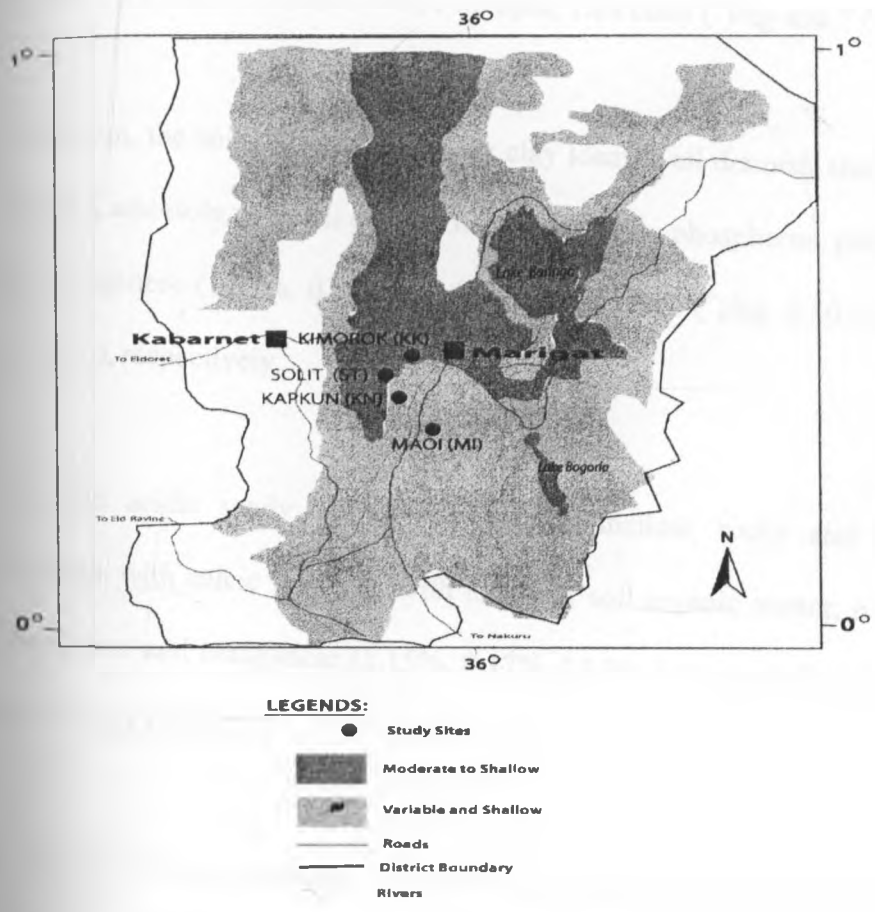

Figure 4.15: Soil Map on Characterization of Study Sites

The soil map shows the locations, colour representation and delineation boundaries of soil types of Solit, Kimorok, Kapkun and Maoi (Figure 4.15). Soil texture in Kimorok and Kapkun was sandy clay loam with ratio of sandy clay to silt clay of 2:3 and 1:2, while Solit and Maoi was sandy loam with ratio of sandy clay to silt clay of 1:5 and 2:1, respectively.

The soils of Solit were characterized as neutral sandy loam, well drained, shallow, rocky and stony calcic Xerosols with nitrogen, phosphorus, calcium, magnesium and copper of 0.18%, 11.54 ppm, 17.33 cmol ($^{+}$)/kg, 6.08cmol($^{+}$)/kg and 1.67 ppm, respectively (Table 4.2). Soils in Kimorok were acidic sandy clay loam, well drained, shallow, rocky and stony Lithosols and Xerosols with soil organic matter, carbon, nitrogen, phosphorus, potassium and zinc of 1.97%, 1.15%, 0.14%, 14.6 ppm, 1.24 cmol ($^{+}$)/kg and 7.64 ppm, respectively.

In Kapkun, the soils were acidic sandy clay loam, well drained, shallow, rocky and stony ferralic Cambisols with soil organic matter, nitrogen, phosphorus, potassium, calcium, iron and manganese (1.73%, 0.3%, 14.10 ppm, 1.58 cmol ($^{+}$)/kg, 6.40 cmol ($^{+}$)/kg, 250 ppm, 344 ppm), respectively.

Maoi had acidic sandy loam, well drained, shallow, rocky and stony ando-chromic Cambisols with calcic Xerosols with levels of soil organic matter, nitrogen, phosphorus, sodium, iron and manganese (1.15%, 0.17%, 13.90, 1.17 cmol ($^{+}$)/kg, 287 and 383 ppm), respectively (Table 4.2).

Two varieties of *Acacia senegal*; *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis* were also used to characterize the study sites. *Acacia senegal* variety *senegal* was dominant in calcic Xerosols and ferralic Cambisols with calcic Xerosols of Solit and Kapkun, while Lithosols and Xerosols and ando-chromic Cambisols with calcic xerosols of Kimorok and Maoi had only *Acacia senegal* variety *kerensis* and other closely related species.

4.3 Soil Fertility Status in the Study Sites

The nutrient levels were used to rate the soil fertility status of the study sites in relation to occurrence of *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis* according to the method of Landon (1991).

In Solit, *Acacia senegal* variety *senegal* grows well in neutral, sandy loam, calcic Xerosols, low to medium fertile with high levels of nitrogen, calcium, magnesium and copper and low levels of soil organic matter, C: N ratio, carbon, potassium, sodium, iron, manganese and zinc, respectively (Table 4.2).

The soils of Kimorok were acidic, sandy clay loam, Lithosols and Xerosols which sustained the growth of *Acacia senegal* variety *kerensis*, medium to high fertile with high levels of carbon, C: N ratio, soil organic matter, phosphorus, potassium, calcium and zinc, and low levels of nitrogen, magnesium, sodium, copper, iron and manganese.

Acacia senegal variety *senegal* in Kapkun grows well in acidic, sandy clay loam, ferralic Cambisols with calcic Xerosols, medium to high fertile with high levels of carbon, C: N ratio, soil organic matter, phosphorus, potassium, calcium and zinc, and low levels of nitrogen, magnesium, sodium, copper, iron and manganese, respectively.

In Maoi, the soils were acidic, sandy loam, ando-chromic Cambisols with calcic xerosols which supported the growth of *Acacia senegal* variety *kerensis*, low to medium fertile with high levels of nitrogen, calcium, magnesium and copper, and low levels of soil organic matter, C: N ratio, carbon, potassium, sodium, iron, manganese and zinc, respectively.

Gum arabic, a natural exudate obtained from branches and stems of *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis* is produced and the trees grow in abundance and occupies over 80 % of the vegetation cover in the study area.

4.4 Conclusions

All the soil types of the study sites had high sand content and low soil moisture and high levels of calcium and magnesium. The effect of low soil moisture regimes in sandy soils limits the nutrient uptake by plants and the physiological growth of plants and conditions of soil microorganisms in arid and semi-arid environments.

Acacia senegal variety *senegal* grows well in neutral, calcic Xerosols and acidic, ferralic Cambisols with high levels of nitrogen, potassium, calcium, magnesium and copper, respectively.

Acacia senegal variety *kerensis* grows well in acidic Lithosols and Xerosols and ando-chromic Cambisols with calcic Xerosols in high levels of carbon, phosphorus, iron, manganese and zinc, respectively.

Gum arabic, a natural exudate obtained from branches and stems of *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis* was produced in the study area.

CHAPTER FIVE

STUDIES ON MICRONUTRIENTS UPTAKE BY *ACACIA SENEGAL* VARIETIES IN A SIMULATED ARID AND SEMI-ARID ENVIRONMENT

5.1 Determination of Micronutrients Uptake by *Acacia senegal* varieties

Studies on micronutrients uptake by two *Acacia senegal* varieties using normal, low and high dosage treatments in soil and vermiculite media are given in Tables 5.1- 5.7 and Figures 5.1 – 5.12, respectively. The uptake of copper, iron, manganese and zinc by *Acacia senegal* seedlings, heights (Ht) and diameter at ground level (Dgl) and their relationships are discussed. The concentrations of micronutrients uptake by tree seedlings in soil and vermiculite media are given in Table 5.1 and 5.2.

(a) Uptake of Micronutrients on Normal and Dosage treatments in Soil Medium

(i) Copper

Uptake of copper (102.7 ppm) on dosage treatments in Solit was significantly higher ($P < 0.05$) than those of Maoi, Kimorok and Kapkun (41.4, 33.4 and 30.1 ppm), respectively (Table 5.1). This was because of *Acacia senegal* variety *senegal* that seemed to take higher levels of available copper than *Acacia senegal* variety *kerensis* from the soil than other micronutrients.

Table 5.1: Uptake of Micronutrients by *Acacia senegal* seedlings, Heights and Diameter at on Normal and Dosage Treatments in Soil Medium

Site	Variety	Medium	Cu (ppm) n=36	Fe (ppm) n=36	Mn (ppm) n=36	Zn (ppm) n=36
			Normal Treatments			
			means±S.E.	means ± S.E.	means± S.E.	means±S.E.
Solit	*senegal*	Soil	31.4±13.7	595.5±227.6	264.6±24.8	94.4±22.8
Kapkun	*senegal*	Soil	155.6±13.7	499.2±227.6	339.2±24.8	132.3±22.8
Kimorok	*kerensis*	Soil	126.9±13.7	388.7±227.6	409.9±24.8	107.1±22.8
Maoi	*kerensis*	Soil	87.1±19.4	399.8±321.9	342.1±35.1	68.5±32.2
			Dosage Treatments			
Solit	*senegal*	Soil	102.7±6.6	552.8±46.4	300.5±93.9	422.8±55.7
Kapkun	*senegal*	Soil	30.1±6.5	653.5±45.7	638.3±92.4	274.9±54.8
Kimorok	*kerensis*	Soil	33.4±5.5	366.0±38.5	307.1±78.0	533.2.0±46.2
Maoi	*kerensis*	Soil	41.4±9.0	233.8.6±62.7	519.7±126.8	200.2±75.2

Footnote: **n = number of samples analysed**

S.E. = ± Standard error

Copper uptake (155.6 ppm) in soil medium on normal treatments in Kapkun was significantly higher than the quantities of Kimorok, Solit and Maoi (126.9, 31.4 and 87.1 ppm), respectively ($P < 0.05$). This was attributed to acidic sandy clay loam soils (pH 5.95) with high soil organic matter (1.97%) that increased the availability of copper to seedlings of *Acacia senegal* variety *senegal* (Parker and Walker, 1986).

Copper uptake in soil medium on normal treatments in Kimorok and Maoi was 126.9 and 87.1 ppm and was significantly higher than 33.4 and 41.4 ppm in dosage treatments, respectively ($P < 0.05$). This was as a result of high levels of soil organic matter (1.97 and 1.15%) which enhanced the availability of copper ions to tree seedlings in the soil solution. The copper uptake (33.4 and 41.4 ppm) on dosage treatments was low because of high levels of available iron and manganese (287.20 and 383.23 ppm) that reduced the availability of copper ions in the soils. This indicates that *Acacia senegal* variety *kerensis* seems to take low concentrations of available Cu from the soil.

(ii) Iron

Iron uptake in soil medium on normal treatments (595.5 and 499.2 ppm) in Solit and Kapkun were significantly higher than 388.7 and 399.8 ppm in Kimorok and Maoi, respectively ($P < 0.05$, Table 5.1). This was ascribed to acidic sandy clay loam soils (pH 5.96) with high soil organic matter (1.73%) that increased the availability of iron to seedlings of *Acacia senegal* variety *senegal*. This shows that *Acacia senegal* variety *senegal* seems to take low concentrations of available Fe from the soil.

The uptake of iron (653.5 ppm) on dosage treatments in Kapkun was significantly higher than those of Maoi, Kimorok and Solit (233.8, 366.0 and 552.8 ppm), respectively ($P <$

0.05). This was as a result of sandy clay soils with high level of soil organic matter (1.73%), which increased iron ions that become available for uptake by tree seedlings in the soil solution. The high level of iron ions was also attributed to soil pH (5.96). At this pH iron becomes more available in low soil reaction, since the solubility of manganese is highly dependent upon soil pH (Woolhouse, 1983). Iron uptake (126.9 and 87.1 ppm) in Kimorok and Maoi, in soil medium on dosage treatments was low because of high levels of phosphorus (14.6 and 13.9 ppm, respectively) that interacted in the soil solution with iron ions that reduced its availability for the uptake by tree seedlings.

(iii) Manganese

In Kimorok, uptake of manganese (409.9 ppm) in soil medium on normal treatments was significantly higher than concentrations in Solit, Kapkun and Maoi (264.6, 339.2 and 342.1 ppm) respectively ($P < 0.05$, Table 5.1). This was as a result of soil pH (6.05). At this pH Mn becomes more available in acidic soils, and since the solubility of manganese in soil solution is highly dependent upon soil pH (Woolhouse, 1983).

In dosage treatments for Kapkun, manganese uptake of 638.3 ppm was significantly higher than those of Solit, Kimorok and Maoi (300.5, 307.1 and 519.7 ppm), respectively ($P < 0.05$). This was as a result of acid sandy clay soils with high soil organic matter (1.73%) that increased the availability of manganese to tree seedlings. This shows that *Acacia senegal* variety *senegal* tends to take higher concentrations of available Mn from the soil than other micronutrients.

Manganese uptake in soil medium on dosage treatments (300.5 ppm) at Solit was significantly lower than the quantities of Kimorok, Maoi and Kapkun (307.1, 519.7 and

638.3 ppm), respectively ($P < 0.05$). This was low due to neutral calcic Xerosols (pH 7.05). At soil pH 7.05 available Mn becomes immobile as a result of low solubility in the soil, since the solubility of manganese is highly dependent upon soil pH (Woolhouse, 1983).

Uptake of manganese decreases with high levels of soil pH, available phosphorus and copper (7.05, 11.4 and 1.67 ppm) in soils which made it unavailable to tree seedlings. Mn uptake was considerably affected by competitive interaction with high level of calcium (17.33 cmol ($^{+}$)/kg) which decreased its availability to tree seedlings. Manganese uptake of 519.7 ppm in soil medium on dosage treatments at Maoi was high as a result of high level of available Mn and soil organic matter (383 ppm and 1.15%) in the soils that increased its availability to tree seedlings.

(iv) Zinc

Zinc uptake in soil medium on normal treatments in Kapkun and Kimorok (132.30 and 107.1 ppm) was significantly higher than those of Maoi and Solit (68.5 and 94.4 ppm), respectively ($P < 0.05$, Table 5.1). This was because of high level of soil organic matter (1.97 and 1.73%) which adsorbed zinc ions in the soil solution that released to tree seedlings. Zinc uptake (68.5 ppm) in soil medium on normal treatments at Solit was low on the basis of neutral calcic Xerosols (pH 7.05). At this pH, available Zn becomes immobile because of low solubility in the soil, since the solubility of zinc is highly dependent upon soil pH (Woolhouse, 1983). Zinc uptake decreases with high levels of available copper at high pH in the soils. The uptake of zinc (94.4 ppm) on normal treatments in Maoi was low as a result of high level of available phosphorus (13.9 ppm) in the soils which may have reduced the zinc uptake by the seedlings of *Acacia senegal* variety *kerensis*.

The uptake of zinc (533.2 ppm) in dosage treatments in Kimorok was significantly higher than 200.2, 274.9 and 422.8 ppm in Maoi, Kapkun, and Solit, respectively ($P < 0.05$). This was as a result of acid sandy clay soils with high soil organic matter (1.73%) that increased the availability of zinc to be more available to tree seedlings. This shows that *Acacia senegal* variety *senegal* tends to take higher concentrations of available Zn from the soil than other micronutrients.

Uptake of zinc by tree seedlings in soil medium on dosage treatments in Maoi and Kapkun (200.2 and 274.9 ppm) was significantly lower ($P < 0.05$) than 422.8 ppm in Solit, respectively. This was low on the basis of high levels of available phosphorus (13.9 and 14.05 ppm) that interacted with available Zn that made it unavailable to tree seedlings (Woolhouse, 1983). Uptake of zinc (422.8 ppm) in soil medium on dosage treatments in Solit was high as a result of low level of available Fe (151 ppm). The available iron ions interacted with Zn in the soils with soil organic matter (0.78%) that enhanced its availability to tree seedlings.

Table 5.2: Uptake of Micronutrients by Acacia senegal seedlings, Heights and Diameter on Normal and Dosage Treatments in Vermiculite Medium

Site	Variety	Medium	Cu (ppm) n=36	Fe (ppm) n=36	Mn (ppm) n=36	Zn (ppm) n=36	P n
				Normal Treatments			
			means±S.E.	Means ± S.E.	means± S.E.	means±S.E.	n
Solit	***senegal***	Verm	29.8±13.70	383.2±227.60	114.5±24.80	86.6±22.80	1
Kapkun	***senegal***	Verm	39.9±13.70	291.8±227.60	95.3±24.80	112.5±22.80	1
Kimorok	***kerensis***	Verm	33.8±14.10	376.2±234.20	161.0±25.60	81.8±23.50	1
Maoi	***kerensis***	Verm	87.7±13.70	672.1±59.20	157.6±242.80	153.4±22.80	1
				Dosage Treatments			
Solit	***senegal***	Verm	49.0±6.30	547.1±44.30	468.9±89.70	284.3±53.20	1
Kapkun	***senegal***	Verm	46.0±6.30	353.3±44.30	422.9±89.70	356.0±53.20	1
Kimorok	***kerensis***	Verm	55.9±7.30	485.1±50.70	499.60±97.32	621.6±60.80	1
Maoi	***kerensis***	Verm	65.0±9.00	405.7±62.70	264.1±126.80	594.9±75.20	1

Footnote: n = number of samples analysed; S.E. = Standard error; Ver

(b) Uptake of Micronutrients on Normal and Dosage treatments in Vermiculite Medium

(i) Copper

In vermiculite medium, copper uptake (87.7 ppm) on normal treatments in Maoi was significantly higher than for Kapkun, Solit and Kimorok (39.9, 29.8 and 33.8 ppm), respectively ($P < 0.05$, Table 5.2). In Kimorok, Kapkun and Solit, copper uptake of 33.8, 39.9 and 29.8 ppm were not significantly different from each other. This was as a result of *Acacia senegal* variety *kerensis* that had an affinity for copper uptake in the medium. The effect of vermiculite medium showed that copper uptake increased growth of tree seedlings of *Acacia senegal* variety *kerensis*. This effect confirmed that vermiculite is a good medium for determining the levels of micronutrient uptake by each variety of *Acacia senegal*. Growth of seedlings in vermiculite medium indicates that *Acacia senegal* variety *kerensis* in Maoi tends to take high concentrations of copper in the nutrient solutions. In Maoi, copper uptake (65.0 ppm) in vermiculite medium on dosage treatments was significantly higher ($P < 0.05$) than those of Kimorok, Solit and Kapkun (39.9, 29.8 and 33.8 ppm), respectively. This reason was similar to that of normal treatments.

(ii) Iron

In Maoi, iron uptake (672.08 ppm) in vermiculite on normal treatments was significantly higher than those of Solit, Kapkun and Kimorok (383.2, 291.8 and 376.18 ppm), respectively ($P < 0.05$, Table 5.2). This was as a result of the effect of vermiculite medium, a homogenous inert medium which indicated that *Acacia senegal* variety *kerensis* had high affinity for iron uptake in the nutrient solutions. The level of iron uptake (547.1 ppm) in vermiculite medium on dosage treatments at Solit was higher than those of Kimorok, Maoi

and Kapkun (485.1, 405.7 and 353.3 ppm), respectively. This was attested to *Acacia senegal* variety s*enegal* that had high tendency for iron uptake in the nutrient solutions. Vermiculite medium also revealed the interaction effects of high levels of Cu (102.7 ppm) in the soil medium on dosage treatments through competitive interactions with cations of iron and copper. This inhibited the uptake of iron that led to decrease in the growth of tree seedlings from 169.7 mm to 168.3 mm and also concentrations of copper from 595.5 to 552.8 ppm (Table 5.2). This also reveals that *Acacia senegal* variety *senegal* take higher levels of available iron than *Acacia senegal* variety *kerensis* from the soil than other micronutrients.

(iii) Manganese

In Kimorok, manganese uptake (161.0 ppm) in vermiculite on normal treatments was significantly higher than those of Kapkun Solit, and Maoi (95.3, 114.5 and 157.6 ppm), respectively ($P < 0.05$, Table 5.2). This was on the basis of *Acacia senegal* variety *kerensis* that had high affinity for manganese in the nutrient solutions.

Uptake of Mn (468.9 ppm) in vermiculite medium on dosage treatments at Solit was significantly higher than those of Maoi, Kimorok and Kapkun (64.1, 400.6 and 422.9 ppm), respectively ($P < 0.05$, Table 5.2). This was as a result of similar cation ratio Cu: Mn (1:1) which interacted with Mn ions because of similar ionic radii with Cu (in the oxidation state of Cu^{2+} and Mn^{2+}) that increased the uptake of manganese by tree seedlings. Manganese uptake (400.6 and 422.9 ppm) in vermiculite at Kimorok and Kapkun was also high because of high levels of iron (485.1 and 353.3 ppm) which may have enhanced the availability of manganese uptake by seedlings of *Acacia senegal* variety *kerensis* and *Acacia senegal* variety *senegal*.

Vermiculite medium also showed consistent growth pattern on the concentrations of uptake of micronutrients by seedlings of *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis*.

(iv) Zinc

Zinc uptake (153.4 ppm) in vermiculite medium on normal treatments in Maoi was significantly higher ($P < .05$) than those of Kapkun, Kimorok and Solit (112.5, 81.8 and 86.6 ppm), respectively (Table 5.2). This was because of high level of iron and manganese that enhanced the availability of zinc which indicates *Acacia senegal* variety *kerensis* to tend to take high level of iron in the nutrient solutions.

The uptake of zinc (621.6 ppm) in dosage treatments in Kimorok was significantly higher ($P < 0.05$) than those in Maoi, Kapkun, and Solit (594.9, 356.0 and 284.3 ppm), respectively. This was as a result of high level of magnesium that enhanced zinc availability and the effect of vermiculite medium, a homogenous inert medium with no organic matter apart from the applied nutrients. This revealed that *Acacia senegal* variety *kerensis* had high affinity for zinc uptake.

(b) Heights and diameter at ground level (Dgl) on Normal and Dosage treatments in Soil and Vermiculite media

(i) Heights of Tree seedlings on Normal treatments in Soil and Vermiculite medium

The heights and diameter at ground levels (Dgl) of *Acacia senegal* seedlings on normal and dosage treatments in soil and vermiculite media are given in Tables 5.1 and 5.2. Comparisons of heights on normal treatments in soil and vermiculite media are showed in Figure 5.1.

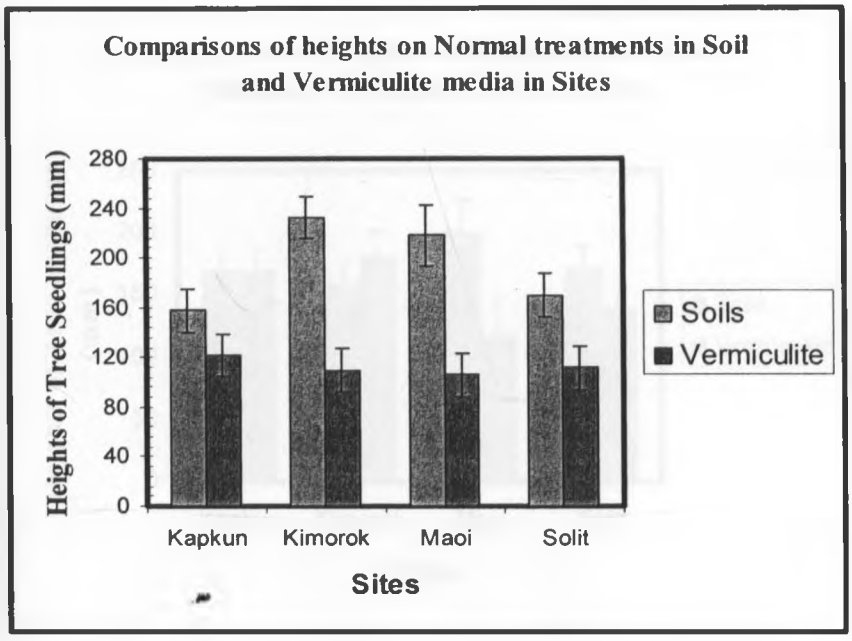

Figure 5.1 Comparisons of Heights on Normal treatments in Soil and Vermiculite media

The height of *Acacia senegal* seedlings in soil medium of 232.4 mm in Kimorok was higher than those of Kapkun, Solit and Maoi (158.0, 169.7 and 217.8 mm), respectively ($P < 0.05$). This was as a result of high level of soil organic matter (1.97%) that increased the growth of tree seedlings. In vermiculite medium, Kapkun had 121.8 mm higher than those in Maoi, Kimorok and Solit (106.1, 109.8 and 111.4 mm), respectively. This was attributed to high levels of Fe and Zn (291.8 and 112.5 ppm) that enhanced the growth of seedlings.

The heights in soil medium in all the sites were higher than those in vermiculite medium. This was because soil, a heterogeneous medium had inherent nutrients while vermiculite was homogeneous inert medium.

(ii) Heights of Tree seedlings on Dosage treatments in Soil and Vermiculite medium

Figure 5.2 shows the comparisons of heights of *Acacia senegal* seedlings on dosage treatments in soil and vermiculite media in the sites.

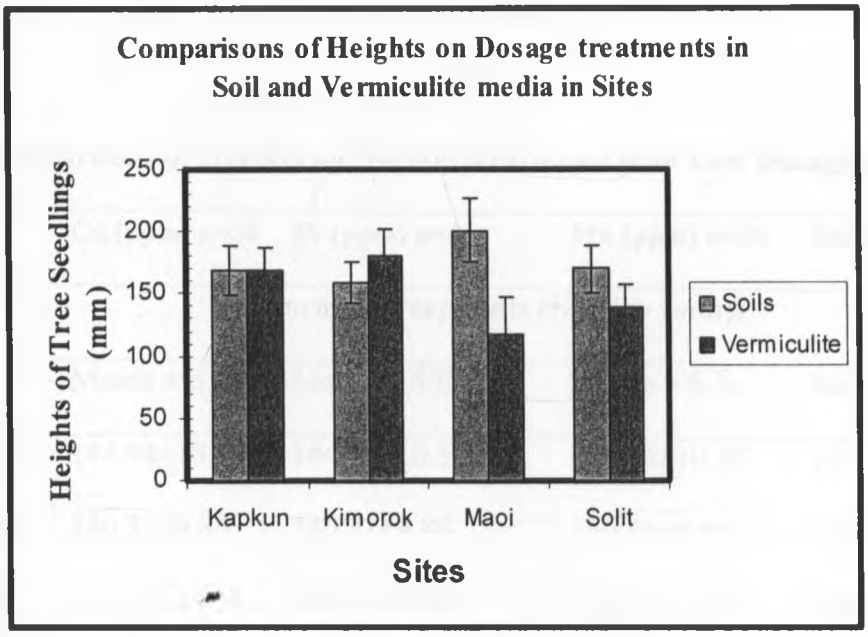

Figure 5.2 Comparisons of Heights on Dosage treatments Soil and Vermiculite media

The height of seedlings in Maoi (201.1 mm) on dosage treatments in soil medium was higher ($P < 0.05$) than those of Kapkun, Solit and Kimorok (170.1, 168.3 and 159.0 mm), respectively. This was as a result of high level of soil organic matter (1.15%) that increased the growth of tree seedlings. In vermiculite medium, the height of tree seedlings in Kimorok (180.1 mm) was higher ($P < 0.05$) than 116.8, 169.2 and 139.2 mm in Maoi, Kapkun and Solit, respectively. This was attested to *Acacia senegal* variety *kerensis* that

tends to take high level of Zn (621.6 ppm) in the nutrient solutions that enhanced the growth of seedlings. The heights of tree seedlings in soil medium in Maoi, Kapkun and Solit (except in Kimorok) were higher than in vermiculite medium. This is because soils (heterogeneous medium) have inherent nutrients while vermiculite has homogeneous inert medium.

(c) Comparisons of Heights on Normal treatments with Low Dosage treatments

The comparisons micronutrients uptake by tree seedlings for heights on copper normal treatments with low dosage treatments is given in Table 5.3.

Table 5.3 Comparisons of Heights on Normal treatments with Low Dosage treatments

Site	Cu (ppm) n=36	Fe (ppm) n=36	Mn (ppm) n=36	Zn(ppm) n=36
	Normal Treatments (Heights (mm))			
	Means ± S.E.	Means ± S.E.	Means ± S.E.	Means ± S.E.
Solit	144.94±10.58	144.94±10.58	144.94±10.58	144.94±10.58
Kapkun	140.71±9.86	140.71±9.86	140.71±9.86	140.71±9.86
Kimorok	184.63±13.18	184.63±13.18	184.63±13.18	184.63±13.18
Maoi	162.61±10.58	162.61±10.58	162.61±10.58	162.61±10.58
	Low Dosage Treatments			
Solit	206.69±10.58	172.85±11.59	170.42±11.59	172.20±10.58
Kapkun	149.20±11.60	159.20±10.01	172.88±9.86	154.71±9.86
Kimorok	162.11±13.22	177.91±11.61	160.67±13.20	179.15±11.60
Maoi	155.74±10.58	168.41±11.60	161.54±10.58	186.32±11.59

Footnote: n= number of samples analysed

S.E. = Standard error

(i) Comparisons of Heights on Cu Normal treatments with Low Cu Dosage

Heights of *Acacia senegal* seedlings in low dosage of Cu (206.69 mm) in Solit was significantly higher than heights of seedlings with copper in normal treatments (144.94 mm) for Kapkun, Kimorok and Maoi (149.2, 162.11 and 155.74 mm), respectively ($P < 0.05$, Table 5.3, Figure 5.3 and Appendix II).

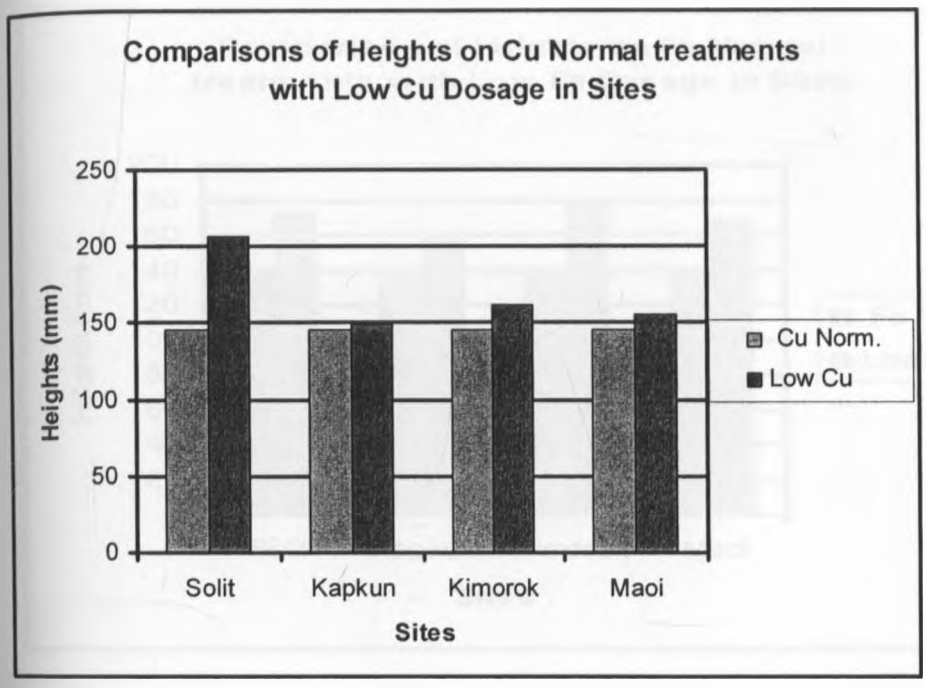

Figure 5.3 Comparisons of Heights on Cu Normal treatments with Low Cu Dosage

This was because of high level of iron (653.51 ppm) which interacted with copper ions in the soil solution. This interactive effect may have been suppressed by the high levels of calcium and magnesium (17.33 and 6.08 cmol (+)/kg) in the nutrient solutions. This enhanced the growth of the tree seedlings to height of 206.69 mm (Table 5.3). The copper and iron interaction in Solit was higher than in Kapkun, Kimorok and Maoi with Cu/Fe cation ratios (Solit: Kapkun 15:1, Solit: Kimorok 4:1, and Solit: Maoi 6:1). High levels of iron ions (Fe^{3+}) in the oxidation state of +3 in the soil solution may have reduced high levels of available calcium and magnesium to release copper ions for uptake by plants (Tisdale *et al.*, 1985).

(ii) Comparisons of Heights on Iron Normal with Low Fe treatments

The heights of *Acacia senegal* seedlings in low Fe dosage (177.91 mm) in Kimorok was significantly higher than heights of seedlings in Solit, Kapkun and Maoi (172.85, 159.2 and 168.41 mm), respectively, compared with iron normal treatment of 140.71 mm ($P < 0.05$, Figure 5.4).

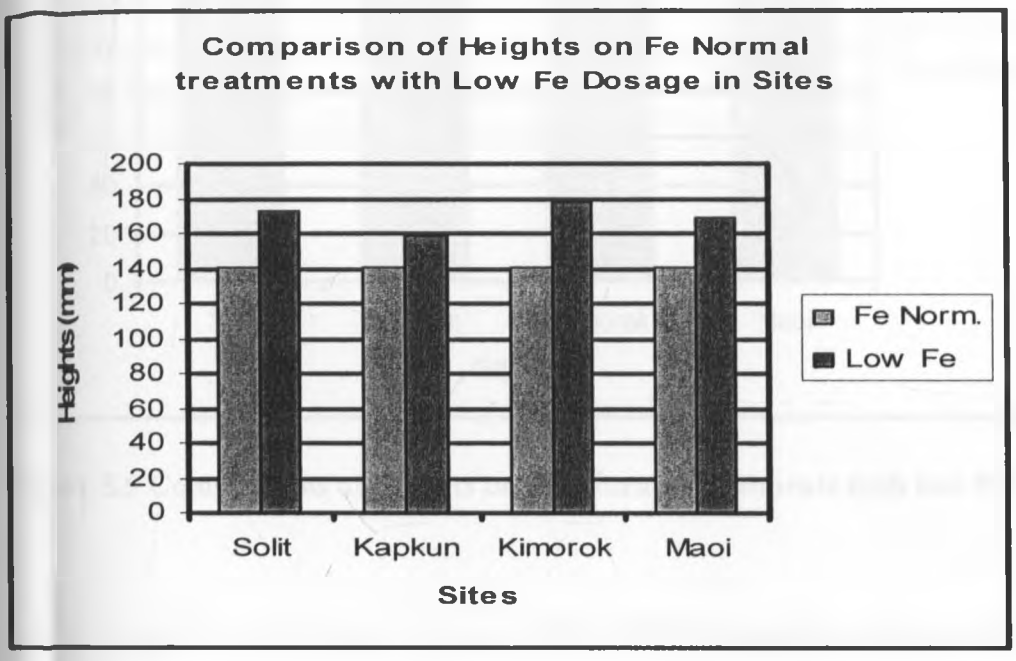

Figure 5.4 Comparisons of Heights on Fe Normal treatments with low Fe Dosage

The height of tree seedlings in Kimorok attained 177.91 mm on the basis of high level of available Zn (7.50 ppm) in the soils that interacted with iron ions of similar ionic radii (Fe^{3+} = 0.73 and Zn^{2+} = 0.83 nm) in the soil solution that enhanced Fe uptake by tree seedlings.

(iii) Comparisons of Heights on Manganese Normal with Low Mn treatments

The heights of tree seedlings in Kapkun on low Mn dosage treatments attained 172.88 mm compared with 140.71 mm on normal treatments. This was higher than those of Solit, Kimorok and Maoi (170.42, 160.67 and 161.54 mm), respectively (($P < 0.05$, Figure 5.5 and Appendix II).

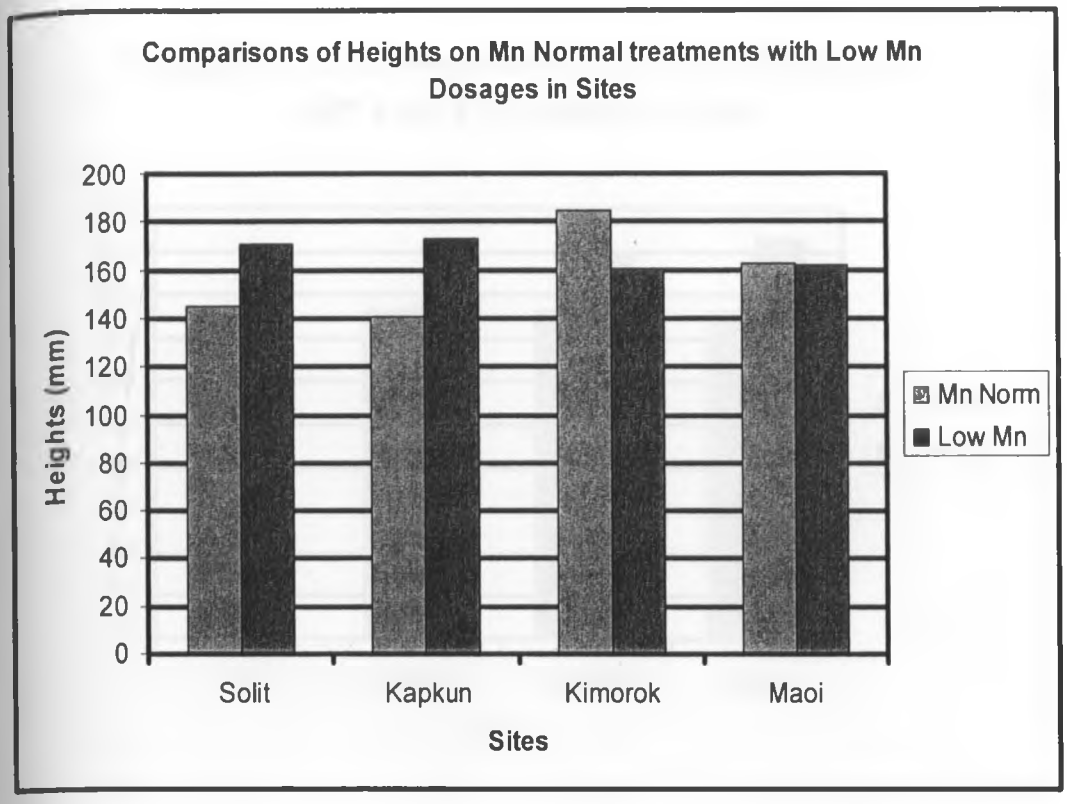

Figure 5.5 Comparisons of Heights on Mn Normal treatments with low Mn Dosage

This was as a result of acid sandy clay soils (pH 5.96) with high soil organic matter (1.73%) that increased the availability of manganese to be more available for uptake by tree seedlings.

(iv) Comparisons of Heights on Zinc Normal with Low Zn treatments

Heights of *Acacia senegal* seedlings on low Zn dosage (186.3 mm) in Maoi compared with 152.6 mm on normal treatments was higher than those of Kimorok, Kapkun and Solit (179.2, 154.7 and 172.2 mm), respectively ($P < 0.05$, Figure 5.6).

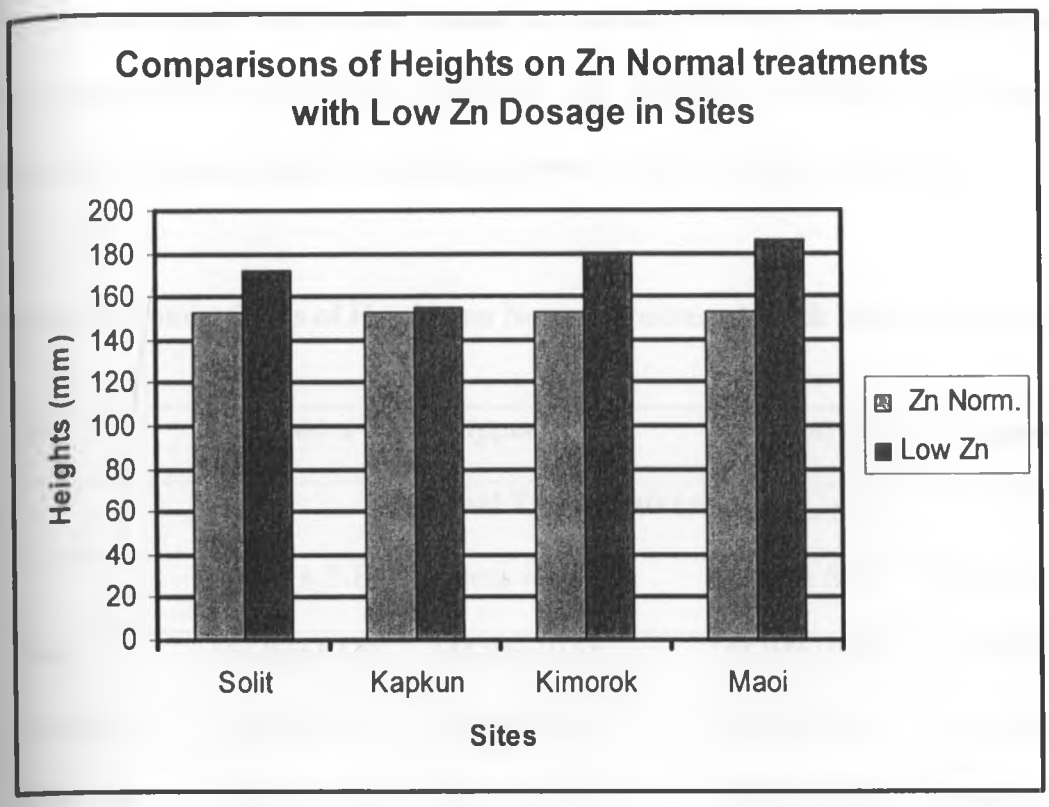

Figure 5.6 Comparisons of Heights on Zn Normal treatments with low Zn Dosage

Heights of tree seedlings (186.3 and 179.2mm) in Maoi and Kimorok were high on the basis of available Zn at low soil pH (6.2 and 6.0). At this pH Zn becomes more available to seedlings of *Acacia senegal* variety *kerensis*. These results agree with work by Parker and Walker (1986) which states that the solubility of zinc is highly dependent upon soil pH and its availability decreases at high pH in the soil solution. At Kapkun, the heights of *Acacia senegal* variety *senegal* seedlings were low as a result of high level of nitrogen (0.3%) in the soils which reduced the availability of Zn uptake. *Acacia senegal* variety *kerensis* in Kimorok and Maoi (186.3 and 179.2mm) attained higher heights in soil medium than *Acacia senegal* variety *senegal* in Solit and Kapkun (172.2 and 154.71 mm), respedtively. This was attested to *Acacia senegal* variety *kerensis* that seemed to take higher levels of available zinc than *Acacia senegal* variety *senegal* from the soil than other micronutrients.

(d) Comparisons of Heights on Normal treatments with High Dosage treatments

The comparisons micronutrients uptake by tree seedlings for heights on copper normal treatments with high dosage treatments is given in Table 5.4 (See Appendix II).

Table 5.4 Comparisons of Heights on Normal treatments with High Dosage treatments

Site	Cu (ppm) n=36	Fe (ppm) n=36	Mn (ppm) n=36	Zn (ppm) n=36
	Normal Treatments (mm)			
	Means ± S.E.	Means ± S.E.	Means ± S.E.	Means ± S.E.
Solit	144.94±10.58	144.94±10.58	144.94±10.58	144.94±10.58
Kapkun	140.71±9.86	140.71±9.86	140.71±9.86	140.71±9.86
Kimorok	184.63±13.18	184.63±13.18	184.63±13.18	184.63±13.18
Maoi	162.61±10.58	162.61±10.58	162.61±10.58	162.61±10.58
	High Dosage Treatments			
Solit	160.63±10.58	189.37±11.60	155.41±10.58	145.98±10.57
Kapkun	163.58±9.860	168.21±9.86	160.25±9.86	148.92±9.86
Kimorok	172.03±11.642	161.52±13.23	154.05±13.18	178.40±11.60
Maoi	167.61±13.75	130.16±11.61	145.48±10.58	158.46±10.58

Footnote:

n= number of samples analysed

S.E. = Standard error

(i) Comparisons of Heights on Copper Normal with High Cu treatments

The height of tree seedlings on high dosage of Cu in Kimorok had 172.03 mm compared with 144.94 mm of copper at normal treatment. This was significantly higher than those of Kapkun, Solit and Maoi (163.58, 160.63 and 167.61 mm), respectively ($P < 0.05$, Figure 5.7 and Appendix II).

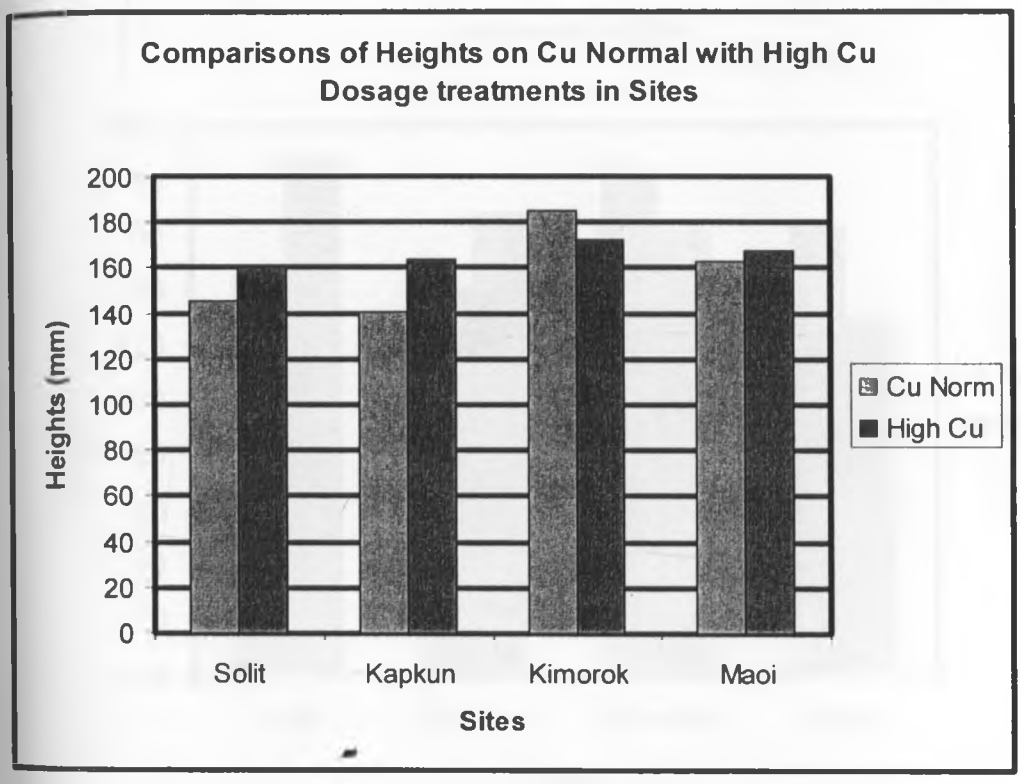

Figure 5.7 Comparisons of Heights on Cu Normal treatments with High Cu Dosage

This was because of high level of soil organic matter (1.97%) mineralized through microbial decomposition process to release available Cu ions in the soil solution which increased the height of tree seedlings to 172.03 mm. The height of tree seedlings in Maoi on high copper dosage (167.61 mm) was significantly higher than those of Kapkun and Solit (163.58 and 160.63 mm), respectively ($P < 0.05$). This was attributed to 6.2 pH. At this pH, copper ions in the soil solution were oxidized to Cu^{+2} and becomes more available for uptake by the seedlings.

(ii) Comparisons of Heights on Iron Normal with High Fe treatments

The height of tree seedlings on high Fe dosage in Solit had 189.37 mm compared with 140.71 mm on normal treatments. This was significantly higher than those of Kapkun, Kimorok and Maoi (168.21, 161.52 and 130.16 mm), respectively ($P < 0.05$, Figure 5.8).

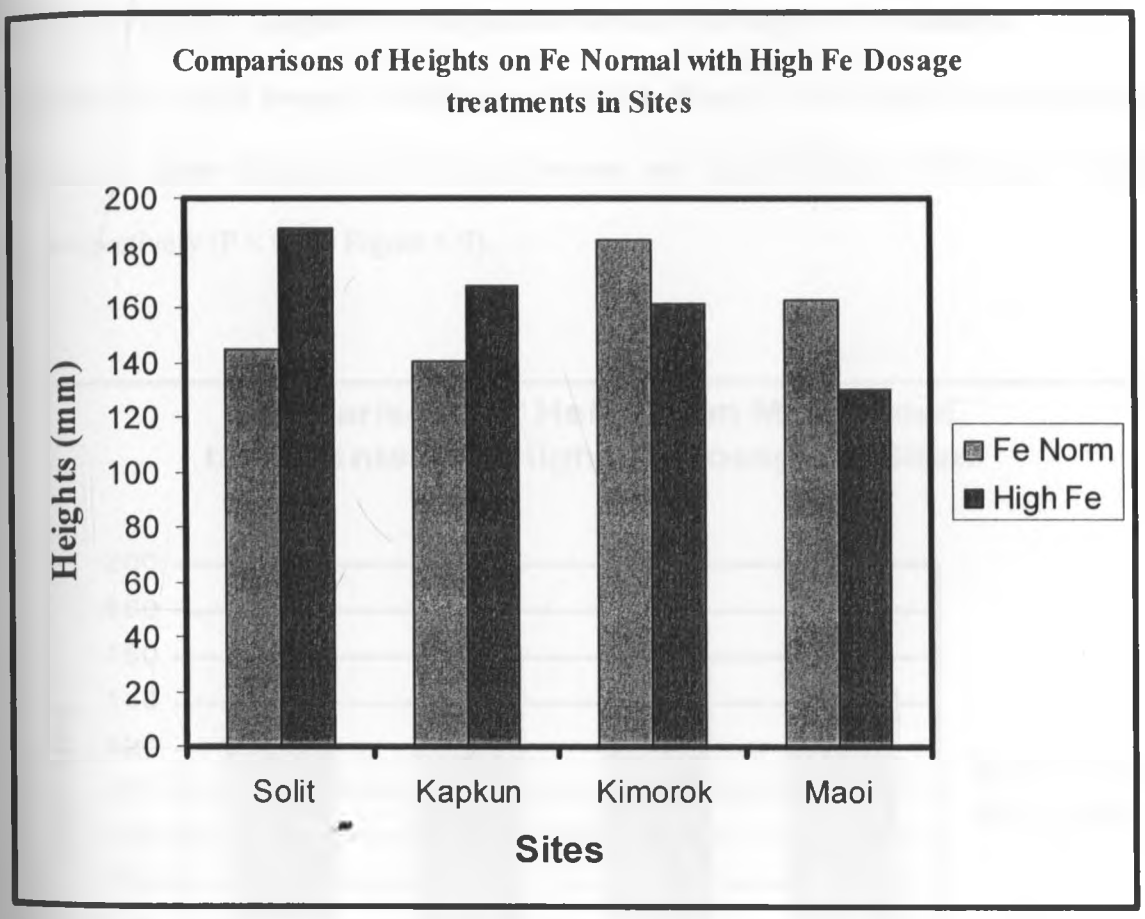

Figure 5.8 Comparisons of Heights on Fe Normal treatments with high Fe Dosage

This was as a result of *Acacia senegal* variety *senegal* that showed a tendency to take higher levels of available iron than *Acacia senegal* variety *kerensis* from the soils. Tree seedlings on high iron dosage (130.16 mm) in Maoi were significantly lower than those of Solit, Kapkun and Kimorok (189.37, 168.21 and 161.52 mm), respectively ($P < 0.05$).

This was ascribed to acidic soils (pH 6.2) with high levels of nitrogen and phosphorus (0.17% and 13.9 ppm) which reacted with iron, forming a precipitate of iron ammonium phosphate (Fe (NH_4) $PO_4.H_2O$)) in the soil solution. This made iron less available for uptake by tree seedlings.

(iii) Comparisons of Heights on Manganese Normal with high Mn treatments

The height of *Acacia senegal* seedlings on high Mn dosage (160.25 mm) in Kapkun was significantly higher than those of Solit, Kimorok and Maoi (155.41, 154.05 and 145.48 mm), respectively ($P < 0.05$, Figure 5.9).

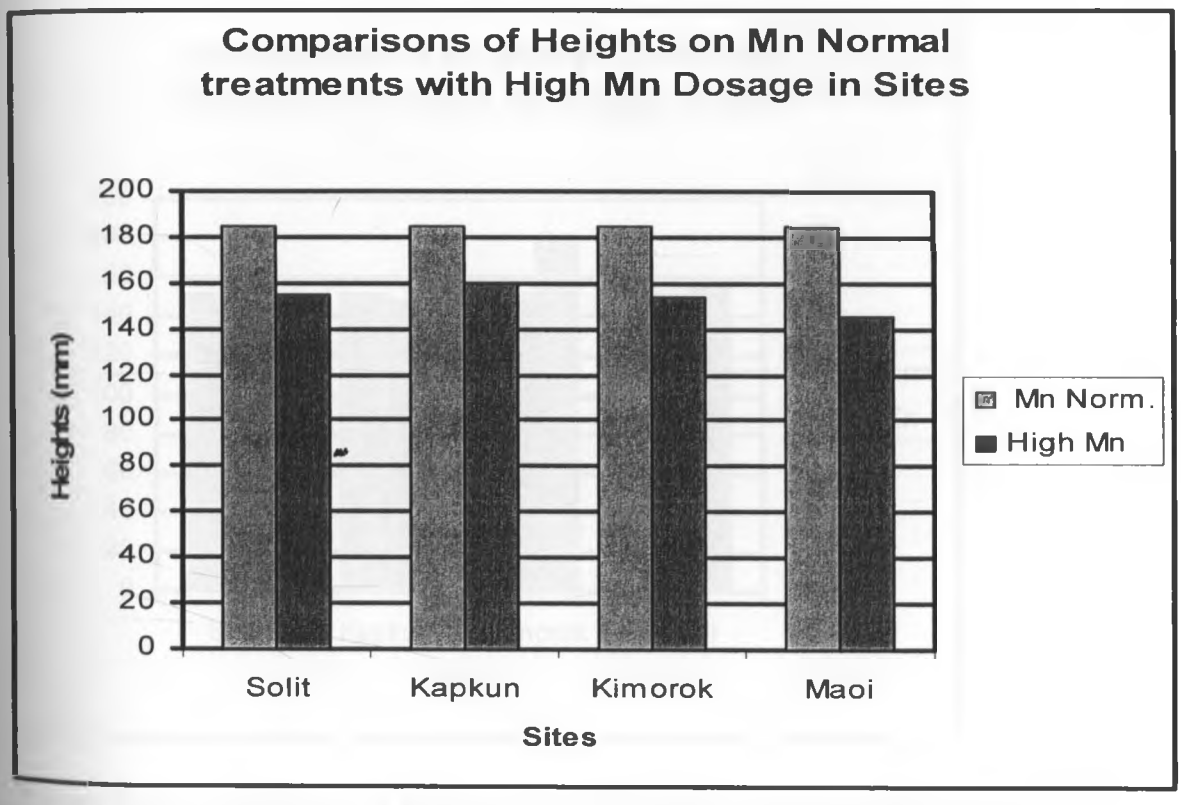

Figure 5.9 Comparisons of Heights on Mn Normal treatments with high Mn Dosage

This was on the basis of soil pH 5.96. As soil pH decreases, Mn^{+2} become more available for uptake by tree seedlings. High levels of calcium and magnesium (6.38 and 3.96 cmol (+)/kg) may have interacted with manganese ions in the soil solution which made Mn less available for uptake by tree seedlings.

(iv) Comparisons of Heights on Zinc Normal with High Zn treatments

At Kimorok, the height of seedlings on high Zn dosage was 178.4 mm compared with zinc normal treatments of 152.6 mm. This was significantly higher than those of Solit, Kapkun and Maoi (146.0, 148.9 and 158.5 mm), respectively ($P < 0.05$, Figure 5.10).

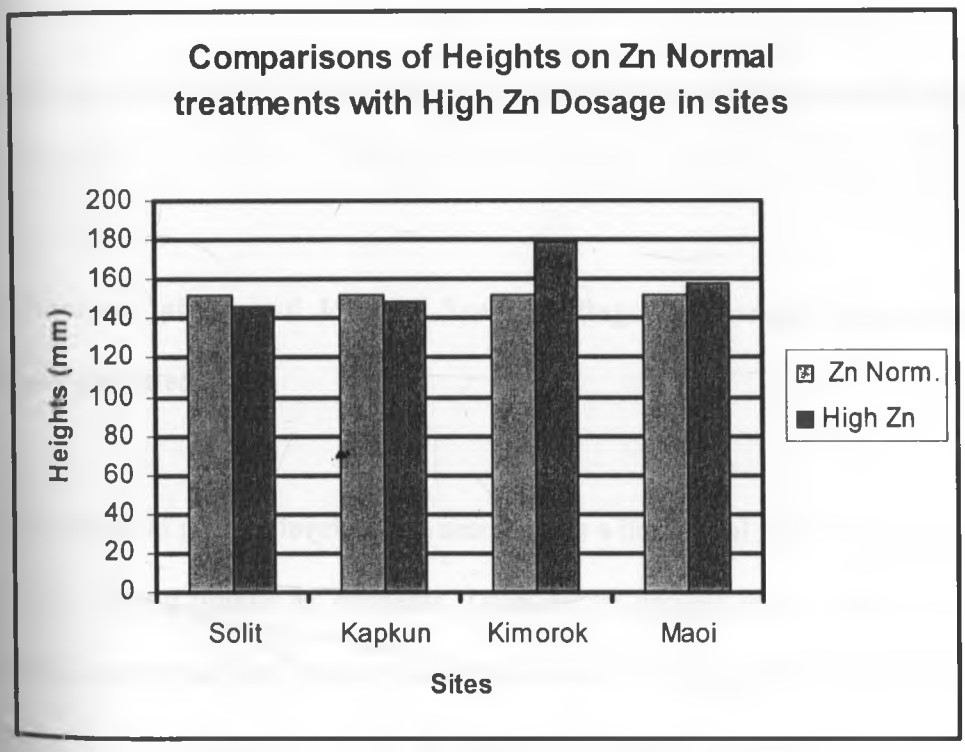

Figure 5.10 Comparisons of Heights on Zn Normal treatments with high Zn Dosage

The heights of tree seedlings on high Zn dosage treatments in Kimorok and Maoi were 178.4 and 158.5 mm, respectively. This was as a result of available zinc that hydrolysed as Zn^{2+} ions in the soil solution at low soil pH (6.19 and 6.05), since the solubility of zinc is highly dependent upon soil pH. At low pH, Zn becomes more available to seedlings of *Acacia senegal* variety *kerensis.*

At Solit and Kapkun, the heights of the seedling were low as a result of the presence of high levels of calcium and phosphorus (17.33 cmol $(^{+})$/kg and 14.4 ppm) in the soils which decreased the availability of zinc for uptake by seedlings of *Acacia senegal* variety *senegal.*

(e) Diameter at ground level (Dgl) on Uptake of Micronutrients on Normal and Dosage treatments

(i) Diameter at ground level of Tree seedlings on Normal treatments in Soil and Vermiculite media

The diameter at ground level of tree seedlings is a horizontal growth that increases the basal diameter during uptake of nutrients. Diameter at ground levels (Dgl) of *Acacia senegal* seedlings on normal and dosage treatments in soil and vermiculite media are given in Tables 5.1 and 5.2. Comparisons of Dgl on normal and dosage treatments in soil and vermiculite media are showed in Figures 5.11 and 12.

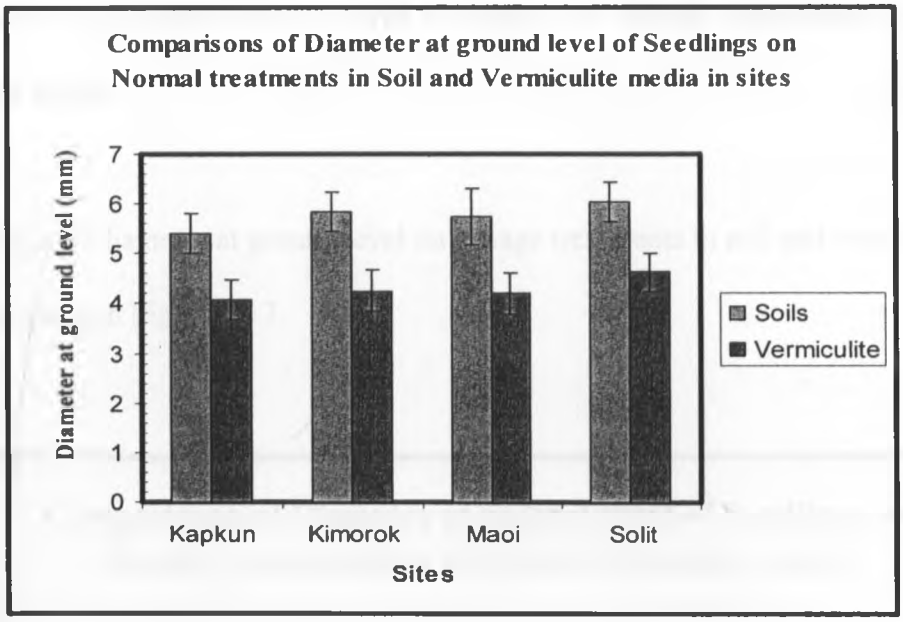

Figure 5.11 Comparisons of Diameter at ground level on Normal treatments in Soil and Vermiculite media

The diameter at ground levels (Dgl) of *Acacia senegal* seedlings on normal treatments in soil and vermiculite media in Solit, Kimorok, Maoi and Kapkun were 6.0, 5.9, 5.7 and 5.4 mm and 4.6, 4.1, 4.3 and 4.2 mm, respectively. These were not significantly different from each other at $P > 0.05$. This was as a result of slow growth rate of *Acacia senegal* variety *kerensis* and *Acacia senegal* variety *senegal* as adaptation mechanism to survive in low soil moisture regimes under dryland conditions. The diameter at ground level of seedlings in soil medium in all the sites were higher than in vermiculite medium as a result of soil that had inherent nutrients while vermiculite was an inert medium.

(ii) Diameters at ground level of Tree seedlings on Dosage treatments in Soil and Vermiculite media

Comparisons of diameter at ground level on dosage treatments in soil and vermiculite media are given in Figure 5.12.

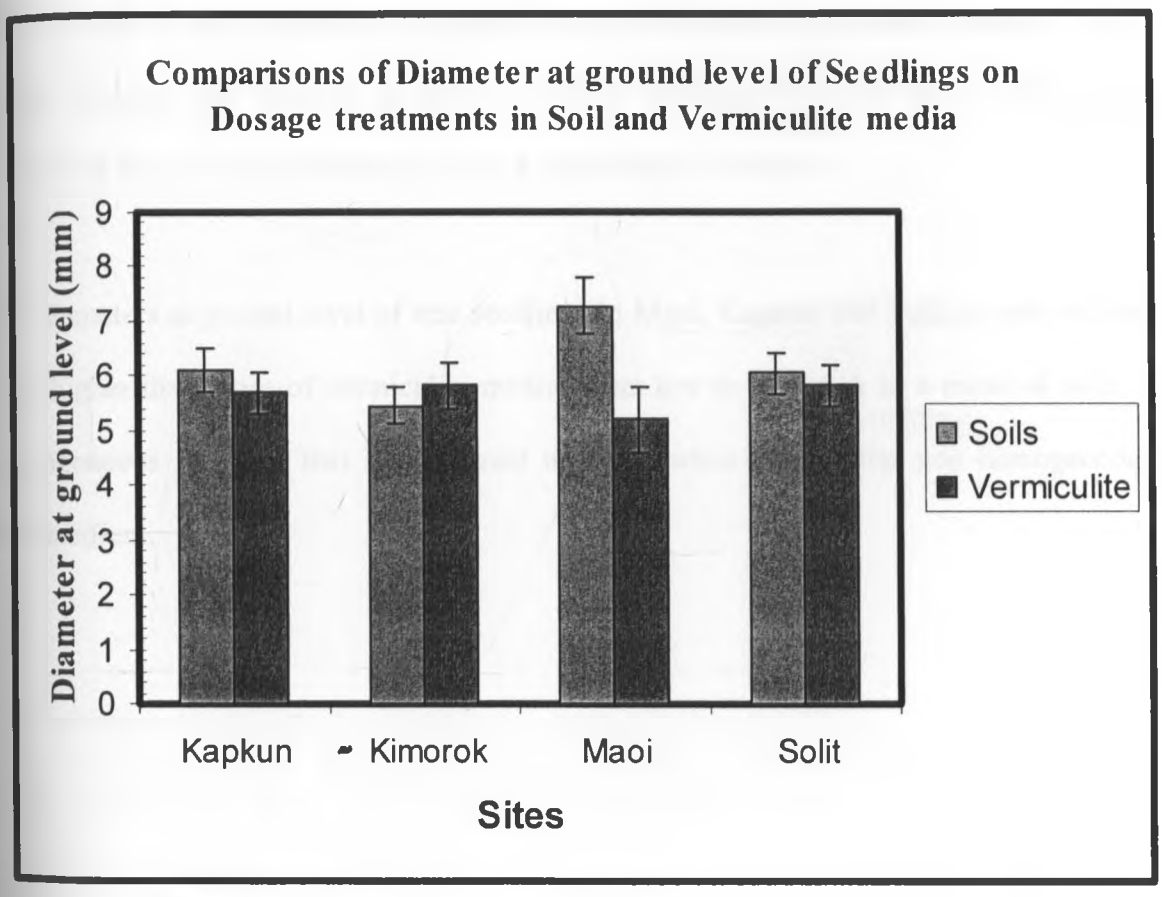

Figure 5.12 Comparisons of Diameter at ground level on Dosage treatments in Soil and Vermiculite media

The diameter at ground level of seedlings in Maoi of 7.3 mm on dosage treatments in soil medium was higher than 6.0, 6.1 and 5.5 mm in Kapkun, Solit and Kimorok, respectively ($P < 0.05$). This was as a result of high level of soil organic matter (1.15%) that increased the growth.

There were no significant differences in Dgl of tree seedlings in Solit, Kimorok and Kapkun (5.8, 5.8 and 5.7 mm), respectively, except in Maoi (5.2 mm) in vermiculite medium. These results indicate that diameter at ground level of seedlings is not a good indicator for measuring the growth performance of the *Acacia senegal* varieties.

The diameters at ground level of tree seedlings in Maoi, Kapkun and Solit in soil medium were higher than those of vermiculite medium, but low in Kimorok as a result of soils, a heterogeneous medium, that had inherent nutrients while vermiculite was homogeneous inert medium.

(f) Comparisons of Diameter at ground level on Copper Normal treatments with Low Cu treatments

The diameters at ground level of *Acacia senegal* seedlings for normal and dosage treatments of micronutrients uptake are given in Table 5.5.

Table 5.5: Diameter at Ground level of Tree seedlings for Normal and Dosage Treatments

	Diameter at Ground level (Dgl)			
Site	**Cu (ppm) n=36**	**Fe (ppm) n=36**	**Mn (ppm) n=36**	**Zn (ppm) n=36**
	Normal Treatments (mm)			
	mm±S.E.	**mm±S.E.**	**mm±S.E.**	**mm±S.E.**
Solit	6.14±0.53	5.91± 0.49	6.64±0.66	5.61±0.53
Kapkun	6.14±0.53	5.91± 0.49	6.64±0.66	5.61±0.53
Kimorok	6.14±0.53	5.91± 0.49	6.64±0.66	5.61±0.53
Maoi	6.14±0.53	5.91± 0.49	6.64±0.66	5.61±0.53
	Low Dosage Treatments			
Solit	6.74±0.53	6.60± 0.58	4.88± 0.58	5.71±0.53
Kapkun	4.85±0.58	5.21±0.51	5.20±0.49	5.65±0.49
Kimorok	5.33±0.66	5.78±0.58	6.48±0.66	5.05±0.58
Maoi	5.71±0.53	5.45±0.58	5.80±0.53	5.25±0.58
	High Dosage Treatments			
Solit	5.95±0.53	5.86±0.58	6.31±0.53	5.60 ±0.53
Kapkun	5.80±0.49	5.75±0.49	8.10±0.49	5.16±0.49
Kimorok	5.89±0.58	5.86±0.66	5.95±0.66	5.65±0.58
Maoi	4.91±0.69	5.18±0.58	5.63±0.53	5.35±0.53

Footnote: n= number of samples analysed

S.E. = Standard error

The comparisons of diameters at ground level of tree seedlings in Solit on low Cu dosage of 6.74 mm with copper normal treatments of 6.14 mm was higher than those of Kapkun, Kimorok and Maoi (4.85, 5.33 and 5.71 mm), respectively ($P < 0.05$, Table 5.5 and Appendix II).

Copper uptake in both treatments at Solit was high because of high levels of iron (552.8 ppm) that interacted with copper ions in soils and enhanced copper uptake by tree seedlings. Diameter at ground level on iron uptake in Solit with low and high dosages was 6.60 and 5.86 mm, respectively. This was as a result of nitrogen (0.18%), in the soils which enhanced the iron uptake by seedlings of *Acacia senegal* variety *senegal*.

Diameter at ground level of 8.10 mm in Kapkun for manganese uptake on high dosage was higher than 6.48 mm on low dosage in Kimorok, respectively. This was ascribed to acid sandy soils (6.0 and 5.96) in both sites. At this pH, manganese becomes more available to seedlings of *Acacia senegal* variety *kerensis* and *Acacia senegal* variety *senegal*.

There were no significant differences in Dgl of tree seedlings (5.71, 5.65, 5.25 and 5.05 mm) on low Zn dosage in Solit, Kapkun, Kimorok and Maoi, respectively. The seedlings with diameter at ground level of 5.71 mm in Solit on low Zn dosage (6.74 mm) were higher ($P < 0.05$) than 5.25 and 5.05 mm in Kimorok and Maoi, respectively. This was attributed to high level of available copper (1.67 ppm) in the soils which enhanced the uptake of zinc by promoting the growth of the seedlings. There were no significant differences in Dgl of tree seedlings (5.60, 5.16, 5.65 and 5.35 mm) on high Zn dosage treatment in Solit, Kapkun, Kimorok and Maoi, respectively. In Kimorok, the diameter at ground level of tree seedlings on high Zn dosage treatment was 5.65 mm higher than 5.60, 5.16 and 5.35 mm in Solit, Kapkun and Maoi, respectively.

This was attributed to high clay (16.27%) and soil organic matter (1.97%) that released Zn uptake as required by the tree seedlings. In Solit, zinc uptake was low because of soil pH of 7.05. At this pH, Zn becomes less soluble in the soil, since the solubility of zinc is highly dependent upon soil pH (Woolhouse, 1983). *Acacia senegal* variety *kerensis* in Kimorok and Maoi seems to take higher level of zinc from the soils than other micronutrients, respectively.

The average heights and diameter at ground level (Dgl) of seedlings on dosage treatments of 197.2 and 6.3 mm in soil medium were higher than 130.2 and 5.3 mm in vermiculite medium in all the sites. This was attributed to interactive effects in the soil, a heterogeneous medium with factors affecting the soil characteristics such as pH, nutrient changes, soil organic matter, sites, treatments (nutrients) and other cations within soil aggregates that influence the physiological growth of plants. These results revealed that *Acacia senegal* variety *senegal* tends to take high levels of copper, iron and manganese while *Acacia senegal* variety *kerensis* takes high levels of zinc from the soils than other micronutrients.

These results indicate that variations in micronutrient uptake and growth pattern are on the basis of soil medium, a heterogeneous medium with unequal competitions of cation and different levels of interactions with other cations in the soils. Vermiculite, a homogenous inert medium, with equal competitions and interactions of cations, differentiated the concentrations of Cu, Fe, Mn and Zn uptake for the two varieties of *Acacia senegal*. The medium also showed the effect of micronutrients uptake on levels of tolerance and response of seedlings of *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis*.

5.2 Response of *Acacia senegal* varieties to Micronutrient uptake

Copper uptake of 102.7 ppm in Solit indicated that *Acacia senegal* variety *senegal* absorbed high levels of Cu, while *Acacia senegal* variety *kerensis* in Kimorok and Maoi absorbed low levels of copper uptake, respectively. This was ascribed to the ability of *Acacia senegal* variety *senegal* which absorbed higher concentrations of available Cu than that of *Acacia senegal* variety *kerensis*. *Acacia senegal* variety *senegal* was more tolerant to high level of copper, while *Acacia senegal* variety *kerensis* was tolerant to low levels of Cu. These findings do not agree with report by Mitchell (1964) on ranges of concentration of copper in plants (7 to 30 mg kg^{-1}). However, the result agrees with the suggestion that the concentration depends on the type of soil and plant species and may fall outside these ranges. The high levels of iron uptake of 751.71 ppm in vermiculite medium in Solit was due to the efficiency of *Acacia senegal* variety *senegal* which absorbed high levels of Fe, while *Acacia senegal* variety *kerensis* in Maoi and Kimorok had low efficiency of iron uptake at low levels. This implies that *Acacia senegal* variety *senegal* is less susceptible to iron deficiency while *Acacia senegal* variety *kerensis* is highly sensitive to iron toxicity at high levels of Fe.

The uptake of iron and manganese of 653.5 and 638.25 ppm in soil medium in Kapkun showed that *Acacia senegal* variety *senegal* has higher affinity to absorb available Mn than *Acacia senegal* variety *kerensis*. This showed that *Acacia senegal* variety *senegal* was more tolerant to manganese toxicity than *Acacia senegal* variety *kerensis*.

The levels of zinc uptake of 533.20 and 882.68 ppm in soil and vermiculite media in Kimorok is attributed to the ability of *Acacia senegal* variety *kerensis* in Kimorok to take up high levels of Zn.

Acacia senegal variety *senegal* in Solit and Kapkun absorbed low levels of zinc. This showed that *Acacia senegal* variety *kerensis* tolerated high levels of Zn while *Acacia senegal* variety *senegal* tolerated low levels of Zn. *Acacia senegal* variety *senegal* tends to take high levels of copper, iron and manganese uptake from the soils than other micronutrients. *Acacia senegal* variety *kerensis* takes high levels of zinc from the soils than other micronutrients. *Acacia senegal* variety *kerensis* was less susceptible to high levels of iron and copper.

5.2.1 Concentrations of Micronutrient uptake by *Acacia senegal* varieties

Micronutrient concentrations in *Acacia senegal* seedlings was based on low, normal and high range, according to ratings of Mitchell (1964), Stout (1961), Jones (1972) and Landon (1991). The concentrations of micronutrients uptake by plants as deficient, sufficient, excessive or toxic are given in Table 5.6. These ranges were from mature leaves of different species and varieties of crops.

Table 5.6 Concentration of micronutrients uptake by plants

	Micronutrients		
	Deficient	**Sufficient (Adequate)**	**Excessive or toxic**
	Ppm		
Copper	< 4	5 – 20	> 20
Iron	< 50	50 – 250	Not known
Manganese	< 20	20 – 500	> 500
Zinc	< 20	25 – 150	> 400

Ref: Stout (1961); Mitchell (1964), Jones (1972) and Landon (1991)

Copper concentrations in plants range between 5 -20 ppm and deficiencies and toxicity occur at less than 4 ppm and above 20 ppm, respectively (Jones, 1972). Sufficient iron concentrations range from 50 to 250 ppm, and young plants have normal concentrations of 300 to 400 ppm, while deficiencies at levels below 50 ppm and toxicity are rare under field conditions. Manganese range from 20 to 500 ppm and deficiencies at levels below 50 ppm and toxicity levels exceed 500 ppm. Zinc concentrations range from 25 to 150 ppm and deficiencies and toxicity occur at less than 20 ppm and above 400 ppm, respectively. These are generalized ranges but there are considerable different between species and even between varieties of the same species (Jones, 1972). The categorized concentration range of micronutrients uptake by *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis* on low and high levels of tolerance are given in Table 5.7.

Table 5.7 Concentration Ranges of Micronutrients uptake by *Acacia senegal* varieties

	Micronutrients		
	Low range	**Normal range**	**High range**
		Ppm	
Copper	39.4 - 48.3	53.5 - 66.6	68.5 - 100.1
Iron	252.8 - 271.1	396.9 - 510.8	535.0 - 654.7
Manganese	235.5 - 280.1	340.7 - 346.7	366.3 - 400.0
Zinc	182.5 - 217.3	313.3 - 341.3	340.8 - 440.9

The concentration of copper in *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis* in normal range was 53.5 - 66.6 ppm while low and high ranges were 39.4 - 48.3 and 68.5 - 100.1 ppm, respectively.

Iron uptake ranged in low, normal and high was 252.8 - 271.1, 396.9 - 510.8 and 535.0 - 654.7 ppm while manganese and zinc 235.5 - 280.1, 340.7 - 346.7 and 366.3 - 400.0 ppm, and 182.5 - 217.3, 182.5 - 217.3 and 340.8 - 440.9 ppm, respectively.

Copper, iron and zinc uptake by *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis* in low, normal and high ranges were higher than the ratings while manganese in low, normal and high range were within the range in plants by Mitchell (1964), Stout (1961), Jones (1972) and Landon (1991).

5.3 Conclusions

The heights and diameter at ground level of tree seedlings of seedlings in soil medium in all the sites were higher than in vermiculite medium as a result of soils as heterogeneous medium that had inherent nutrients while vermiculite was homogeneous inert medium.

Vermiculite, a homogenous inert medium, with equal competitions and interactions of cations, differentiated and revealed the concentrations of Cu, Fe, Mn and Zn uptake for the two varieties of *Acacia senegal*. The medium also showed the effect of micronutrients uptake on levels of tolerance and response of seedlings of *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis*.

The heights were good measure of growth performance while diameters at ground level of seedlings were not a good indicator for measuring the growth performance of the varieties. *Acacia senegal* variety *senegal* tends to take high levels of copper, iron and manganese while *Acacia senegal* variety *kerensis* takes high levels of zinc from the soils than other micronutrients. *Acacia senegal* variety *senegal* less tolerant to high levels of zinc, while *Acacia senegal* variety *kerensis* was less tolerant to high level of iron and copper.

Copper, iron and zinc uptake by seedlings of *Acacia senegal* varieties were higher than those ranges of concentrations of uptake of Cu, Fe and Zn for agricultural crops (Jones, 1972). The results of micronutrients uptake and effect of *Acacia senegal* varieties may help to determine quality parameters and the factors influencing the quality of gum arabic under arid and semi-arid environments.

CHAPTER SIX

INFLUENCE OF *ACACIA SENEGAL* VARIETIES ON QUALITY OF GUM ARABIC

6.0 Introduction

This chapter examines factors that may influence the quality of gum arabic exudate harvested from the natural stands of two *Acacia senegal* varieties in the four study sites. Physical and chemical properties of soils and gum arabic were used to determine the quality of the Kenyan gum.

6.1 Quality of Gum Arabic

The international specifications of quality parameters of gum arabic are given in Table 6.1.

Table 6.1 International Specifications of Quality parameters of Gum Arabic *

Source of Gum arabic: Kordofan gum belt region, Sudan			
Species: *Acacia senegal* var.*senegal* and its varieties			
Moisture content (105^0C)	13	-	15 %
Ash content (550^0C)	2	-	4 %
Volatile matter (105^0C)	51	-	65 %
Internal energy (850^0C)	30	-	39 %
Optical rotation	-26^0	-	-34^0
Nitrogen content	0.26	-	0.39 %
Cationic compositions of total ash content (550^0C)			
Copper	Iron	Manganese	Zinc
52 – 66 ppm	730 – 2490 ppm	69 – 117 ppm	45 – 111 ppm

* **Ref: FAO (1990)**

6.2 Physical properties of Gum arabic

The physical properties of gum arabic, established as quality parameters include moisture, total ash, volatile matter, and internal energy. Gum arabic is a natural product complex mixture of hydrophilic carbohydrate and hydrophobic protein components (FAO, 1990). Hydrophobic protein component functions as an emulsifier which adsorbs onto surface of oil droplets while hydrophilic carbohydrate component inhibits flocculation and coalescence of molecules through electrostatic and steric repulsions in food additives (Anderson and Weiping, 1990).

Moisture content facilitates the solubility of hydrophilic carbohydrates and hydrophobic proteins in gum arabic. Total ash content is used to determine the critical levels of foreign matter, acid insoluble matter, salts of calcium, potassium and magnesium. The cationic compositions of ash content are used to determine the specific levels of heavy metals in quality of gum arabic (FAO, 1990).

Volatile matter of gum arabic determines the number of hydrocarbons contained in sugar compositions (arabinose, galactose and rhamnose); these function as binders in the making of cough syrups in pharmaceutical industry.

Internal energy of gum arabic is the actual energy required to produce the amount of carbon when the gum is heated to 500^0C to release carbon dioxide gas. Carbon dioxide plays an important role as a stabilizer, thickener, binder and protective agent in food, pharmaceutical, and technical industries (FAO, 1995).

Optical rotation is used to determine the nature of sugars in gum arabic obtained from *Acacia senegal* variety *senegal*. The specifications state that the best quality of gum arabic must have negative optical rotation with the range of -26^0 to -34^0 (Table 6.1). Nitrogen content in gum arabic determines the number of amino acid compositions with the range of 0.26 % to 0.39%.

6.3 Physical Properties of Gum arabic in the four Study sites

The physical properties of gum arabic from the four study sites are given in Table 6.2. *Acacia senegal* variety *senegal* was dominant in Solit and Kapkun while *Acacia senegal* variety *kerensis* was dominant in Kimorok and Maoi, respectively.

Table 6.2: Physical properties of Gum arabic from the study sites

Sites	Variety	Moisture content (%)	Ash content (%)	Volatile matter (%)	Internal energy (%)
		Mean± S.E	Mean± S.E	Mean± S.E	Mean± S.E
Solit	*senegal*	15.00 ±0.50	2.94±0.20	63.72±0.40	32.96±0.30
Kapkun	*senegal*	14.90±1.80	3.16±0.20	64.24±0.30	33.00 ±0.30
Kimorok	*kerensis*	17.50±1.00	2.88±0.20	63.80±0.20	33.40±0.30
Maoi	*kerensis*	15.40±0.40	2.72±0.20	63.60±0.50	33.76±0.60

Footnote: n = 5

S.E. = Standard error

(a) Moisture content

Moisture content in gum arabic obtained from variety *kerensis* in Kimorok and Maoi (17.5 and 15.4%) were higher ($P< 0.05$) than those of variety *senegal* in Solit and Kapkun (15.0 and 14.9%), respectively.

Moisture content in gum arabic from variety *senegal* in Solit and Kapkun (15.0% and 14.9%) fell within international specifications (13% to 15%), while variety *kerensis* in Kimorok and Maoi (17.5% and 15.4%) fell outside the specifications. Gum arabic from *Acacia senegal* variety *senegal* in Solit and Kapkun was of better quality than that of variety *kerensis* in Kimorok and Maoi (Anderson and Weiping, 1990).

(b) Ash content

Ash content in gum arabic from variety *senegal* in Solit and Kapkun (2.94 and 3.16%) was higher ($P < 0.05$) than those of variety *kerensis* found in Kimorok and Maoi (2.88% and 2.72%), respectively (Table 6.2). Ash content in gum arabic from *Acacia senegal* varieties in the study sites fell within the international specifications. The ash content of the Kenyan *Acacia senegal* varieties was better than that found in Uganda (4.5%) which falls outside the international specifications (Anderson and Weiping, 1991).

(c) Volatile matter

In Kapkun, volatile matter in gum arabic from variety *senegal* (64.2%) was higher ($P < 0.05$) than the quantities of variety *kerensis* found in Kimorok, Solit and Maoi (63.8%, 63.7% and 63.6%), respectively (Table 6.2). Volatile matter contents of the gum arabic from both varieties (64.2%, 63.7%, 63.8 % and 63.6%) were within the international specifications range of 51% to 65% (Table 6.1).

(d) Internal energy

Internal energy in gum arabic obtained from *Acacia senegal* variety *kerensis* in Maoi and Kimorok (33.76% and 33.4%), were not significantly different ($P > 0.05$) from those of variety *senegal* found in Kapkun and Solit (33.0% and 32.96%), respectively (Table 6.2).

The internal energy in gum arabic from *Acacia senegal* varieties meets the international specifications (30 % to 39%) FAO (1990).

6.4 Influence of Soil Composition on the Quality of Gum arabic Varieties

The chemical composition of soils and gum arabic are given in Table 6.3. The correlations between chemical composition of soils and gum arabic in relation to sites and varieties were used to establish which variety of *Acacia senegal* produces better quality of gum arabic in the study sites.

Table 6.3 Chemical compositions of Soils and Gum Arabic

	Site	Solit	Kimorok	Kapkun	Maoi
			Gum arabic		
		Mean± S.E.	**Mean± S.E.**	**Mean± S.E.**	**Mean± S.E.**
N	%	0.30 ± 0.02	0.31 ± 0.02	0.28 ± 0.02	0.34 ± 0.02
Cu	ppm	40±5.49	38.5±5.49	45.2±5.34	32.0±5.49
Fe	ppm	973±20	1243 ±20	1415±19	861 ±20
Mn	ppm	93±8.8	72 ±8.8	109±8.5	93±8.8
Zn	ppm	78±13.7	124±13	83±13.7	44±13.7
			Soils		
N	%	0.18 ± 0.02	0.14 ± 0.02	0.30 ± 0.02	0.17 ± 0.02
Cu	ppm	1.67±0.08	0.73±0.08	0.61±0.08	0.58±0.08
Fe	ppm	151±11	234±11	250±11	287±11
Mn	ppm	263±14	320±14	344±14	383±14
Zn	ppm	1.73±0.47	7.64±0.46	6.00±0.47	5.06±0.46

Footnote: **n = 17**

S.E. = Standard error

6.4.1 Nitrogen

The mean nitrogen contents of gum arabic from *Acacia senegal* variety *kerensis* in Maoi (0.34%) and Kimorok (0.31%) were higher ($P < 0.05$) than those of variety *senegal* found in Kapkun and Solit (0.28% and 0.30%) (Table 6.3, Figure 6.1).

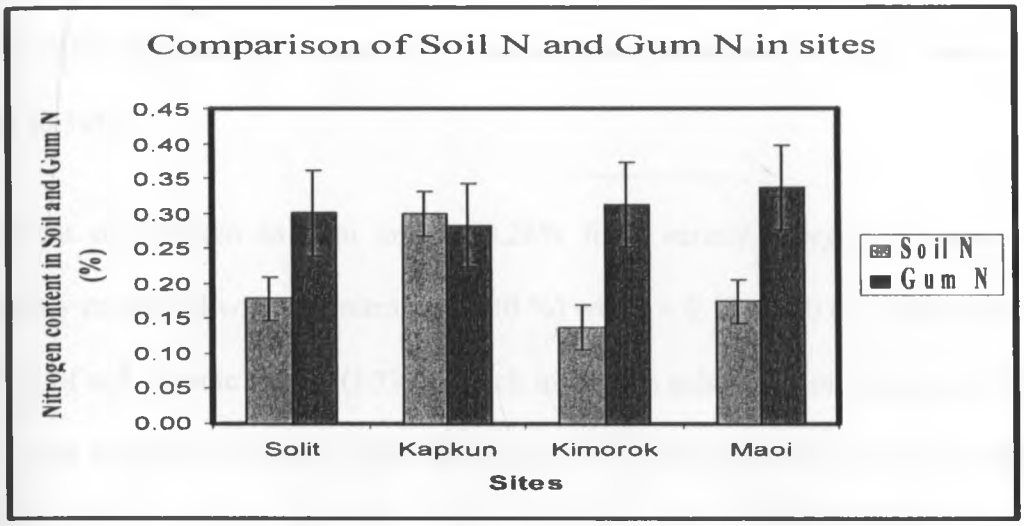

Figure 6.1 Comparison of Soil Nitrogen and Gum arabic Nitrogen

Nitrogen content in gum arabic from variety *kerensis* in Kimorok (0.31%) was significantly correlated with soil nitrogen (0.14 % with ($r = 0.26$, $P < 0.05$) (Appendix III). The positive correlation may be attributed to high concentration of zinc (7.64 ppm) in the soils, which may have interacted with soil nitrogen (0.14%) resulting to an increase in available nitrogen for uptake by the variety, which resulted in increased content of gum nitrogen (0.31%). This observation agrees with the work of Jones (1972) on nitrogen uptake by subterranean clover. He added high concentration of zinc in the soil with low percentage of nitrogen. He found an increase in growth of subterranean clover due to high Zn concentration by applying nitrogen and zinc fertilizers together but not to zinc concentration alone. Jones (1972) reported that Zn concentration in the roots correlated with high level of nitrogen in the leaves.

The report by Jones (1972) on interaction between high concentration of Zn and nitrogen in the leaves of subterranean clover can also be applied on the process of gum arabic exudates from the varieties. Soil nitrogen (0.17 %) was negatively correlated with gum nitrogen arabic (0.34%) from variety *kerensis* in Maoi with r = – 0.12. The negative correlation may have been due to the influence of soil organic matter (1.15%) in the soils which supplied more available nitrogen for uptake by the variety which resulted in high content of gum nitrogen (0.34%).

The content of nitrogen in gum arabic (0.28% from variety *senegal* in Kapkun was significantly correlated with soil nitrogen (0.30 %) with r = 0.13 ($P < 0.05$). This was due to high level of soil organic matter (1.73%) which may have enhanced soil nitrogen (0.3%) to produce gum nitrogen of 0.28%. Gum nitrogen (0.3 %) was negatively correlated with soil nitrogen (0.18 %) in Solit with r = - 0.52 ($P < 0.05$). The negative correlation may be attributed to the influence of soil pH (7.05) on availability of soil nitrogen (0.18 %). At soil pH 7.05, nitrogen becomes less available in the soil because the best soil pH for microorganism to break nitrogen is between 5.8 and 6.6 (Watson and Brown, 1998).

The results of gum nitrogen from the two varieties in the four study sites do not agree with the observations of Chikamai and Banks (1993) on levels of nitrogen in gum arabic from *Acacia senegal* variety *kerensis* found in Kargi, Isiolo and Ngurunit (0.5, 0.4 and 0.43%, respectively) in Marsabit and Isiolo districts. The levels of nitrogen in gum arabic (0.28% - 0.34%) from variety *kerensis* and *senegal* were within the international specifications (0.26% -0.39% N) while those of Chikamai and Banks (1993) fell outside the specifications given in Table 6.1.

6.4.2 Copper

The concentration of copper in gum arabic from Kapkun (45.2 ppm) was higher ($P < 0.05$) than those found in Solit, Kimorok and Maoi (40, 38.5 and 32.0 ppm, respectively) (Table 6.3, Figure 6.2).

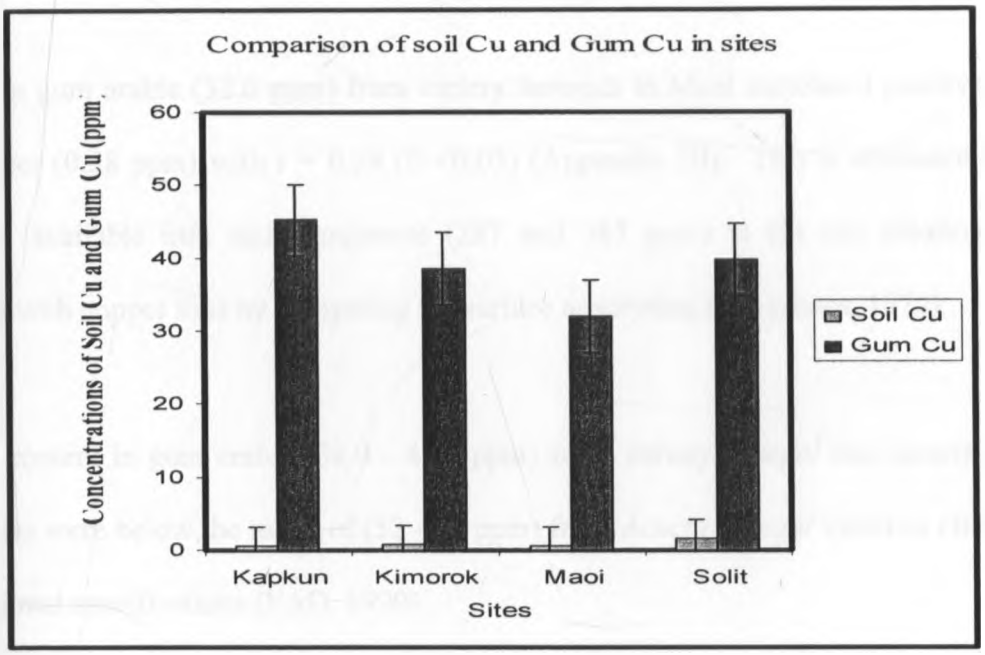

Figure 6.2 Comparison of Soil Cu and Cu concentrations in Gum arabic

Copper content in gum arabic (45.2 ppm) from variety *senegal* in Kapkun was positively correlated with soil copper (0.61 ppm) with $r = 0.41$ ($P < 0.05$) (Appendix III). This may be ascribed to ferralic Cambisols with soil organic matter (1.73%) and carbon: nitrogen ratio (4.82:1) which may have enhanced copper uptake by the variety resulting to high copper content in gum arabic (45.2 ppm). The concentration of copper in gum arabic (40 ppm) from variety *senegal* in Solit was correlated negatively with soil copper (1.67 ppm) with $r = -0.31$ ($P < 0.05$). The negative correlation between soil and gum copper in Solit may be due to high levels of calcium (17.33 cmol ($^{+}$)/kg) and phosphorus (11.54 ppm), which can reduce copper uptake resulting to decreased copper content in gum arabic (40 ppm).

The content of copper in gum arabic (ppm) from variety *kerensis* in Kimorok correlated positively with soil copper (0.73 ppm) with r = 0.49 (P <0.05) (Appendix III). This was most likely due to high levels of phosphorus (14.6 ppm) in the soils which may have reduced the availability copper uptake by the variety which produced copper content in gum arabic (38.48 ppm) (Marschner, 1986).

Copper in gum arabic (32.0 ppm) from variety *kerensis* in Maoi correlated positively with soil copper (0.58 ppm) with r = 0.29 (P <0.05) (Appendix III). This is attributed to high levels of available iron and manganese (287 and 383 ppm) in the soil solution which interacts with copper ions by competing for surface adsorption sites (Jones, 1972).

Copper content in gum arabic (32.0 - 45.2 ppm) from variety *senegal* and *kerensis* in the study sites were below the range of (52 - 66 ppm) from *Acacia senegal* varieties cited in the international specifications (FAO, 1990).

6.4.3 Iron

The concentration of iron in gum arabic from *Acacia senegal* variety *senegal* found in Kapkun and Solit (1415 and 973 ppm) were significantly higher (P < 0.05) than those of *Acacia senegal* variety *kerensis* in Kimorok and Maoi (1243 and 861 ppm) (Table 6.3, Figure 6.3).

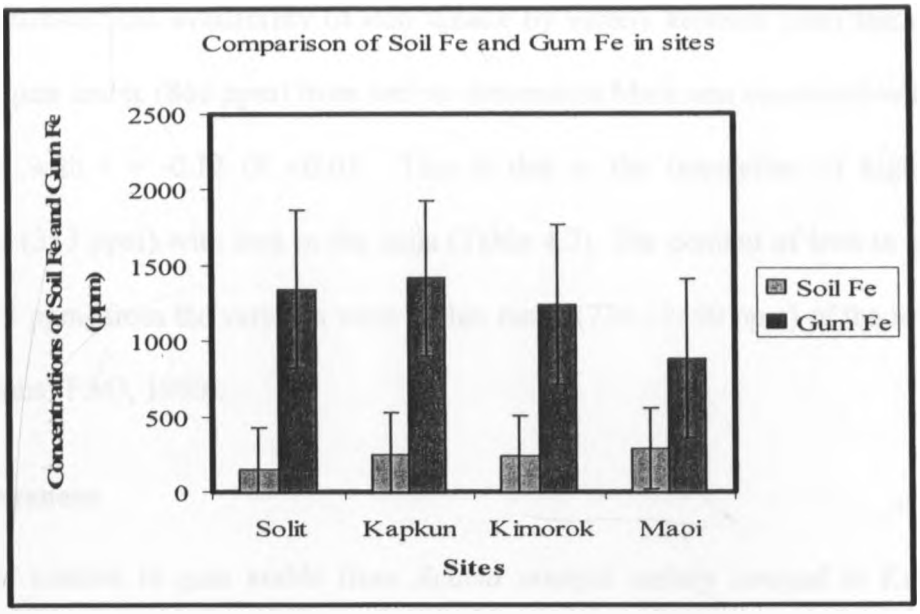

Figure 6.3 Comparison of Soil Fe and Fe concentrations in Gum arabic

Iron content in gum arabic (1415 ppm) from variety *senegal* in Kapkun was correlated negatively with soil iron (250 ppm) with r = -0.04 ($P < 0.05$) (Appendix III). The concentration of iron in gum arabic (973 ppm) from variety *senegal* in Solit was correlated with soil iron (151 ppm) with r = - 0.16 ($P < 0.05$). These weak negative correlations between soil and gum iron in Solit and Kapkun were due to soil pH (5.96 - 7.05), which may have influenced the decrease of Fe in the soils (Table 4.2). Fe becomes more available the lower the pH (5.96) and it decreases at high pH (7.05), because the solubility of iron is highly dependent upon soil pH (Woolhouse, 1983; Mclean, 1982).

The concentration of iron in gum arabic (1243) from variety *kerensis* found in Kimorok was correlated negatively with soil iron (234 ppm) with r = -0.52 (Appendix III). The strong negative correlation between soil and gum iron in Kimorok may be ascribed to interaction with high levels of zinc (7.64 ppm) in the soils (Table 4.2). The interaction between Zn and Fe in the soils is due to their similar ionic radii of 0.83 and 0.73 nm, respectively, which

may have reduced the availability of iron uptake by variety *kerensis* from the soils. Iron content in gum arabic (861 ppm) from variety *kerensis* in Maoi was correlated with soil iron (287 ppm) with r = -0.12 (P <0.05. This is due to the interaction of high levels of manganese (383 ppm) with iron in the soils (Table 4.2). The content of iron in gum arabic (861 - 1415 ppm) from the varieties were within range (730 - 2490 ppm) of the international specifications (FAO, 1990).

6.4.4 Manganese

Manganese content in gum arabic from *Acacia senegal* variety *senegal* in Kapkun (109 ppm) was higher (P < 0.05) than the quantities of *Acacia senegal* variety *kerensis* found in Kimorok, Solit and Maoi (93, 93 and 72 ppm) (Table 6.3, Figure 6.4).

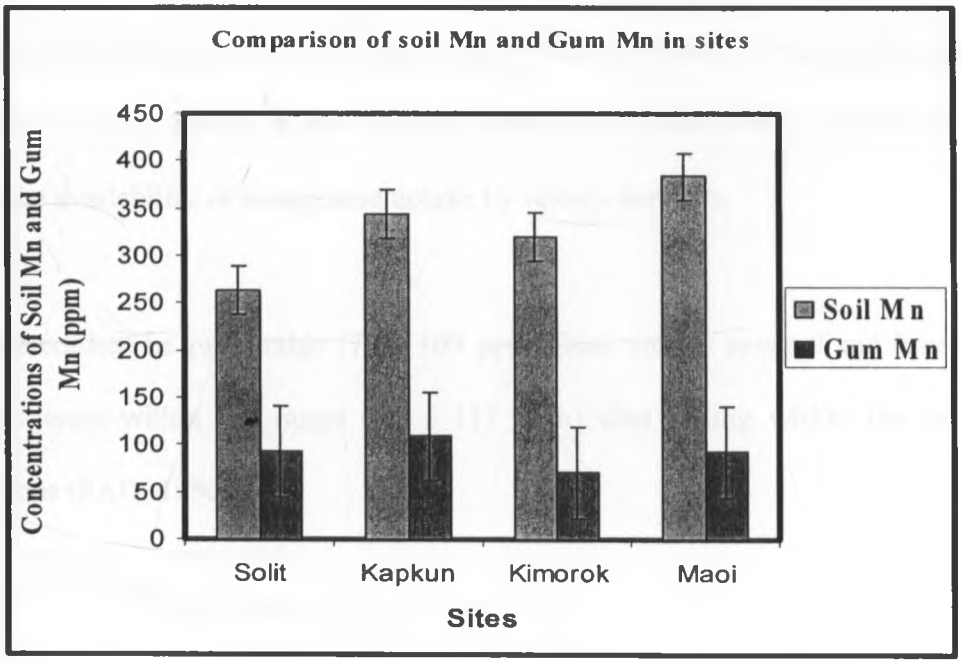

Figure 6.4 Comparison of Soil Mn and Mn concentrations in Gum arabic

The content of manganese in gum arabic (109 ppm) from variety *senegal* in Kapkun was correlated negatively with soil manganese (344 ppm) with r = - 0.28 (P <0.05) (Appendix III). The negative correlation may be attributed to soil organic matter (1.73%) which may

have increased the level of manganese in the soil resulting in high manganese content in gum arabic (109 ppm). Manganese in gum arabic (93 ppm) from variety *senegal* in Solit was correlated negatively with soil manganese (263 ppm) with r = - 0.23 (P <0.05). The negative correlation may be due to high level of soil pH (7.05) which increases the availability of manganese uptake by variety *senegal* from the soils. At pH (7.05), Mn becomes less available in the soil (263 ppm), since the solubility of manganese is highly dependent upon soil pH (Woolhouse, 1983).

The level of manganese in gum arabic (93 ppm) from variety *kerensis* found in Kimorok was significantly correlated (r = 0.40, P <0.05) with soil iron (320 ppm) (Appendix III). Manganese content in gum arabic (72 ppm) from variety *kerensis* in Maoi was correlated positively with soil manganese (383 ppm) with r = 0.25 (P <0.05). The positive correlations may be due to high levels of soil organic matter (1.73 and 1.15%, respectively) which enhances the availability of manganese uptake by *variety kerensis*.

Manganese content in gum arabic (72 – 109 ppm) from variety *senegal* and *kerensis* in the study sites were within the range (69 – 117 ppm) thus falling within the international specifications (FAO, 1990).

6.4.5 Zinc

Zinc in gum arabic from *Acacia senegal* variety *kerensis* in Kimorok was 124 ppm and was significantly (P < 0.05) higher than the quantities of zinc from Maoi, Solit and Kapkun (44, 78 and 83 ppm), respectively (Table 6.3, Figure 6.5).

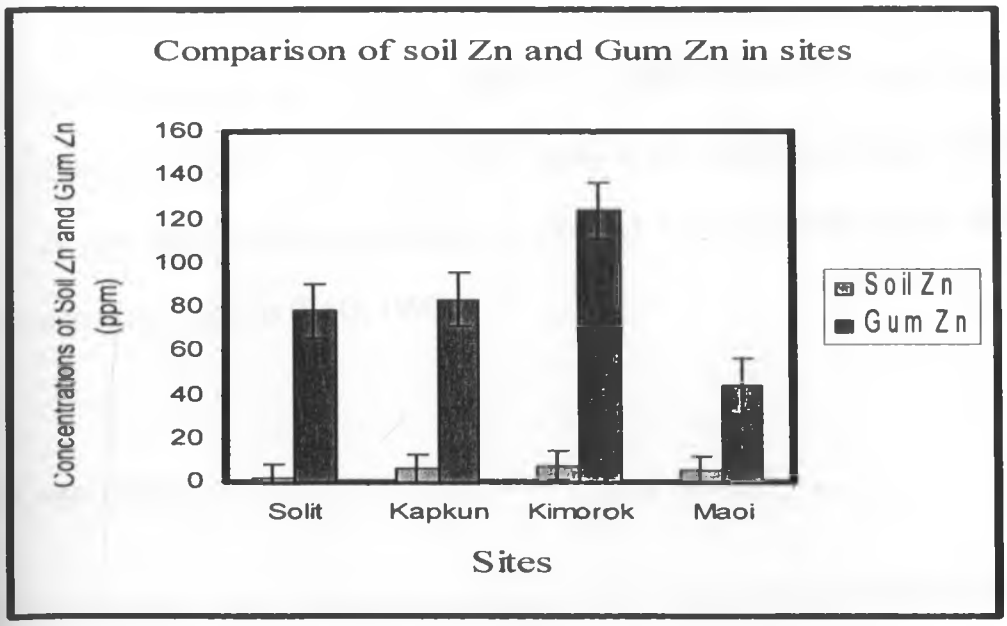

Figure 6.5 Comparison of Soil Zn and Gum arabic Zn concentrations

The concentration of zinc in gum arabic (78) from variety *senegal* in Solit was correlated positively with soil zinc (1.73 ppm) ($r = 0.48$, $P < 0.05$) (Appendix III). The positive correlation was due to high soil pH (7.05), which reduces the availability of zinc in the soils (Watson and Brown, 1998). Zinc content in gum arabic (83 ppm) from variety *senegal* in Kapkun was correlated negatively with soil zinc (6.00 ppm) with $r = -0.37$ ($P < 0.05$) (Appendix III). The negative correlation may be due to high level of phosphorus (14.10 ppm) which reduces the availability of zinc uptake by variety *senegal* from the soils (Jones, 1991).

The concentration of zinc in gum arabic (124 ppm) from variety *kerensis* in Kimorok was correlated with soil zinc (7.64 ppm) with $r = 0.36$ ($P < 0.05$) (Appendix III). Zinc in gum arabic (44) from variety *kerensis* in Maoi significantly correlated ($r = 0.63$, $P < 0.05$) with soil zinc (5.06 ppm). Positive correlations between soil and gum zinc in Kimorok and Maoi may due to the high levels of soil organic matter (1.97% and 1.15%, respectively), which enhances the availability of zinc in the soils (Jones, 1991).

Zinc concentrations in gum arabic in Solit and Kapkun (78 and 83 ppm) from variety *senegal* were within the range of (45 – 111 ppm) in the international specifications while those of gum arabic in Maoi and Kimorok (44 and 124 ppm) from variety *kerensis* fell outside the specifications (FAO, 1990).

6.5 Conclusions

Moisture content in gum arabic from *Acacia senegal* variety *senegal* fell within international specifications while *Acacia senegal* variety *kerensis* fell outside the specifications, while ash, volatile matter, zinc and internal energy contents in gum arabic from *Acacia senegal* variety *kerensis* and variety *senegal* fell within the specifications.

By contrast, nitrogen, iron and manganese contents in gum arabic from *Acacia senegal* variety *kerensis* and *Acacia senegal* variety *senegal* fell within the international specifications while copper and zinc did not.

Gum arabic obtained from *Acacia senegal* variety *senegal* had high levels of copper, iron and manganese, contrary to *Acacia senegal* variety *kerensis* which instead had high levels of zinc and nitrogen.

The quality of gum arabic parameters depends on the variety, the soil conditions and soil types as well as availability of the nutrients in the study sites. The gum arabic from *Acacia senegal* variety *senegal* in Solit and Kapkun was of better quality than that of *Acacia senegal* variety *kerensis* in Kimorok and Maoi.

CHAPTER SEVEN

INTEGRATING DISCUSSION AND RECOMMENDATIONS

Most gums are produced by *Acacia senegal* and other closely related *Acacia* species which grow in abundance in the vast areas of arid and semi-arid ecosystems in Kenya. The Acacia species are also very useful in soil stabilization and nitrogen fixation, which improves soil fertility by increasing soil organic matter and availability of both macro and micronutrients. The canopies of Acacia gum trees control wind velocity, maintain water balance of plants, and protect soils against rainfall torrents that lead to soil erosion. The canopies also lessen solar radiation and reduce rates of evaporation.

Gum arabic from Sudan is tapped from *Acacia senegal* variety *senegal* trees, which are cultivated as a cash crop in agroforestry system known as the bush-fallow system of shifting cultivation. The main gum producing regions are the sandy clay plains situated in east and central Sudan covering most of Kordofan and Darfur and parts of White Nile state. The quality parameters of gum arabic depend on the source of origin of gum exudates, soil characteristics and climate of the area.

The international specifications used to assess the quality of gum arabic in the world market are based on the Sudan gum obtained from *Acacia senegal variety senegal.* There are no suitable alternative synthetic additives to substitute the use of gum arabic, owing to its excellent shelf life stability to oil-in-water emulsions and long lasting fresh taste in foodstuff.

The main factors affecting quality of Kenyan gums are the botanical sources, poor tapping methods and harvesting period. The harvesting period is particularly important since mixing

of wet and immature gums with mature products can lead to adulteration. Kenya's gum is not able to attract premium prices because of problems relating to quality caused by adulteration and impurities. These impurities can result from transportation of the gum on the dust roads, making it unsuitable for use in the pharmaceutical industry. As a result, exporters have to spend a lot of money (about 20% of their costs) cleaning the gum, thereby reducing profits.

Results presented and discussed in this thesis have shown *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis* can be good sources of gum arabic in the study area. Attention was also focused on quality of gum arabic from specific botanical source (*Acacia senegal* varieties), sites and soil types.

Results presented in Chapter Four have shown that physico-chemical properties on characterization of soils based on and soil fertility were factors influencing the quality of gum arabic. The effect of low moisture regimes in sandy soils limits the nutrient uptake, physiological growth of plants and conditions of soil microorganisms' survival in arid and semi-arid environments. The low moisture characteristics affect the solubility of hydrophilic carbohydrates and hydrophobic proteins in gum arabic which determine the emulsification and stabilization properties in food industry.

Acacia senegal variety *senegal* grows well in neutral calcic Xerosols and acidic ferralic Cambisols which prevail in Solit and Kapkun. The soils are sandy loam to clay loam, of low to medium fertility with respect to nitrogen, potassium, calcium, magnesium and copper.

Acacia senegal variety *kerensis* grows well in shallow, rocky and stony acidic Lithosols and Xerosols, and ando-chromic Cambisols which prevail in Kimorok and Maoi. The soils are well drained, sandy clay loam to sandy loam and have medium to high fertility especially with respect to carbon, phosphorus, iron, manganese and zinc.

The mean nitrogen content of gum arabic from *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis* (0.28 % - 0.34%) indicate high functionalities of amino acids which provide stable and strong emulsification properties. The levels of nitrogen fall within international specifications range of 0.26% - 0.39% N (FAO, 1990). The Cu content of gum arabic ash (550^0C) from *Acacia senegal* variety *senegal* and *Acacia senegal* variety *kerensis* (32 - 45 ppm) is below the specifications range (52 – 66 ppm), while the levels of Fe, Mn and Zn of (861 - 1415 ppm, 72 – 109 ppm and 78 - 83 ppm) are within the international specifications (730 -2490 ppm, 69 -117 ppm and 45 – 111 ppm).

The established standard quality control parameters and specific levels of cationic compositions in total ash content at 550^0C are as follows: 52 – 66 ppm Cu, 730 -2490 ppm Fe, 69 -117 ppm Mn and 45 – 111 ppm Zn, respectively. The results of this study indicated that the quality of gum arabic from Kenya is not of low quality as stated by JECFA specifications (FAO, 1990).

The results presented in Chapter Five on uptake of micronutrients have shown that *Acacia senegal* variety *senegal* tends to absorb high levels of copper, iron and manganese while *Acacia senegal* variety *kerensis* tends to absorb high levels of zinc from the soils than other micronutrients. The uptake results showed that *Acacia senegal* variety *senegal* was more tolerant to copper, iron and manganese toxicities than *Acacia senegal* variety *kerensis,*

which by contrast was more tolerant to zinc toxicity. This may imply that gum quality parameters depend on the variety, the soil conditions and availability of the nutrients for uptake by the varieties.

Variations in soil types, soil fertility status and micronutrients uptake and the *Acacia senegal* variety are important in assessing the of type of agronomic practices required for establishment and identifying the factors influencing the quality of gums.

Further research is required to compare gums from natural stands of *Acacia senegal* and closely related species considering the geographical locations, sites, soil types, single botanical sources and climate in the arid and semi-arid regions of Kenya. The research should also include boron and molybdenum uptake by the varieties and their possible effect on gum quality.

The JECFA specifications (FAO, 1990) on gum quality also need to be revised to cover gums of unique character from natural stands of *Acacia senegal* and closely related species for new countries which are yearning to join the world market like Kenya. The parameters should be based on gum arabic specific rotations, nitrogen contents, boron and molybdenum composition, intrinsic viscosity, proteins and carbohydrates compositions as well as heavy metals and individual amino acid composition.

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APPENDICES

SOIL ANALYSIS

APPENDIX I: Raw data on Soil chemical analysis during dry and wet seasons in sites

Codes used soil sampling in the four study sites:

ST – Solit

KK – Kimorok

KN – Kapkun

MI – Maoi

SS – Surface samples at depth between 0 – 25 cm

M1–Soil sample number one from medium elevation

L1–Soil sample number one from low elevation

SOLIT DRY SEASON – Soil samples

Senders ref.	H_2O	$CaCl_2$	Ec	C	N	C:N	SOM	P	K	Ca	Mg	Na	Soil type
	pH	pH	mS/cm	%	%	Ratio	%	ppm	E Bases C mol (+)/Kg				
SSM1/STM1	7.9	7.3	0.09	0.2	0.15	1.60	0.41	12	0.2	1.29	4.18	0.79	Caclic xerosols
SSM2/STM2	8.1	7.6	0.07	0.4	0.15	2.33	0.60	12	0.46	1.26	4.14	0.61	Caclic xerosols
SSM3/STM3	8.2	7.1	0.07	0.4	0.11	3.64	0.69	15	0.36	1.33	4.14	0.61	Caclic xerosols
SSM4/STM4	7.9	7.2	0.08	0.5	0.15	3.20	0.83	12	0.41	1.3	4.28	0.53	Caclic xerosols
SSM5/STM5	8.0	7.7	0.05	0.4	0.11	3.45	0.66	12	0.25	1.28	6.26	0.48	Caclic xerosols
SSM6/STM6	8.0	7.7	0.05	0.3	0.08	3.88	0.53	11	0.41	1.33	6.32	0.7	Caclic xerosols

SSM7/STM7	*8.1*	7.1	0.06	0.3	0.11	2.45	0.47	16	0.23	1.23	6.78	0.75	Caclic xerosols
SSM8/STM8	7.9	7.3	0.05	0.6	0.19	2.95	0.97	12	0.46	1.01	3.74	0.75	Caclic xerosols
SSM9/STM9	8.1	7.2	0.06	0.4	0.11	3.64	0.69	13	0.36	1.07	4.24	0.66	Caclic xerosols
SSM10/STM10	8.1	7.2	0.07	0.5	0.11	4.09	0.78	13	0.25	1.09	3.67	0.79	Caclic xerosols
SSM11/STM11	7.5	7.2	0.08	0.5	0.19	2.37	0.78	16	0.41	1.31	4.01	0.83	Caclic xerosols
SSM12/STM12	8.1	7.2	0.05	0.4	0.23	1.57	0.62	14	0.5	1.3	4.1	0.7	Caclic xerosols
SSM13/STM13	8.4	7.3	0.05	0.4	0.15	2.80	0.72	14	0.41	1.35	4.36	1.21	Caclic xerosols
SSM14/STM14	8.0	7.1	0.04	0.6	0.19	3.16	1.03	14	1.22	0.63	4.32	0.7	Caclic xerosols
SSM15/STM15	8.1	7.3	0.06	0.6	0.15	3.80	0.98	14	1.27	0.6	4.82	0.18	Caclic xerosols
SSL1/STL1	7.6	7.1	0.06	0.6	0.11	5.45	1.03	14	0.41	1.02	3.95	0.13	Caclic xerosols
SSL2/STL2	7.7	7.05	0.09	0.5	0.11	4.45	0.84	13	0.31	0.97	3.76	0.31	Caclic xerosols
SSL3/STL3	7.1	7.1	0.05	0.4	0.11	3.82	0.72	13	0.41	1.1	3.8	0.13	Caclic xerosols
SSL4/STL4	8.0	7.1	0.08	0.3	0.11	2.82	0.53	12	0.25	0.67	2.85	0.13	Caclic xerosols
SSL5/STL5	7.7	7.3	0.06	0.3	0.34	0.94	0.55	24	0.31	0.89	6.87	0.18	Caclic xerosols
SSL6/STL6	7.7	7.05	0.06	0.6	0.11	5.27	1.00	22	0.46	0.92	3.75	0.44	Caclic xerosols
SSL7/STL7	7.8	7.05	0.06	0.4	0.11	3.27	0.62	12	0.36	1.35	4.38	0.18	Caclic xerosols
SSL8/STL8	7.2	7.1	0.05	0.4	0.26	1.42	0.64	11	0.15	1.14	4.38	0.35	Caclic xerosols
SSL9/STL9	8.0	7.1	0.06	0.4	0.11	3.64	0.69	14	0.2	1.39	3.73	0.09	Caclic xerosols
SSL10/STL10	7.8	7.1	0.06	0.4	0.19	2.00	0.66	9	0.2	1.38	3.53	0.26	Caclic xerosols
SSL11/STL11	7.9	7.1	0.06	0.7	0.26	2.50	1.12	13	0.25	1.15	1.58	0.22	Caclic xerosols
SSL12/STL12	7.9	7.05	0.05	0.5	0.26	2.00	0.90	11	0.25	1.46	2.63	0.31	Caclic xerosols
SSL13/STL13	8.1	7.05	0.05	0.6	0.19	3.05	1.00	16	0.25	1.52	3.19	0.31	Caclic xerosols
SSL14/STL14	8.2	7.1	0.05	0.6	0.11	5.55	1.05	13	0.25	1.51	3.97	0.22	Caclic xerosols
SSL15/STL15	8.0	7.5	0.06	0.2	0.19	1.21	0.40	13	0.2	1.51	5.82	0.22	Caclic xerosols
SSL16/STL16	8.1	7.4	0.05	0.6	0.49	1.16	0.98	11	0.36	1.35	3.15	0.31	Caclic xerosols
SSL17/STL17	8.2	7.1	0.06	0.3	0.34	0.79	0.47	11	0.25	1.12	2.48	0.22	Caclic xerosols

	pH	CaCl2 pH	EC µs/cm	C %	N %	C:N Ratio	SOM %	P ppm	K	Ca	Mg	Na	Soil type
									E Bases C mol (+)/Kg				
ST01/SS	7.2	7.05	50	0.6	0.19	3.16	1.03	19	0.5	40.1	5.9	1.8	Caclic xerosols
ST02/SS	7.1	6.6	100	0.5	0.34	1.47	0.86	3	0.4	46.9	5.4	1.7	Caclic xerosols
ST03/SS	7.4	7.1	121	0.8	0.34	2.35	1.38	22	1.0	34.8	6.0	1.9	Caclic xerosols
ST04/SS	7.1	6.7	68	0.5	0.11	4.09	0.78	4	1.1	21.5	5.8	1.7	Caclic xerosols
ST05/SS	7.4	7.1	85	0.9	0.19	4.84	1.59	4	0.4	47.05	9.9	1.7	Caclic xerosols
SS/ST/1	7.3	7.1	120	0.3	0.19	1.79	0.59	4	0.7	37.7	9.6	1.8	Caclic xerosols
SS/ST/2	7.2	7.05	112	0.1	0.34	0.35	0.21	6	0.5	39.1	10.2	1.8	Caclic xerosols
SS/ST/3	7.2	6.9	67	0.4	0.26	1.58	0.71	31	0.8	50.9	7.05	2.5	Caclic xerosols
SS/ST/4	7.3	6.9	76	0.2	0.11	2.00	0.38	3	0.5	30.5	9.9	1.8	Caclic xerosols
SS/ST/5	7.3	6.9	37	0.1	0.19	0.26	0.09	4	0.2	17.8	9.3	1.9	Caclic xerosols
SS/ST/6	7.3	7.05	41	0.8	0.19	4.05	1.33	5	1.5	28.3	6.2	2.2	Caclic xerosols
SS/ST/7	7.1	6.6	59	0.8	0.19	4.26	1.40	43	0.9	16.3	7.05	1.8	Caclic xerosols
SS/ST/8	7.1	6.8	68	0.2	0.34	0.62	0.36	2	0.3	29.6	6.2	1.8	Caclic xerosols
SS/ST/9	6.9	6.7	72	0.1	0.19	0.26	0.09	2	0.1	64.3	6.5	1.9	Caclic xerosols
SS/ST/10	7.1	6.9	90	0.1	0.19	0.63	0.21	3	0.8	30.0	7.6	1.8	Caclic xerosols
ST/01/SS	7.6	6.7	61	0.5	0.08	5.63	0.78	19	0.3	68.8	14.7	2.2	Caclic xerosols
ST/02/SS	7.4	7.1	6	0.3	0.15	2.07	0.53	3	0.5	24.9	16.0	3.0	Caclic xerosols
ST/03/SS	7.3	6.5	34	0.6	0.23	2.44	0.95	3	0.5	14.3	5.9	1.9	Caclic xerosols
ST/04/SS	8.2	7.3	154	0.4	0.08	5.47	0.71	14	0.4	19.9	10.6	6.6	Caclic xerosols
ST/05/SS	7.1	6.8	70	0.6	0.15	4.00	1.03	32	0.6	17.6	7.2	0.3	Caclic xerosols
ST/05/SS	7.1	6.8	50	0.8	0.15	5.53	1.43	3	0.9	37.8	8.9	2.0	Caclic xerosols
ST/06/SS	7.05	7.05	75	1.0	0.15	6.93	1.79	2	0.4	41.4	2.0	2.0	Caclic xerosols
ST/07/SS	7.3	6.7	16	0.4	0.15	2.93	0.76	2	0.4	15.9	7.3	0.3	Caclic xerosols
ST/08/SS	7.1	7.05	33	0.6	0.08	7.73	1.00	3	0.5	13.7	7.3	0.2	Caclic xerosols
ST/09/SS	7.4	6.9	50	0.4	0.15	2.73	0.71	10	0.7	18.5	7.1	0.5	Caclic xerosols
ST/10/SS	7.5	6.9	40	0.5	0.15	3.20	0.83	13	0.3	19.2	5.2	0.3	Caclic xerosols
ST/11SS	7.8	6.9	47	0.3	0.15	2.00	0.52	5	0.2	40.5	8.6	0.1	Caclic xerosols
ST/12/SS	7.6	7.2	86	0.3	0.15	1.80	0.47	4	0.3	50.2	6.0	0.1	Caclic xerosols
ST/13/SS	8.0	6.8	53	0.8	0.15	5.20	1.34	5	0.5	55.8	8.9	0.5	Caclic xerosols
ST/14/SS	7.3	6.9	68	0.5	0.15	3.53	0.91	17	0.2	37.1	9.5	0.2	Caclic xerosols
ST/15/SS	7.2	6.9	62	0.2	0.15	1.00	0.26	5	0.1	43.5	11.9	0.3	Caclic xerosols

Senders ref.	pH	pH	Ec mS/cm	C %	N %	C:N Ratio	SOM %	P ppm	K	Ca	Mg	Na	Soil type
									E Bases c mol (+)/Kg				
KK1SS	6.8	6.2	0.07	0.56	0.04	14.00	0.97	12	1.38	5.87	1.85	0.87	Lithosols/xerosols
KK2SS	6.5	6.1	0.05	1.71	0.19	9.00	2.95	17	1.83	5.99	2.12	0.87	Lithosols/xerosols
KK3SS	6.5	5.9	0.05	1.47	0.19	7.74	2.53	16	3.16	14.5	2.1	1.29	Lithosols/xerosols
KK4SS	5.9	5.7	0.04	1.44	0.19	7.58	2.48	4	1.48	4.83	2.13	0.82	Lithosols/xerosols
KK5SS	6.5	5.8	0.05	1.76	0.11	16.00	3.03	15	1.53	5.36	2.42	0.82	Lithosols/xerosols
KK6SS	6.0	5.7	0.06	2.03	0.26	7.81	3.50	23	1.68	5.32	2.57	0.77	Lithosols/xerosols
KK7SS	5.9	5.8	0.04	1.09	0.19	5.74	1.88	26	1.73	6.55	2.08	0.87	Lithosols/xerosols
KK8SS	5.6	5.6	0.03	1	0.19	5.26	1.72	26	1.58	5.93	2.27	0.87	Lithosols/xerosols
KK9SS	6.4	6.1	0.03	1.21	0.11	11.00	2.09	8	1.14	5.73	2.1	0.82	Lithosols/xerosols
KK10SS	6.0	5.9	0.06	2.44	0.26	9.38	4.21	6	1.43	5.72	2.1	0.67	Lithosols/xerosols
KK11SS	5.8	5.7	0.04	0.94	0.11	8.55	1.62	7	1.23	5.65	2.42	0.82	Lithosols/xerosols
KK12SS	6.2	5.9	0.03	0.97	0.26	3.73	1.67	10	1.43	6.36	2.36	0.98	Lithosols/xerosols
KK13SS	6.0	5.8	0.04	0.76	0.11	6.91	1.31	7	1.58	5.48	2.08	0.87	Lithosols/xerosols
KK14SS	6.1	5.7	0.03	1.03	0.15	6.87	1.78	3	1.33	6.95	2.24	0.62	Lithosols/xerosols
KK15SS	6.2	5.7	0.03	1.23	0.08	15.38	2.12	3	1.32	5.7	2.65	0.82	Lithosols/xerosols
KK16SS	5.6	5.5	0.03	1.06	0.19	5.58	1.83	14	1.28	5.73	2.54	0.77	Lithosols/xerosols
KK17SS	6.2	5.8	0.04	1.32	0.19	6.95	2.28	12	1.33	6.28	2.37	0.62	Lithosols/xerosols
KK18SS	6.8	6.0	0.05	1	0.11	9.09	1.72	15	1.38	9.75	2.54	0.82	Lithosols/xerosols
KK19SS	6.5	5.8	0.03	1.12	0.15	7.47	1.93	12	1.48	7.53	2.27	0.77	Lithosols/xerosols
KK20SS	6.4	5.9	0.03	0.97	0.15	6.47	1.67	15	1.58	6.73	2.16	0.77	Lithosols/xerosols
KK21SS	6.3	5.9	0.04	1.3	0.11	11.64	2.21	2	1.63	7.057	2.16	0.87	Lithosols/xerosols
KK22SS	6.4	5.9	0.05	1.7	0.26	6.54	2.93	3	1.88	7.86	2.02	0.98	Lithosols/xerosols
KK23SS	6.4	5.7	0.03	1.1	0.19	5.79	1.90	2	1.23	6.55	2.22	0.77	Lithosols/xerosols
KK24SS	6.0	5.7	0.05	1.5	0.11	13.36	2.53	3	1.48	6.82	2.25	0.87	Lithosols/xerosols
KK25SS	6.4	6.0	0.03	1.0	0.19	5.05	1.66	3	2.12	5.88	2.06	0.87	Lithosols/xerosols
KK26SS	6.2	5.7	0.03	0.9	0.19	4.89	1.60	2	1.14	5.59	2.11	0.57	Lithosols/xerosols
KK27SS	6.6	5.5	0.03	1.2	0.19	6.47	2.12	2	1.38	6.26	2.23	0.67	Lithosols/xerosols
KK28SS	6.3	5.9	0.05	1.3	0.11	12.00	2.28	3	2.52	7.15	2.22	0.82	Lithosols/xerosols
KK29SS	6.3	5.7	0.04	0.9	0.19	4.63	1.52	13	2.02	6.08	2	0.82	Lithosols/xerosols
KK30SS	5.8	5.8	0.03	0.7	0.11	6.00	1.14	2	1.63	6.48	2.11	0.77	Lithosols/xerosols

KIMOROK WET SEASON – Soil samples

KK01/SS	6.5	6.3	41	1.1	0.11	9.55	1.81	10	0.9	4.9	4.5	0.2	Lithosols/xerosols
KK02/SS	6.4	6.2	55	0.9	0.11	8.36	1.59	18	0.7	4.5	4.6	0.2	Lithosols/xerosols
KK03/SS	6.6	6.4	85	1.0	0.09	10.89	1.69	20	1	5.2	3.9	0.2	Lithosols/xerosols
KK04/SS	6.8	6.3	35	0.9	0.11	8.36	1.59	19	0.9	5.6	4.3	0.5	Lithosols/xerosols
KK05/SS	6.3	6.1	42	0.7	0.11	6.64	1.26	17	0.6	4.9	5	0.4	Lithosols/xerosols
KK06/SS	6.5	6.3	66	0.8	0.11	7.18	1.36	9	0.9	4.9	4.6	0.3	Lithosols/xerosols
KK07/SS	6.5	6.2	65	1.2	0.11	10.55	2.00	18	1.1	5.9	4.7	0.2	Lithosols/xerosols
KK08/SS	6.3	6.1	46	1.2	0.11	10.64	2.02	9	0.7	4.1	4.3	0.3	Lithosols/xerosols
KK09/SS	6.5	6.4	55	1.2	0.11	10.55	2.00	18	1	4.1	4.5	0.3	Lithosols/xerosols
KK10SS	6.1	6.0	61	1.2	0.09	13.33	2.07	16	1	3.5	5.5	0.2	Lithosols/xerosols
KK11/SS	6.3	6.1	60	1.6	0.11	14.64	2.78	35	0.9	3.3	4.2	0.2	Lithosols/xerosols
KK12/SS	6.4	6.1	58	1.6	0.11	14.91	2.83	26	0.7	4.9	4.3	0.4	Lithosols/xerosols
KK13/SS	6.7	6.3	40	1.4	0.11	12.91	2.45	29	1.2	4.1	4	0.3	Lithosols/xerosols
KK14/SS	6.6	6.3	39	1.2	0.11	10.91	2.07	24	1.1	4.3	4.3	0.2	Lithosols/xerosols
KK15/SS	6.7	6.2	38	0.6	0.19	3.11	1.02	15	0.7	4.7	4	0.4	Lithosols/xerosols
KK16/SS	6.8	6.3	42	0.9	0.11	8.27	1.57	8	0.6	5	4.7	0.2	Lithosols/xerosols
KK17/SS	6.9	6.3	50	1.1	0.11	9.73	1.84	24	1.4	5.8	3.7	0.2	Lithosols/xerosols
KK18/SS	6.6	6.3	40	0.8	0.04	19.50	1.34	14	0.7	5.4	4.5	0.3	Lithosols/xerosols
KK19/SS	6.9	6.5	54	0.9	0.11	8.27	1.57	34	1.1	5.8	4	0.3	Lithosols/xerosols
KK20/SS	6.5	6.4	57	1.1	0.15	7.60	1.97	16	0.9	4.8	4.2	0.3	Lithosols/xerosols
KK21/SS	6.9	6.4	56	1.3	0.09	14.33	2.22	21	0.8	4.8	3.8	0.3	Lithosols/xerosols
KK22/SS	6.9	6.3	41	1.1	0.11	9.73	1.84	8	0.8	4.3	4.4	0.3	Lithosols/xerosols
KK23/SS	6.7	6.2	35	0.8	0.09	9.11	1.41	11	0.5	3.4	4.3	0.2	Lithosols/xerosols
KK24/SS	6.8	6.2	38	0.9	0.09	9.56	1.48	12	0.7	3.7	4	0.4	Lithosols/xerosols
KK25/SS	6.9	6.3	55	1.2	0.11	10.91	2.07	21	0.8	5.4	4.1	0.3	Lithosols/xerosols
KK26/SS	6.8	6.5	47	1.0	0.04	25.00	1.72	27	1.2	6.7	4.2	0.3	Lithosols/xerosols
KK27/SS	6.5	6.3	83	1.7	0.19	9.11	2.98	28	1.2	6.1	4.1	0.3	Lithosols/xerosols
KK28/SS	6.5	6.3	39	1.2	0.11	11.27	2.14	20	0.9	5.1	3.4	0.5	Lithosols/xerosols
KK29/SS	6.6	6.3	48	1.0	0.11	8.91	1.69	31	0.9	4.7	3.7	0.3	Lithosols/xerosols
KK32/SS	6.8	6.2	41	0.8	0.26	3.00	1.34	13	0.8	7	5.3	0.4	Lithosols/xerosols
KK/04/SS	7.6	6.6	26	0.9	0.11	8.09	1.53	14	0.9	5.7	4.5	0.1	Lithosols/xerosols

***KAPKUN DRY SEASON* – Soil samples**

Senders ref.	H_2O	$CaCl_2$	Ec	C	N	C:N	SOM	P	K	Ca	Mg	Na	Soil type
	pH	pH	mS/cm	%	%	Ratio	%	ppm	E Bases C mol (+)/Kg				
SS1KN1	6.3	5.5	0.03	0.9	0.15	5.93	1.53	15	1.22	6.15	2.64	1.51	Ferralic cambisols/calcic xerosols
SS2KN2	5.9	5.4	0.05	1.3	0.23	5.60	2.17	10	1.73	5.26	2.36	1.93	Ferralic cambisols/calcic xerosols
SS3KN3	6.2	5.9	0.03	0.9	0.15	5.87	1.52	12	1.78	7.1	2.6	2.18	Ferralic cambisols/calcic xerosols
SS4KN4	5.9	5.1	0.04	1.2	0.23	5.29	2.05	17	1.73	5.88	2.45	2.18	Ferralic cambisols/calcic xerosols
SS5KN5	6.3	5.8	0.04	0.8	0.15	5.53	1.43	10	2.09	5.84	2.68	2.6	Ferralic cambisols/calcic xerosols
SS6KN6	5.6	5.7	0.05	1.2	0.23	5.11	1.98	12	1.68	5.72	2.27	1.93	Ferralic cambisols/calcic xerosols
SS7KN7	6.3	5.6	0.03	0.9	0.15	6.27	1.62	9	1.37	5.83	2.45	1.43	Ferralic cambisols/calcic xerosols
SS8KN8	6.2	5.5	0.04	1.0	0.23	4.22	1.64	9	1.93	5.3	2.12	1.43	Ferralic cambisols/calcic xerosols
SS9KN9	6.6	6.1	0.05	1.0	0.23	4.22	1.64	19	1.93	6.92	2.31	2.1	Ferralic cambisols/calcic xerosols
SS10KN10	6.1	5.4	0.04	1.0	0.15	6.33	1.64	8	1.37	5.02	2.42	1.43	Ferralic cambisols/calcic xerosols
SS11KN11	6.5	5.9	0.04	1.3	0.19	6.99	2.26	13	1.68	6.15	2.2	1.85	Ferralic cambisols/calcic xerosols
SS12KN12	6.1	5.7	0.05	1.4	0.26	5.41	2.45	12	1.7	5.7	2.4	1.9	Ferralic cambisols/calcic xerosols
SS13KN13	6.3	5.7	0.04	1.0	0.19	5.44	1.76	9	1.48	6.09	2.46	1.6	Ferralic cambisols/calcic xerosols
SS14KN14	6.0	5.6	0.04	0.9	0.19	4.91	1.59	10	1.17	5.96	2.54	1.76	Ferralic cambisols/calcic xerosols
SS15KN15	6.2	5.8	0.04	1.1	0.15	7.40	1.91	9	1.32	6.21	2.46	1.85	Ferralic cambisols/calcic xerosols
SS16KN16	6.4	5.9	0.04	0.7	0.23	2.98	1.16	7	1.22	4.97	2.15	1.85	Ferralic cambisols/calcic xerosols
SS17KN17	6.2	5.6	0.04	0.7	0.15	4.87	1.26	13	1.22	4.59	2.13	1.93	Ferralic cambisols/calcic xerosols
SS18KN18	6.5	6.1	0.04	1.2	0.23	5.33	2.07	11	1.63	6.56	2.48	2.27	Ferralic cambisols/calcic xerosols
SS19KN19	6.3	5.7	0.05	1.1	0.26	4.34	1.97	19	1.58	6.45	2.38	2.1	Ferralic cambisols/calcic xerosols
SS20KN20	6.3	5.5	0.04	0.8	0.19	4.00	1.29	12	1.42	5.66	2.36	2.18	Ferralic cambisols/calcic xerosols
SS21KN21	5.7	4.9	0.04	0.7	0.23	2.98	1.16	12	1.02	4.67	2.2	1.43	Ferralic cambisols/calcic xerosols
SS22KN22	6.4	5.9	0.04	0.9	0.23	3.78	1.47	11	1.37	6.08	2.39	1.85	Ferralic cambisols/calcic xerosols
SS23KN23	6.6	5.6	0.04	1.2	0.15	8.00	2.07	14	1.53	7.24	2.39	2.1	Ferralic cambisols/calcic xerosols
SS24KN24	6.1	5.6	0.04	0.8	0.23	3.69	1.43	20	1.32	5.68	2.55	2.1	Ferralic cambisols/calcic xerosols
SS25KN25	6.2	6.1	0.03	0.6	0.23	2.71	1.05	12	1.07	5.72	2.47	1.68	Ferralic cambisols/calcic xerosols
SS26KN26	5.9	5.4	0.03	1.0	0.23	4.27	1.66	15	1.07	5.35	2.71	1.76	Ferralic cambisols/calcic xerosols
SS27KN27	6.1	5.4	0.03	0.7	0.23	3.29	1.28	13	1.22	5.65	2.35	1.93	Ferralic cambisols/calcic xerosols
SS28KN28	5.7	5.0	0.04	1.0	0.15	6.53	1.69	15	1.48	5.18	2.41	2.18	Ferralic cambisols/calcic xerosols
SS29KN29	6.2	5.7	0.03	0.8	0.15	5.20	1.34	15	1.32	5.58	2.24	1.93	Ferralic cambisols/calcic xerosols
SS30KN30	6.1	5.4	0.03	0.8	0.23	3.51	1.36	8	0.86	5.09	2.38	1.51	Ferralic cambisols/calcic xerosols

***KAPKUN WET SEASON* – Soil samples**

Senders ref.	H_2O	$CaCl_2$	Ec	C	N	C:N	SOM	P	K	Ca	Mg	Na	Soil type
	pH	pH	µs/cm	%	%	Ratio	%	ppm	E Bases C mol (+)/Kg				
KN01/SS	6.6	6.5	50	1.0	0.71	1.33	1.64	5	1.5	11.3	5.3	0.04	Ferralic cambisols/calcic xerosols
KN02/SS	6.5	6.3	53	1.4	1.04	1.33	2.38	22	1.7	7.1	5.7	0.01	Ferralic cambisols/calcic xerosols
KN03/SS	6.5	6.4	55	1.4	1.07	1.33	2.47	20	1.6	6.4	5.4	0.05	Ferralic cambisols/calcic xerosols
KN04/SS	6.4	6.3	30	0.9	0.69	1.33	1.59	10	1.5	5.5	5.6	0.07	Ferralic cambisols/calcic xerosols
KN05/SS	6.5	6.4	23	0.8	0.63	1.33	1.45	12	1.5	5.1	4.9	0.00	Ferralic cambisols/calcic xerosols
KN06/SS	6.6	6.4	41	1.3	0.94	1.33	2.16	20	1.5	6.5	5.1	0.04	Ferralic cambisols/calcic xerosols
KN07/SS	6.5	6.4	44	1.2	0.88	1.33	2.02	18	1.7	6.2	5.4	0.04	Ferralic cambisols/calcic xerosols
KN08/SS	6.5	6.3	43	1.1	0.80	1.33	1.84	15	1.6	6.7	5.6	0.07	Ferralic cambisols/calcic xerosols
KN09/SS	6.6	6.3	42	1.0	0.76	1.33	1.74	17	1.6	5.6	5.3	0.05	Ferralic cambisols/calcic xerosols
KN10/SS	6.5	6.4	32	0.9	0.64	1.33	1.47	7	1.2	7.2	6.1	0.06	Ferralic cambisols/calcic xerosols
KN11/SS	6.6	6.3	43	0.9	0.71	1.33	1.62	15	1.4	6.9	5.6	0.05	Ferralic cambisols/calcic xerosols
KN12/SS	6.6	6.2	33	1.0	0.15	6.80	1.76	10	2.5	11.7	6.4	0.31	Ferralic cambisols/calcic xerosols
KN13/SS	6.6	6.4	42	1.2	0.19	6.16	2.02	9	2	7.2	5.2	0.01	Ferralic cambisols/calcic xerosols
KN14/SS	6.7	6.5	51	0.8	0.11	7.36	1.40	8	1.2	6.1	5.6	0.06	Ferralic cambisols/calcic xerosols
KN15/SS	6.5	6.4	47	1.0	0.19	5.00	1.64	13	1.9	5.7	5.8	0.07	Ferralic cambisols/calcic xerosols
KN01/SS	7.3	6.3	43	0.9	0.19	4.95	1.62	18	2.3	7.9	4.9	0.17	Ferralic cambisols/calcic xerosols
KN02/SS	6.3	6.0	27	1.2	0.19	6.32	2.07	18	1.3	6.9	6.3	0.11	Ferralic cambisols/calcic xerosols
KN03/SS	7.4	6.0	29	1.3	0.11	12.09	2.29	14	1.5	6.5	3.2	0.16	Ferralic cambisols/calcic xerosols
KN04/SS	6.7	6.0	29	1.2	0.19	6.32	2.07	17	1.5	5.7	5.3	0.14	Ferralic cambisols/calcic xerosols
KN05/SS	6.7	5.8	33	1.3	0.19	6.58	2.16	30	1.8	7.3	6.3	0.27	Ferralic cambisols/calcic xerosols
KN06/SS	6.8	6.8	36	0.9	0.19	4.68	1.53	28	1.4	6.7	5.8	0.23	Ferralic cambisols/calcic xerosols
KN07/SS	6.8	6.5	44	1.1	0.19	5.53	1.81	12	1.7	6.4	5.9	0.39	Ferralic cambisols/calcic xerosols
KN08/SS	6.8	6.8	43	1.1	0.11	10.00	1.90	16	1.8	6.5	5.5	0.13	Ferralic cambisols/calcic xerosols
KN09/SS	7.05	6.0	22	1.0	0.19	5.11	1.67	9	1.6	7.7	6.1	0.19	Ferralic cambisols/calcic xerosols
KN10/SS	6.8	6.5	11	1.0	0.11	8.82	1.67	13	1.3	5.9	4.7	0.04	Ferralic cambisols/calcic xerosols
KN/11/SS	6.5	6.1	28	0.7	0.19	3.63	1.19	28	3.3	8.4	6.1	0.09	Ferralic cambisols/calcic xerosols
KN/12/SS	6.6	6.2	82	1.8	0.19	9.53	3.12	17	1.8	6.3	5.7	0.08	Ferralic cambisols/calcic xerosols
KN/13/SS	7.05	6.3	25	0.8	0.19	4.11	1.34	28	2.2	7.7	5.7	0.26	Ferralic cambisols/calcic xerosols
KN/14/SS	6.9	6.0	20	1.0	0.19	5.47	1.79	15	1.1	5.9	5.9	0.06	Ferralic cambisols/calcic xerosols
KN/15/SS	7.05	6.1	40	0.8	0.11	7.64	1.45	13	1.7	8.4	5.9	0.20	Ferralic cambisols/calcic xerosols

MAOI DRY SEASON – Soil samples

Senders ref.	H_2O	$CaCl_2$	Ec	C	N	C:N	SOM	P	K	Ca	Mg	Na	Soil type
	pH	pH	µs/cm	%	%	Ratio	%	ppm	E Bases C mol (+)/Kg				
MI/01/SS	6.5	6.5	34	0.6	0.11	5.27	1.00	10	1.2	4.2	3.9	1.7	Ando-chromic cambisols/xerosols
MI/02/SS	6.7	6.3	26	0.8	0.19	4.42	1.45	13	1.3	5.2	4.9	1.7	Ando-chromic cambisols/xerosols
MI/03/SS	6.6	6.5	24	0.9	0.19	4.58	1.50	12	1.1	5.5	4.5	1.7	Ando-chromic cambisols/xerosols
MI/04/SS	6.6	6.4	40	0.9	0.11	8.09	1.53	12	1.3	5.4	4.8	1.9	Ando-chromic cambisols/xerosols
MI/05/SS	7.05	6.6	67	0.9	0.26	3.35	1.50	9	0.4	10.9	3.9	1.7	Ando-chromic cambisols/xerosols
MI/06/SS	6.3	6.2	64	1.0	0.19	5.05	1.66	15	1	5.2	4.1	1.9	Ando-chromic cambisols/xerosols
MI/07/SS	6.7	6.4	20	0.6	0.26	2.27	1.02	10	1.1	4.8	3.9	1.8	Ando-chromic cambisols/xerosols
MI/08/SS	6.7	6.4	23	0.4	0.11	3.45	0.66	12	0.9	4.9	3.9	1.8	Ando-chromic cambisols/xerosols
MI/09/SS	6.9	6.6	20	0.3	0.26	1.12	0.50	23	0.9	4.0	4.4	1.7	Ando-chromic cambisols/xerosols
MI/10/SS	6.7	6.1	12	0.3	0.11	2.82	0.53	9	0.7	3.1	4.2	1.8	Ando-chromic cambisols/xerosols
MI/11/SS	6.9	6.5	19	0.4	0.19	2.16	0.71	14	0.7	3.1	0.4	1.7	Ando-chromic cambisols/xerosols
MI/12/SS	6.7	6.5	18	0.3	0.19	1.74	0.57	14	0.9	3.0	4.4	1.8	Ando-chromic cambisols/xerosols
MI/13/SS	7.05	6.5	20	0.9	0.19	4.53	1.48	8	1	3.9	4.3	1.6	Ando-chromic cambisols/xerosols
MI/14/SS	7.05	6.3	26	0.4	0.19	2.21	0.72	22	0.8	3.4	4.2	1.7	Ando-chromic cambisols/xerosols
MI/15/SS	6.8	6.4	39	1.2	0.26	4.65	2.09	10	1.1	5.1	3.9	2.0	Ando-chromic cambisols/xerosols
MI/16/SS	6.4	6.3	32	0.6	0.19	3.05	1.00	12	0.8	4.4	3.4	1.9	Ando-chromic cambisols/xerosols
MI/17/SS	6.7	6.3	23	0.7	0.11	5.91	1.12	11	1.1	38.4	5.8	1.6	Ando-chromic cambisols/xerosols
MI/18/SS	6.6	6.4	37	0.6	0.11	5.45	1.03	35	1.2	3.7	3.6	1.8	Ando-chromic cambisols/xerosols
MI/19/SS	6.6	6.4	21	0.4	0.19	2.05	0.67	40	1.2	3.3	3.5	1.7	Ando-chromic cambisols/xerosols
MI/20/SS	6.6	6.2	18	0.4	0.11	3.82	0.72	45	1.2	3.7	3.7	1.8	Ando-chromic cambisols/xerosols
MI/21/SS	6.7	6.5	28	0.6	0.19	3.05	1.00	9	1.2	5.4	3.9	1.8	Ando-chromic cambisols/xerosols
MI/22/SS	6.7	6.5	54	0.6	0.11	5.27	1.00	32	1.6	4.1	2.6	1.7	Ando-chromic cambisols/xerosols
MI/23/SS	6.8	6.4	24	0.5	0.11	4.55	0.86	13	1	4.0	3.6	1.8	Ando-chromic cambisols/xerosols
MI/24/SS	7.2	6.6	14	0.3	0.11	2.55	0.48	8	0.8	3.3	4.5	1.7	Ando-chromic cambisols/xerosols
MI/25/SS	6.6	6.3	29	0.4	0.11	3.18	0.60	20	1.2	3.0	2.7	1.7	Ando-chromic cambisols/xerosols
MI/26/SS	7.05	6.5	21	0.6	0.04	14.50	1.00	3	1.2	4.6	4.3	1.9	Ando-chromic cambisols/xerosols
MI/27/SS	6.7	6.5	38	0.4	0.11	3.82	0.72	16	1.2	5.9	5	1.8	Ando-chromic cambisols/xerosols
MI/28/SS	7.2	6.7	54	1.2	0.19	6.32	2.07	13	1.5	7.8	3.6	1.8	Ando-chromic cambisols/xerosols
MI/29/SS	6.7	6.6	27	0.5	0.11	4.73	0.90	12	1.3	4.5	4.9	1.7	Ando-chromic cambisols/xerosols

MAOI WET SEASON – Soil samples

Senders ref.	H_2O	$CaCl_2$	Ec	C	N	C:N	SOM	P	K	Ca	Mg	Na	Soil type
	pH	pH	mS/cm	%	%	Ratio	%	ppm	E Bases C mol (+)/Kg				
M1/01/SS	5.9	5.8	0.16	1.02	0.19	5.37	1.76	11	1.1	4.15	1.57	5.3	Ando-chromic cambisols/xerosols
M1/02/SS	6.1	5.8	0.05	0.81	0.19	4.26	1.40	3	1.2	3.64	1.48	0.66	Ando-chromic cambisols/xerosols
M1/03/SS	6.5	6.2	0.06	0.81	0.19	4.26	1.40	5	1.2	3.92	1.75	0.7	Ando-chromic cambisols/xerosols
M1/04/SS	6.1	5.8	0.03	0.69	0.19	3.63	1.19	6	1.25	4.39	1.97	0.66	Ando-chromic cambisols/xerosols
M1/05/SS	6.3	6.0	0.07	0.84	0.19	4.42	1.45	3	1.45	5.3	1.78	0.26	Ando-chromic cambisols/xerosols
M1/06/SS	6.1	5.1	0.07	1.23	0.26	4.73	2.12	5	1.2	4.83	1.75	0.22	Ando-chromic cambisols/xerosols
M1/07/SS	6.1	5.9	0.05	0.95	0.19	5.00	1.64	25	1.25	3.88	1.66	0.31	Ando-chromic cambisols/xerosols
M1/08/SS	6.1	6.0	0.05	0.91	0.11	8.27	1.57	12	0.7	4.33	1.45	0.09	Ando-chromic cambisols/xerosols
M1/09/SS	6.3	6.0	0.07	0.79	0.26	3.04	1.36	8	1.8	3.83	1.41	0.44	Ando-chromic cambisols/xerosols
M1/10/SS	6.4	5.9	0.05	0.57	0.11	5.18	0.98	9	0.85	3.26	1.32	0.13	Ando-chromic cambisols/xerosols
M1/11/SS	6.5	6.0	0.05	1.09	0.19	5.74	1.88	10	1.2	4.59	1.64	0.44	Ando-chromic cambisols/xerosols
M1/12/SS	5.8	5.6	0.04	0.69	0.19	3.63	1.19	8	1.25	2.87	1.5	0.35	Ando-chromic cambisols/xerosols
M1/13/SS	5.9	5.9	0.04	0.83	0.19	4.37	1.43	10	0.7	4.86	1.78	0.31	Ando-chromic cambisols/xerosols
M1/14/SS	6.2	6.1	0.03	0.7	0.19	3.68	1.21	16	1.25	3.92	1.72	0.44	Ando-chromic cambisols/xerosols
M1/15/SS	6.2	6.1	0.07	0.8	0.19	4.21	1.38	8	1.15	4.2	1.85	0.4	Ando-chromic cambisols/xerosols
M1/16/SS	6.5	6.3	0.02	0.74	0.19	3.89	1.28	22	1.3	4.24	1.76	0.53	Ando-chromic cambisols/xerosols
M1/18/SS	6.0	5.7	0.05	1.04	0.19	5.47	1.79	11	1	3.7	1.46	0.31	Ando-chromic cambisols/xerosols
M1/19/SS	5.9	5.8	0.13	0.76	0.26	2.92	1.31	7	1.05	3.94	1.7	0.53	Ando-chromic cambisols/xerosols
M1/20/SS	6.3	5.6	0.06	0.95	0.26	3.65	1.64	11	1.1	5.12	1.51	0.4	Ando-chromic cambisols/xerosols
SS/M1/1	6.3	5.9	0.03	0.69	0.11	6.27	1.19	5	0.9	3.68	1.28	0.31	Ando-chromic cambisols/xerosols
SS/M1/2	6.2	5.6	0.03	0.38	0.19	2.00	0.66	8	1.1	3.18	1.84	0.48	Ando-chromic cambisols/xerosols
SS/M1/3	6.6	6.5	0.04	0.88	0.19	4.63	1.52	4	1.4	4.29	1.82	0.57	Ando-chromic cambisols/xerosols
SS/M1/4	6.3	6.1	0.03	0.32	0.26	1.23	0.55	12	1.1	3.13	1.64	0.48	Ando-chromic cambisols/xerosols
SS/M1/5	6.5	6.3	0.07	0.87	0.19	4.58	1.50	24	1.25	9.75	1.25	0.53	Ando-chromic cambisols/xerosols
SS/M1/6	6.4	6.3	0.03	0.69	0.19	3.63	1.19	10	2.25	3.2	1.71	0.97	Ando-chromic cambisols/xerosols
SS/M1/7	6.4	6.1	0.03	0.79	0.11	7.18	1.36	19	1.25	3.69	1.42	0.53	Ando-chromic cambisols/xerosols
SS/M1/8	6.3	6.1	0.02	0.47	0.11	4.27	0.81	15	1.3	5.44	1.93	0.62	Ando-chromic cambisols/xerosols
SS/M1/9	6.9	6.5	0.04	0.54	0.26	2.08	0.93	15	1.65	4.48	1.53	0.7	Ando-chromic cambisols/xerosols
SS/M1/10	6.9	6.5	0.03	0.35	0.19	1.84	0.60	12	0.9	3.56	2.03	0.48	Ando-chromic cambisols/xerosols

SS/M1/11	6.5	6.2	0.03	1.06	0.19	5.58	1.83	9	0.95	4.42	1.67	0.48	Ando-chromic cambisols/xerosols
SS/M1/12	6.4	5.9	0.05	0.03	0.19	0.17	0.06	14	1.7	5.56	1.5	0.84	Ando-chromic cambisols/xerosols
SS/M1/13	5.9	5.8	0.02	0.5	0.26	1.92	0.86	16	1.15	2.63	1.24	0.53	Ando-chromic cambisols/xerosols
SS/M1/14	5.9	5.6	0.02	0.79	0.19	4.16	1.36	10	0.85	3.29	1.49	0.53	Ando-chromic cambisols/xerosols
SS/M1/15	6.9	6.4	0.03	0.34	0.19	1.79	0.59	36	2.8	5.43	3.07	1.19	Ando-chromic cambisols/xerosols

SOLIT: DRY SEASON - Trace elements – EDTA extractions dry and wet seasons

Lab No.	Senders Ref.	H_2O pH	$CaCl_2$ pH	EC mS/cm	Cu ppm	Fe ppm	Mn ppm	Zn ppm
170	ST/SSM1	7.9	7.3	0.09	0.1	14	20	0.5
172	ST/SSM2	8.1	7.6	0.07	0.6	30	133	0.2
174	ST/SSM3	8.2	7.1	0.07	0.1	32	34	0.2
176	ST/SSM4	7.9	7.2	0.08	0.1	59	38	0.4
178	ST/SSM5	8.0	7.7	0.05	0.1	59	53	1.7
180	ST/SSM6	8.0	7.7	0.05	0.4	60	85	0.8
182	ST/SSM7	8.1	7.1	0.06	0.6	53	79	1.0
184	ST/SSM8	7.9	7.3	0.05	1.1	100	293	1.3
186	ST/SSM9	8.1	7.2	0.06	1.2	102	304	1.0
188	ST/SSM10	8.1	7.2	0.07	1.5	117	301	0.7
190	ST/SSM11	7.5	7.2	0.08	2.3	122	326	2.4
192	ST/SSM12	8.1	7.2	0.05	2.3	159	340	1.2
194	ST/SSM13	8.4	7.3	0.05	1.8	124	246	0.7
196	ST/SSM14	8.0	7.1	0.04	1.7	205	428	1.0
198	ST/SSM15	8.1	7.3	0.06	2.1	199	312	1.5
200	ST/SSL1	7.6	7.1	0.06	2.4	207	364	2.3
202	ST/SSL2	7.7	7.05	0.09	2.1	208	381	2.4
204	ST/SSL3	7.1	7.1	0.05	1.5	209	384	0.9
206	ST/SSL4	8.0	7.1	0.08	1.6	247	445	0.6
208	ST/SSL5	7.7	7.3	0.06	2.1	249	501	0.7
210	ST/SSL6	7.7	7.05	0.06	2.9	256	461	0.6
212	ST/SSL7	7.8	7.05	0.06	2.1	203	206	0.9
214	ST/SSL8	7.2	7.1	0.05	2.6	232	228	0.8
216	ST/SSL9	8.0	7.1	0.06	2.4	230	191	0.9
218	ST/SSL10	7.8	7.1	0.06	3.0	244	226	0.2
220	ST/SSL11	7.9	7.1	0.06	3.0	269	296	1.4
222	ST/SSL12	7.9	7.05	0.05	3.1	263	207	0.6
224	ST/SSL13	8.1	7.05	0.05	3.4	265	228	1.0
226	ST/SSL14	8.2	7.1	0.05	3.4	266	232	1.0
228	ST/SSL15	8.0	7.5	0.06	3.5	311	238	1.1
230	ST/SSL16	8.1	7.4	0.05	4.4	330	273	2.3
232	ST/SSL17	8.2	7.1	0.06	4.2	346	449	2.6

SOLIT: WET SEASON - EDTA Extractables

Lab No.	Senders Ref.	H_2O pH	$CaCl_2$ pH	EC □s/cm	Cu ppm	Fe ppm	Mn ppm	Zn ppm
343	ST01/SS	7.2	7.05	50	1.6	61	226	1.3
344	ST02/SS	7.1	6.6	100	1.9	44	107	1.8
345	ST03/SS	7.4	7.1	121	1.6	95	222	2.5
346	ST04/SS	7.1	6.7	68	1.3	98	247	2.5
347	ST05/SS	7.4	7.1	85	1.0	108	208	2.9
383	SS/ST/1	7.3	7.1	120	0.7	121	226	3.4
384	SS/ST/2	7.2	7.05	112	2.0	137	201	3.0
385	SS/ST/3	7.2	6.9	67	0.6	107	126	2.2
386	SS/ST/4	7.3	6.9	76	1.0	113	212	2.4
387	SS/ST/5	7.3	6.9	37	2.1	138	287	2.3
388	SS/ST/6	7.3	7.05	41	3.2	85	362	3.2
389	SS/ST/7	7.1	6.6	59	1.8	94	417	3.3
390	SS/ST/8	7.1	6.8	68	0.3	189	227	4.0
391	SS/ST/9	6.9	6.7	72	0.8	106	248	2.0
392	SS/ST/10	7.1	6.9	90	2.8	94	280	2.8
233	ST/01/SS	7.6	6.7	61	0.3	146	231	0.9
234	ST/02/SS	7.4	7.1	6	3.0	217	389	1.6
235	ST/03/SS	7.3	6.5	34	1.2	134	323	2.2
236	ST/04/SS	8.2	7.3	154	1.8	167	407	2.2
237	ST/05/SS	7.1	6.8	70	1.6	140	384	2.7
238	ST/05/SS	7.1	6.8	50	2.6	137	309	3.0
239	ST/06/SS	7.05	7.05	75	1.5	103	148	3.1
240	ST/07/SS	7.3	6.7	16	0.4	132	357	4.2
241	ST/08/SS	7.1	7.05	33	0.8	149	470	1.0
242	ST/09/SS	7.4	6.9	50	0.5	113	209	1.1
243	ST/10/SS	7.5	6.9	40	0.1	103	94	1.0
244	ST/11SS	7.8	6.9	47	0.2	118	204	1.7
245	ST/12/SS	7.6	7.2	86	2.1	110	217	2.5
246	ST/13/SS	8.0	6.8	53	1.2	173	502	3.2
247	ST/14/SS	7.3	6.9	68	1.0	101	83	3.4
248	ST/15/SS	7.2	6.9	62	0.5	123	346	0.8

KIMOROK: DRY SEASON - EDTA Extractables

Lab No.	Senders Ref.	H_2O pH	$CaCl_2$ pH	EC mS/cm	Cu ppm	Fe ppm	Mn ppm	Zn ppm
117	KK1SS	6.8	6.2	0.07	0.1	309	255	2.4
118	KK2SS	6.5	6.1	0.05	0.1	213	240	1.3
119	KK3SS	6.5	5.9	0.05	0.2	446	264	2.9
120	KK4SS	5.9	5.7	0.04	0.6	223	230	1.9
121	KK5SS	6.5	5.8	0.05	0.1	357	258	2.1
122	KK6SS	6.0	5.7	0.06	0.2	443	387	2.9
123	KK7SS	5.9	5.8	0.04	0.2	402	355	2.9
124	KK8SS	5.6	5.6	0.03	0.1	307	219	1.7
125	KK9SS	6.4	6.1	0.03	0.1	326	236	3.3
126	KK10SS	6.0	5.9	0.06	0.3	293	228	1.9
127	KK11SS	5.8	5.7	0.04	0.3	306	278	2.4
128	KK12SS	6.2	5.9	0.03	0.4	313	260	3.1
129	KK13SS	6.0	5.8	0.04	0.3	329	426	2.9
130	KK14SS	6.1	5.7	0.03	0.4	371	400	4.0
131	KK15SS	6.2	5.7	0.03	0.5	383	484	4.3
132	KK16SS	5.6	5.5	0.03	0.6	117	161	5.2
133	KK17SS	6.2	5.8	0.04	0.2	178	251	1.8
134	KK18SS	6.8	6.0	0.05	0.3	138	246	1.8
135	KK19SS	6.5	5.8	0.03	0.3	172	293	2.6
136	KK20SS	6.4	5.9	0.03	0.8	145	324	4.7
137	KK21SS	6.3	5.9	0.04	0.6	138	326	4.1
138	KK22SS	6.4	5.9	0.05	0.7	152	340	5.4
139	KK23SS	6.4	5.7	0.03	0.7	172	309	4.7
140	KK24SS	6.0	5.7	0.05	0.8	146	239	5.4
141	KK25SS	6.4	6.0	0.03	0.1	136	204	6.1
142	KK26SS	6.2	5.7	0.03	0.1	129	208	1.8
143	KK27SS	6.6	5.5	0.03	0.1	232	489	2.7
144	KK28SS	6.3	5.9	0.05	0.4	205	317	2.1
145	KK29SS	6.3	5.7	0.04	0.3	157	392	2.7
146	KK30SS	5.8	5.8	0.03	0.5	158	280	3.8

KIMOROK: WET SEASON – EDTA Extractables

Lab No.	Senders Ref.	H_2O pH	$CaCl_2$ pH	EC □s/cm	Cu ppm	Fe ppm	Mn ppm	Zn ppm
373	KK01/SS	6.5	6.3	41	0.8	149	213	14.4
374	KK02/SS	6.4	6.2	55	0.5	213	321	14.5
375	KK03/SS	6.6	6.4	85	0.6	187	374	14.3
376	KK04/SS	6.8	6.3	35	0.6	248	372	14.9
377	KK05/SS	6.3	6.1	42	0.5	186	306	16.0
378	KK06/SS	6.5	6.3	66	0.6	189	367	25.8
379	KK07/SS	6.5	6.2	65	0.7	221	364	16.9
380	KK08/SS	6.3	6.1	46	0.7	210	306	17.7
381	KK09/SS	6.5	6.4	55	0.7	239	304	3.3
382	KK10SS	6.1	6.0	61	0.9	198	452	2.3
383	KK11/SS	6.3	6.1	60	0.8	151	183	2.5
384	KK12/SS	6.4	6.1	58	0.9	326	398	3.1
385	KK13/SS	6.7	6.3	40	1.1	155	181	4.0
386	KK14/SS	6.6	6.3	39	1.2	249	352	4.7
387	KK15/SS	6.7	6.2	38	1.2	185	296	5.2
388	KK16/SS	6.8	6.3	42	1.1	227	376	4.0
389	KK17/SS	6.9	6.3	50	1.2	306	432	5.4
390	KK18/SS	6.6	6.3	40	1.4	164	310	14.5
391	KK19/SS	6.9	6.5	54	1.4	208	361	18.3
392	KK20/SS	6.5	6.4	57	1.5	162	259	16.3
393	KK21/SS	6.9	6.4	56	0.8	254	247	2.2
394	KK22/SS	6.9	6.3	41	1.2	288	482	14.4
395	KK23/SS	6.7	6.2	35	1.4	237	396	14.1
396	KK24/SS	6.8	6.2	38	1.4	217	356	13.9
397	KK25/SS	6.9	6.3	55	2.3	273	374	15.1
398	KK26/SS	6.8	6.5	47	2.0	279	404	14.8
399	KK27/SS	6.5	6.3	83	1.7	253	318	14.7
400	KK28/SS	6.5	6.3	39	1.6	295	472	14.4
401	KK29/SS	6.6	6.3	48	1.8	219	246	14.0
404	KK32/SS	6.8	6.2	41	1.6	237	367	14.4
296	KK/04/SS	7.6	6.6	26	0.3	173	290	14.2
298	KK/06/SS	6.6	6.1	11	0.5	191	444	14.3

KAPKUN: DRY SEASON – EDTA Extractables

Lab No.	Senders Ref.	H_2O pH	$CaCl_2$ pH	EC mS/cm	Cu ppm	Fe ppm	Mn ppm	Zn ppm
276	KN/SS1	6.3	5.5	0.03	1.1	147	264	3.3
278	KN/SS2	5.9	5.4	0.05	1.1	339	483	3.2
280	KN/SS3	6.2	5.9	0.03	0.3	300	419	2.6
282	KN/SS4	5.9	5.1	0.04	0.6	377	495	8.5
284	KN/SS5	6.3	5.8	0.04	0.8	300	361	6.9
286	KN/SS6	5.6	5.7	0.05	0.4	346	411	6.4
288	KN/SS7	6.3	5.6	0.03	0.4	378	446	6.7
290	KN/SS8	6.2	5.5	0.04	0.4	288	247	7.6
292	KN/SS9	6.6	6.1	0.05	0.9	288	427	10.9
294	KN/SS10	6.1	5.4	0.04	0.4	185	301	8.9
296	KN/SS11	6.5	5.9	0.04	0.4	279	455	9.1
298	KN/SS12	6.1	5.7	0.05	0.3	218	215	3.6
300	KN/SS13	6.3	5.7	0.04	0.6	291	413	2.5
302	KN/SS14	6.0	5.6	0.04	0.4	223	303	9.2
304	KN/SS15	6.2	5.8	0.04	0.7	291	364	11.7
306	KN/SS16	6.4	5.9	0.04	0.6	263	295	3.6
308	KN/SS17	6.2	5.6	0.04	0.5	257	274	2.6
310	KN/SS18	6.5	6.1	0.04	0.5	384	542	4.6
312	KN/SS19	6.3	5.7	0.05	1.3	423	527	9.8
314	KN/SS20	6.3	5.5	0.04	1.1	320	307	4.5
316	KN/SS21	5.7	4.9	0.04	0.9	379	330	4.9
318	KN/SS22	6.4	5.9	0.04	1.3	244	400	6.3
320	KN/SS23	6.6	5.6	0.04	1.1	368	581	7.8
322	KN/SS24	6.1	5.6	0.04	0.9	287	442	8.3
324	KN/SS25	6.2	6.1	0.03	1.0	197	327	7.6
326	KN/SS26	5.9	5.4	0.03	2.0	271	466	5.1
328	KN/SS27	6.1	5.4	0.03	1.3	206	386	5.7
330	KN/SS28	5.7	5.0	0.04	1.8	270	480	8.5
332	KN/SS29	6.2	5.7	0.03	1.8	177	360	6.9
334	KN/SS30	6.1	5.4	0.03	1.6	179	311	3.8

KAPKUN: WET SEASON – EDTA Extractables

Lab No.	Senders Ref.	H_2O pH	$CaCl_2$ pH	EC □s/cm	Cu ppm	Fe ppm	Mn ppm	Zn ppm
348	KN01/SS	6.6	6.5	50	0.2	189	292	2.6
349	KN02/SS	6.5	6.3	53	0.2	268	444	5.0
350	KN03/SS	6.5	6.4	55	0.3	197	295	3.1
351	KN04/SS	6.4	6.3	30	0.0	170	203	3.1
352	KN05/SS	6.5	6.4	23	0.4	170	180	3.0
353	KN06/SS	6.6	6.4	41	0.4	258	346	4.7
354	KN07/SS	6.5	6.4	44	0.2	217	340	5.4
355	KN08/SS	6.5	6.3	43	0.4	295	426	4.8
356	KN09/SS	6.6	6.3	42	0.2	194	284	4.5
357	KN10/SS	6.5	6.4	32	0.4	188	266	5.3
358	KN11/SS	6.6	6.3	43	0.2	239	305	5.8
359	KN12/SS	6.6	6.2	33	0.2	265	330	5.8
360	KN13/SS	6.6	6.4	42	0.3	235	330	7.7
361	KN14/SS	6.7	6.5	51	0.2	156	265	7.1
362	KN15/SS	6.5	6.4	47	0.4	166	389	9.4
249	KN01/SS	7.3	6.3	43	0.4	116	239	9.3
250	KN02/SS	6.3	6.0	27	0.5	179	275	9.7
251	KN03/SS	7.4	6.0	29	0.4	331	487	9.3
252	KN04/SS	6.7	6.0	29	0.3	232	266	1.0
253	KN05/SS	6.7	5.8	33	0.5	186	275	10.9
254	KN06/SS	6.8	6.8	36	0.4	146	139	8.8
255	KN07/SS	6.8	6.5	44	0.3	265	314	1.8
256	KN08/SS	6.8	6.8	43	0.1	290	403	2.0
257	KN09/SS	7.05	6.0	22	0.3	162	173	8.1
258	KN10/SS	6.8	6.5	11	0.3	186	175	2.3
259	KN/11/SS	6.5	6.1	28	0.7	244	374	6.1
260	KN/12/SS	6.6	6.2	82	0.6	222	239	4.9
261	KN/13/SS	7.05	6.3	25	0.3	227	264	5.5
262	KN/14/SS	6.9	6.0	20	0.5	240	325	7.7
263	KN/15/SS	7.05	6.1	40	0.6	258	323	7.7
264	KN/16/SS	7.3	6.3	24	0.2	287	380	2.7

MAOI - DRY SEASON –EDTA Extractables

Lab No.	Senders ref.	H_2O pH	$CaCl_2$ pH	EC □s/cm	Cu ppm	Fe ppm	Mn ppm	Zn ppm
265	MI/01/SS	6.5	6.5	34	0.2	91	201	0.9
266	MI/02/SS	6.7	6.3	26	0.2	126	318	2.0
267	MI/03/SS	6.6	6.5	24	0.2	154	310	3.1
268	MI/04/SS	6.6	6.4	40	0.4	167	389	3.4
269	MI/05/SS	7.05	6.6	67	0.7	159	684	5.4
270	MI/06/SS	6.3	6.2	64	0.1	198	408	2.7
271	MI/07/SS	6.7	6.4	20	0.4	129	276	2.3
272	MI/08/SS	6.7	6.4	23	0.3	131	245	3.0
273	MI/09/SS	6.9	6.6	20	0.2	143	246	3.5
274	MI/10/SS	6.7	6.1	12	0.2	140	151	1.6
275	MI/11/SS	6.9	6.5	19	0.3	158	242	1.9
276	MI/12/SS	6.7	6.5	18	0.0	206	314	3.8
277	MI/13/SS	7.05	6.5	20	0.3	189	318	3.1
278	MI/14/SS	7.05	6.3	26	0.2	182	271	2.9
279	MI/15/SS	6.8	6.4	39	0.3	264	400	3.5
280	MI/16/SS	6.4	6.3	32	0.4	260	420	4.0
420	MI/17/SS	6.7	6.3	23	0.5	205	204	2.8
421	MI/18/SS	6.6	6.4	37	0.7	233	278	4.1
422	MI/19/SS	6.6	6.4	21	0.5	221	272	4.2
423	MI/20/SS	6.6	6.2	18	0.4	213	201	2.6
424	MI/21/SS	6.7	6.5	28	0.7	272	330	3.7
425	MI/22/SS	6.7	6.5	54	0.7	221	215	5.8
426	MI/23/SS	6.8	6.4	24	0.4	212	130	3.0
427	MI/24/SS	7.2	6.6	14	0.6	229	186	4.2
428	MI/25/SS	6.6	6.3	29	0.4	251	193	2.8
429	MI/26/SS	7.05	6.5	21	0.7	276	275	2.3
430	MI/27/SS	6.7	6.5	38	0.7	259	244	2.9
431	MI/28/SS	7.2	6.7	54	1.2	359	406	4.8
432	MI/29/SS	6.7	6.6	27	0.9	260	212	2.8
433	MI/30/SS	6.8	6.4	20	0.8	295	295	2.5

MAOI WET: EDTA Extractables

Lab No.	Sender's ref.	H_2O pH	$CaCl_2$ pH	EC mS/cm	Cu ppm	Fe ppm	Mn ppm	Zn ppm
305	M1/SS/01	5.9	5.8	0.16	0.5	404	569	7.8
306	M1/SS/02	6.1	5.8	0.05	0.2	320	478	7.6
307	M1/SS/03	6.5	6.2	0.06	0.2	339	580	4.4
308	M1/SS/04	6.1	5.8	0.03	0.5	291	434	3.6
309	M1/SS/05	6.3	6.0	0.07	0.1	388	646	3.5
310	M1/SS/06	6.1	5.1	0.07	0.7	375	545	7.4
311	M1/SS/07	6.1	5.9	0.05	0.7	397	569	9.6
312	M1/SS/08	6.1	6.0	0.05	0.4	431	548	8.0
313	M1/SS/09	6.3	6.0	0.07	0.3	339	444	7.1
314	M1/SS/10	6.4	5.9	0.05	0.3	311	290	7.6
315	M1/SS/11	6.5	6.0	0.05	0.5	476	635	7.4
316	M1/SS/12	5.8	5.6	0.04	0.6	428	499	8.9
317	M1/SS/13	5.9	5.9	0.04	0.7	314	369	6.3
318	M1/SS/14	6.2	6.1	0.03	0.5	355	372	4.3
319	M1/SS/15	6.2	6.1	0.07	0.6	410	482	2.1
320	M1/SS/16	6.5	6.3	0.02	0.4	371	577	5.7
321	M1/SS/17	6.2	5.8	0.04	0.6	422	496	6.4
322	M1/SS/18	6.0	5.7	0.05	0.6	315	439	5.6
323	M1/SS/19	5.9	5.8	0.13	0.4	290	361	2.6
324	M1/SS/20	6.3	5.6	0.06	1.0	432	490	8.8
400	M1/SS/21	6.3	5.9	0.03	0.7	444	466	6.2
401	M1/SS/22	6.2	5.6	0.03	0.8	133	264	4.9
402	M1/SS/23	6.6	6.5	0.04	1.0	373	426	6.5
403	M1/SS/24	6.3	6.1	0.03	0.8	128	234	4.2
404	M1/SS/25	6.5	6.3	0.07	0.6	289	516	13.2
405	M1/SS/26	6.4	6.3	0.03	1.0	162	434	5.7
406	M1/SS/27	6.4	6.1	0.03	1.0	468	501	9.1
407	M1/SS/28	6.3	6.1	0.02	1.1	183	378	4.2
408	M1/SS/29	6.9	6.5	0.04	1.2	433	432	9.2
409	M1/SS/30	6.9	6.5	0.03	0.7	389	413	2.9
410	M1/SS/31	6.5	6.2	0.03	1.7	304	370	13.4
411	M1/SS/32	6.4	5.9	0.05	1.4	612	746	9.5
412	M1/SS/33	5.9	5.8	0.02	1.1	439	382	5.9
413	M1/SS/34	5.9	5.6	0.02	0.8	413	508	8.5
414	M1/SS/35	6.9	6.4	0.03	1.0	348	434	6.7

APPENDIX II

MICRONUTRIENTS UPTAKE BY ACACIA SENEGAL VARIETIES ON NORMAL, LOW (-) AND HIGH (+) DOSAGE TREATMENTS FOR HEIGHTS IN SITES

			Mean ±	S.E.	(P < 0.05)	
Normal	KAPKUN	1	140.71	9.86	0.05	1
Cu -	KAPKUN	2	149.20	11.60	0.05	2
Cu +	KAPKUN	3	163.58	9.86	0.05	3
Fe -	KAPKUN	4	159.20	10.01	0.05	4
Fe +	KAPKUN	5	168.21	9.86	0.05	5
Mn -	KAPKUN	6	172.88	9.86	0.05	6
Mn +	KAPKUN	7	160.25	9.86	0.05	7
Zn -	KAPKUN	8	154.71	9.86	0.05	8
Zn +	KAPKUN	9	148.92	9.86	0.05	9
Normal	KIMOROK	1	184.63	13.18	0.05	10
Cu -	KIMOROK	2	162.11	13.22	0.05	11
Cu +	KIMOROK	3	172.03	11.64	0.05	12
Fe -	KIMOROK	4	177.91	11.61	0.05	13
Fe +	KIMOROK	5	161.52	13.23	0.05	14
Mn -	KIMOROK	6	160.67	13.20	0.05	15
Mn +	KIMOROK	7	154.05	13.18	0.05	16
Zn -	KIMOROK	8	179.15	11.60	0.05	17
Zn +	KIMOROK	9	178.40	11.60	0.05	18
Normal	MAOI	1	152.61	10.58	0.05	19
Cu -	MAOI	2	155.74	10.58	0.05	20
Cu +	MAOI	3	167.61	13.75	0.05	21
Fe -	MAOI	4	168.41	11.60	0.05	22
Fe +	MAOI	5	130.16	11.61	0.05	23
Mn -	MAOI	6	161.54	10.58	0.05	24
Mn +	MAOI	7	145.48	10.58	0.05	25
Zn -	MAOI	8	186.32	11.59	0.05	26
Zn +	MAOI	9	158.46	10.58	0.05	27
Normal	SOLIT	1	144.94	10.58	0.05	28
Cu -	SOLIT	2	206.69	10.58	0.05	29
Cu +	SOLIT	3	160.63	10.58	0.05	30
Fe -	SOLIT	4	172.85	11.59	0.05	31
Fe +	SOLIT	5	189.37	11.60	0.05	32
Mn -	SOLIT	6	170.42	11.59	0.05	33
Mn +	SOLIT	7	155.41	10.58	0.05	34
Zn -	SOLIT	8	172.20	10.58	0.05	35
Zn +	SOLIT	9	145.98	10.57	0.05	36

MICRONUTRIENTS UPTAKE BY ACACIA SENEGAL VARIETIES ON NORMAL, LOW (-) AND HIGH (+) DOSAGE TREATMENTS FOR DIAMETERS AT GROUND LEVEL IN SITES

			Mean ±	S.E.	(P < 0.05)	
Normal	KAPKUN	1	5.91	0.49	0.05	1
Cu -	KAPKUN	2	4.85	0.58	0.05	2
Cu +	KAPKUN	3	5.80	0.49	0.05	3
Fe -	KAPKUN	4	5.21	0.51	0.05	4
Fe +	KAPKUN	5	5.75	0.49	0.05	5
Mn -	KAPKUN	6	5.20	0.49	0.05	6
Mn +	KAPKUN	7	8.10	0.49	0.05	7
Zn -	KAPKUN	8	5.65	0.49	0.05	8
Zn +	KAPKUN	9	5.16	0.49	0.05	9
Normal	KIMOROK	1	6.64	0.66	0.05	10
Cu -	KIMOROK	2	5.33	0.66	0.05	11
Cu +	KIMOROK	3	5.89	0.58	0.05	12
Fe -	KIMOROK	4	5.78	0.58	0.05	13
Fe +	KIMOROK	5	5.86	0.66	0.05	14
Mn -	KIMOROK	6	6.48	0.66	0.05	15
Mn +	KIMOROK	7	5.95	0.66	0.05	16
Zn -	KIMOROK	8	5.05	0.58	0.05	17
Zn +	KIMOROK	9	5.65	0.58	0.05	18
Normal	MAOI	1	5.61	0.53	0.05	19
Cu -	MAOI	2	5.71	0.53	0.05	20
Cu +	MAOI	3	4.91	0.69	0.05	21
Fe -	MAOI	4	5.45	0.58	0.05	22
Fe +	MAOI	5	5.18	0.58	0.05	23
Mn -	MAOI	6	5.80	0.53	0.05	24
Mn +	MAOI	7	5.63	0.53	0.05	25
Zn -	MAOI	8	5.25	0.58	0.05	26
Zn +	MAOI	9	5.35	0.53	0.05	27
Normal	SOLIT	1	6.14	0.53	0.05	28
Cu -	SOLIT	2	6.74	0.53	0.05	29
Cu +	SOLIT	3	5.95	0.53	0.05	30
Fe -	SOLIT	4	6.60	0.58	0.05	31
Fe +	SOLIT	5	5.86	0.58	0.05	32
Mn -	SOLIT	6	4.88	0.58	0.05	33
Mn +	SOLIT	7	6.31	0.53	0.05	34
Zn -	SOLIT	8	6.01	0.53	0.05	35
Zn +	SOLIT	9	5.60	0.53	0.05	36

APPENDIX III: CORRELATIONS BETWEEN SOIL AND GUM CHEMICAL PROPERTIES

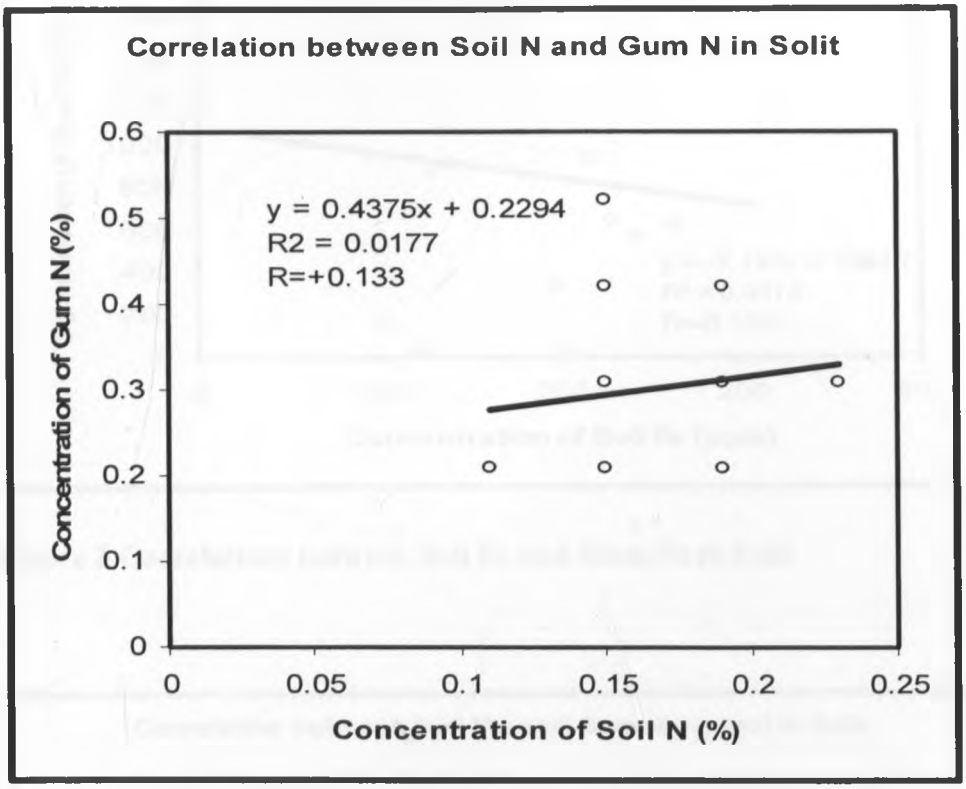

Figure 1 Correlation between Soil N and Gum N in Solit

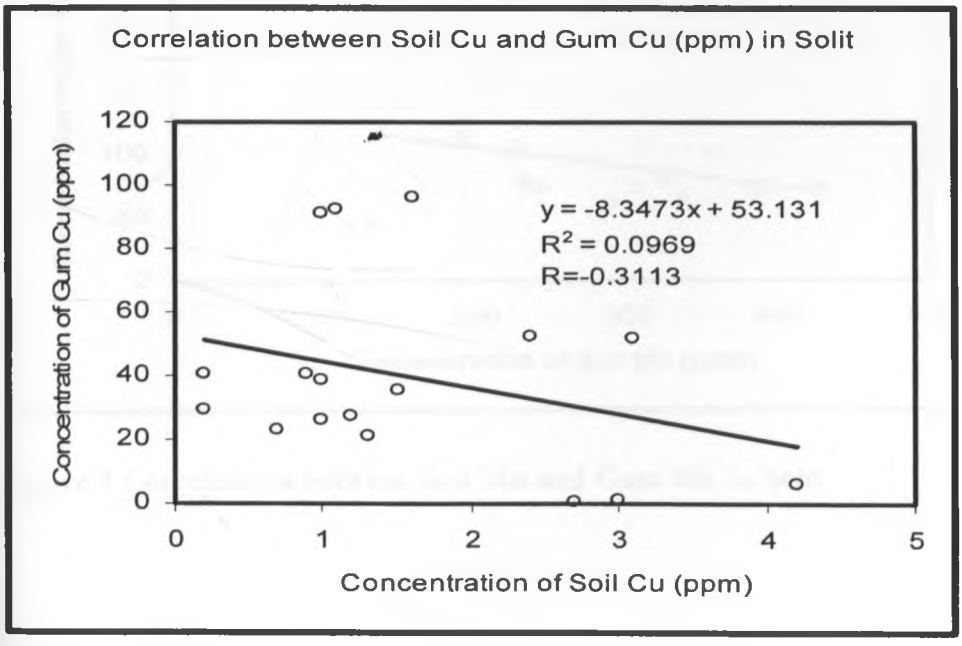

Figure 2 Correlations between Soil Cu and Gum Cu in Solit

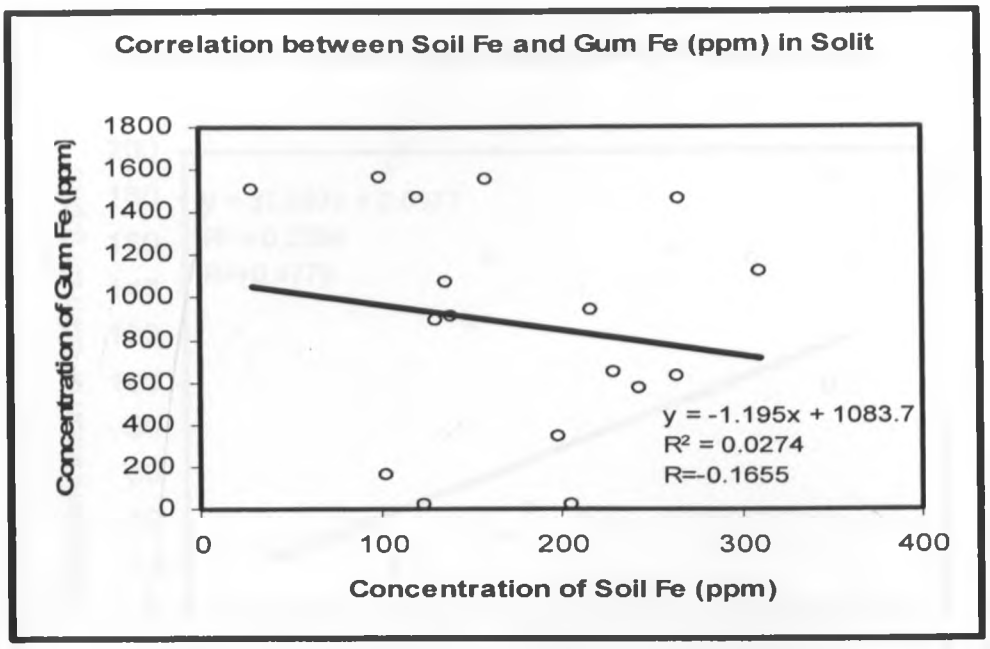

Figure 3 Correlations between Soil Fe and Gum Fe in Solit

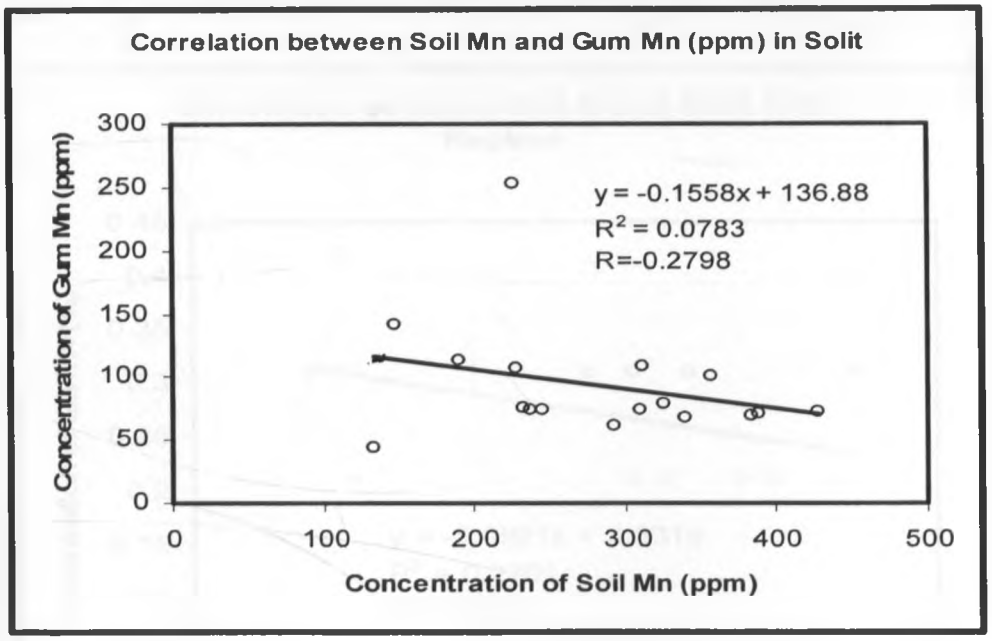

Figure 4 Correlations between Soil Mn and Gum Mn in Solit

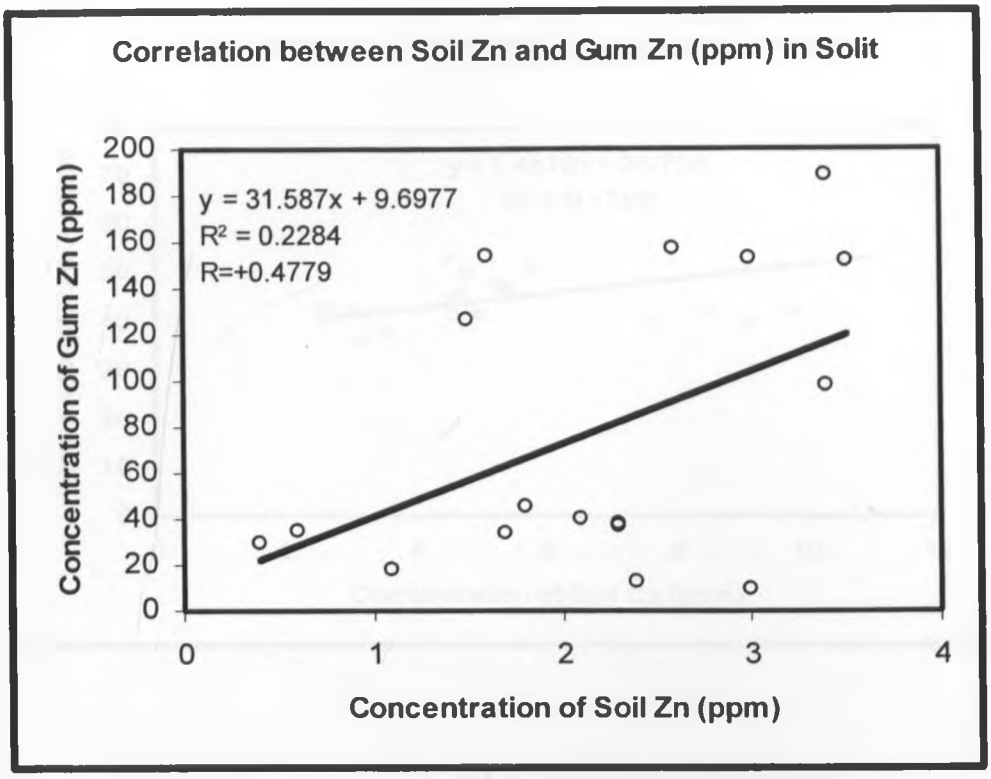

Figure 5 Correlations between Soil Zn and Gum Zn in Solit

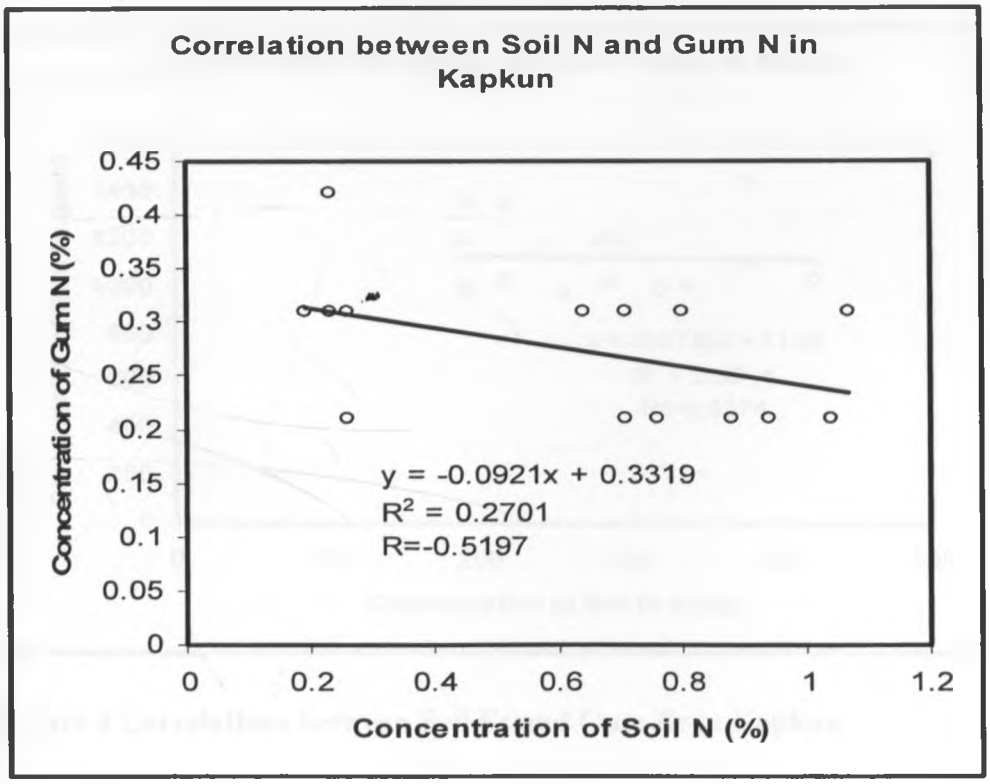

Figure 6 Correlations between Soil N and Gum N in Kapkun

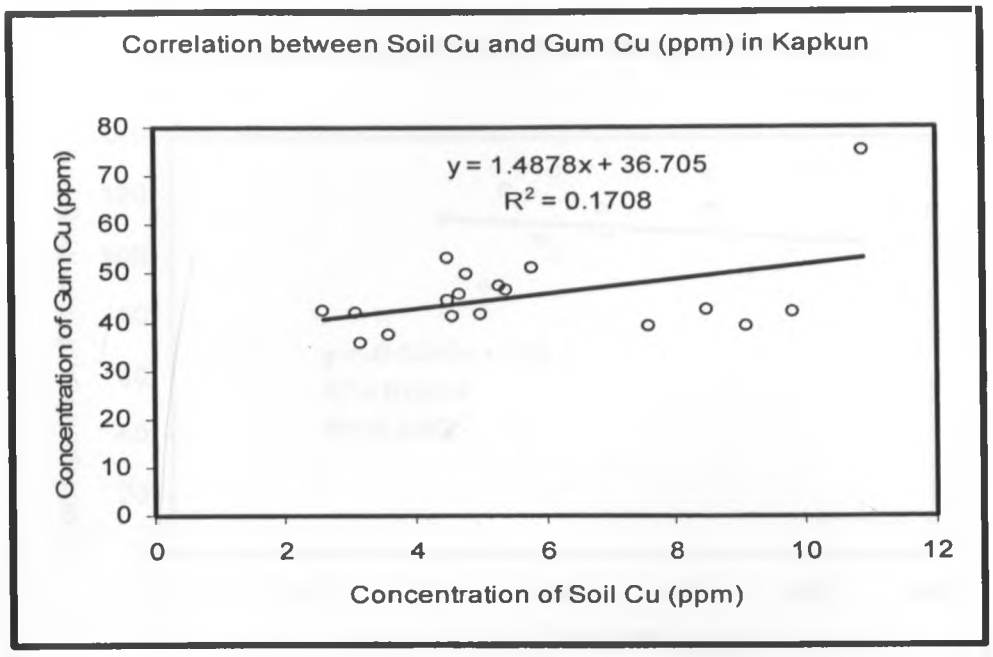

Figure 7 Correlations between Soil Cu and Gum Cu in Kapkun

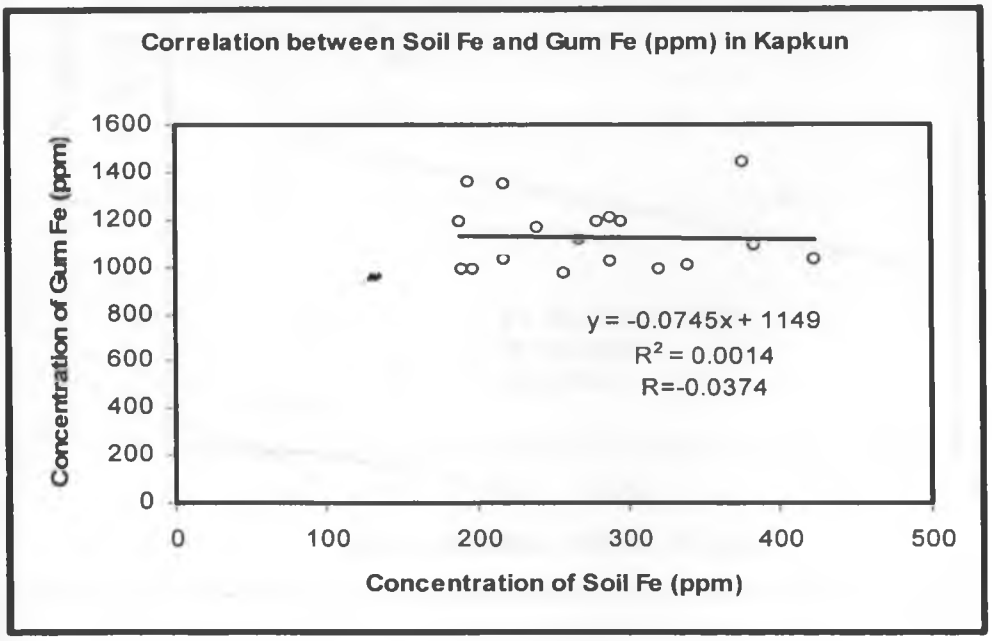

Figure 8 Correlations between Soil Fe and Gum Fe in Kapkun

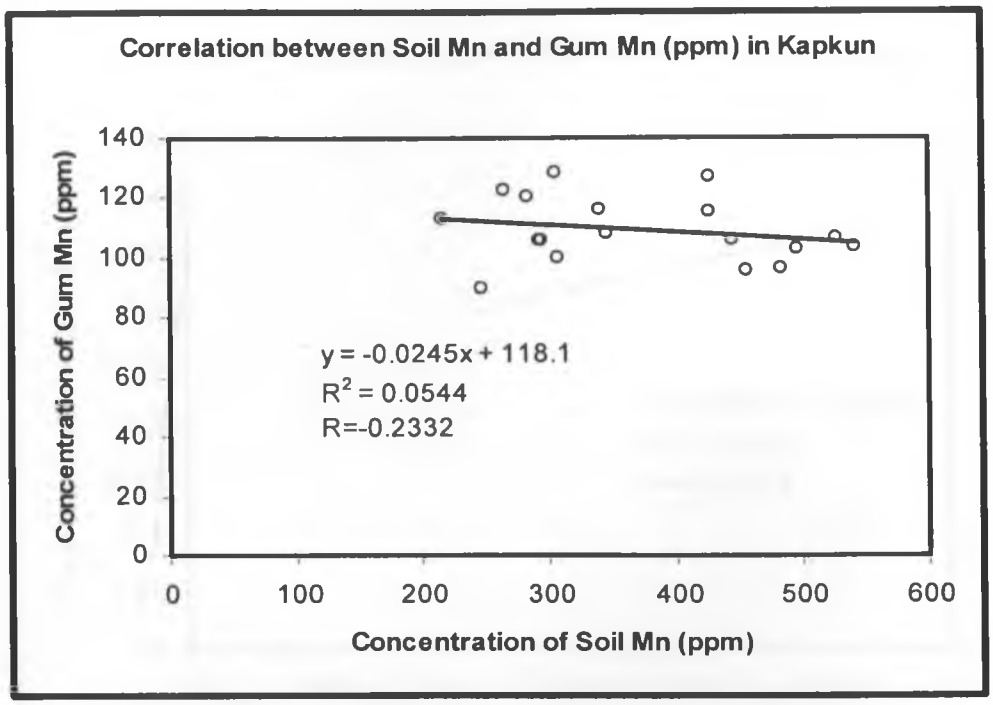

Figure 9 Correlations between Soil Mn and Gum Mn in Kapkun

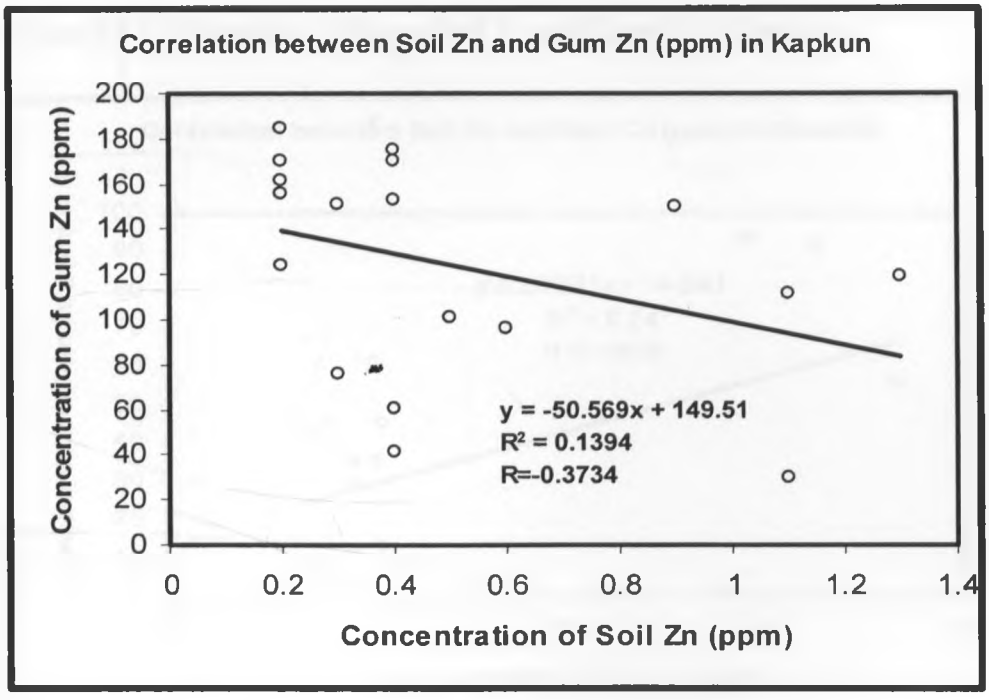

Figure 10 Correlations between Soil Zn and Gum Zn in Kapkun

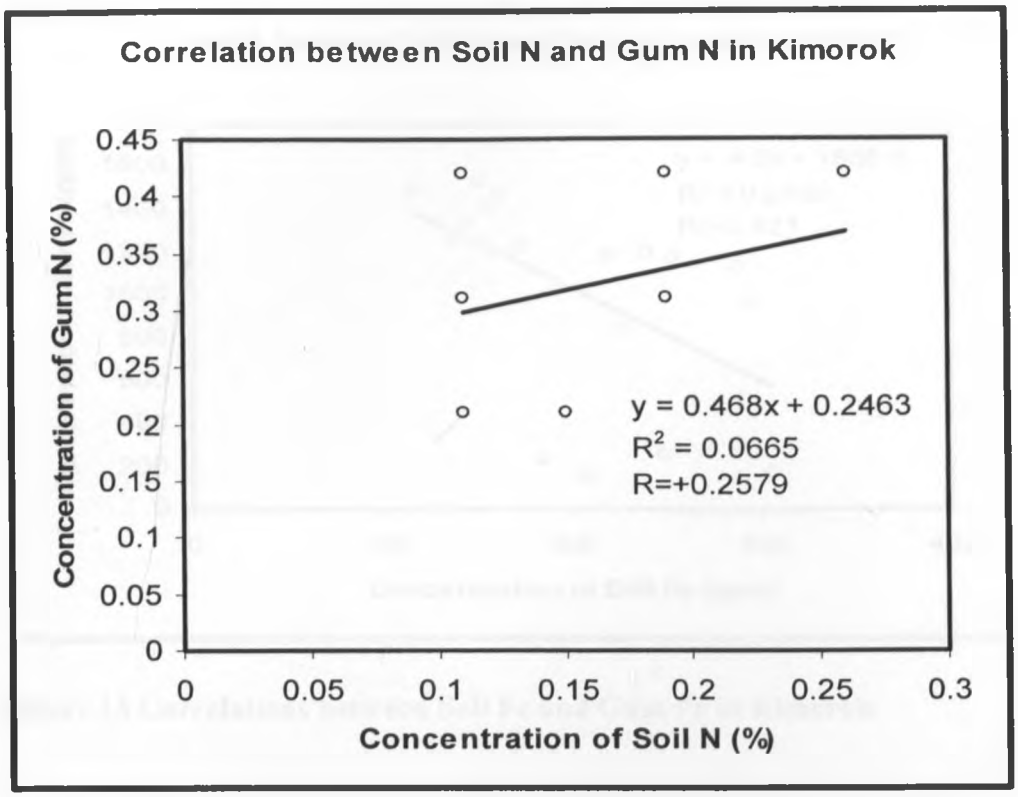

Figure 11 Correlations between Soil N and Gum N in Kimorok

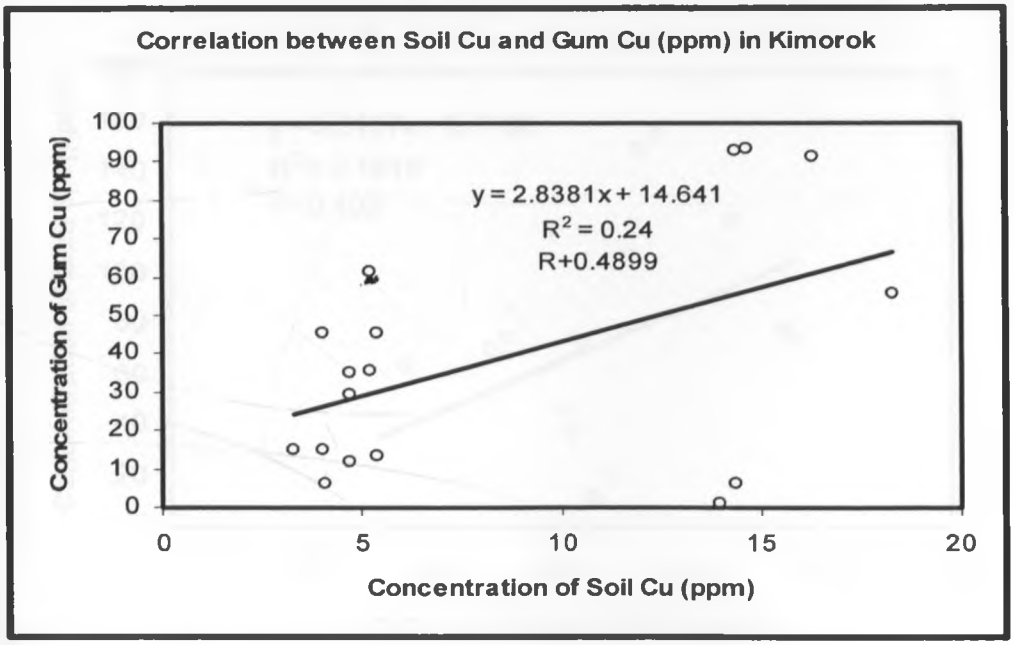

Figure 12 Correlations between Soil Cu and Gum Cu in Kimorok

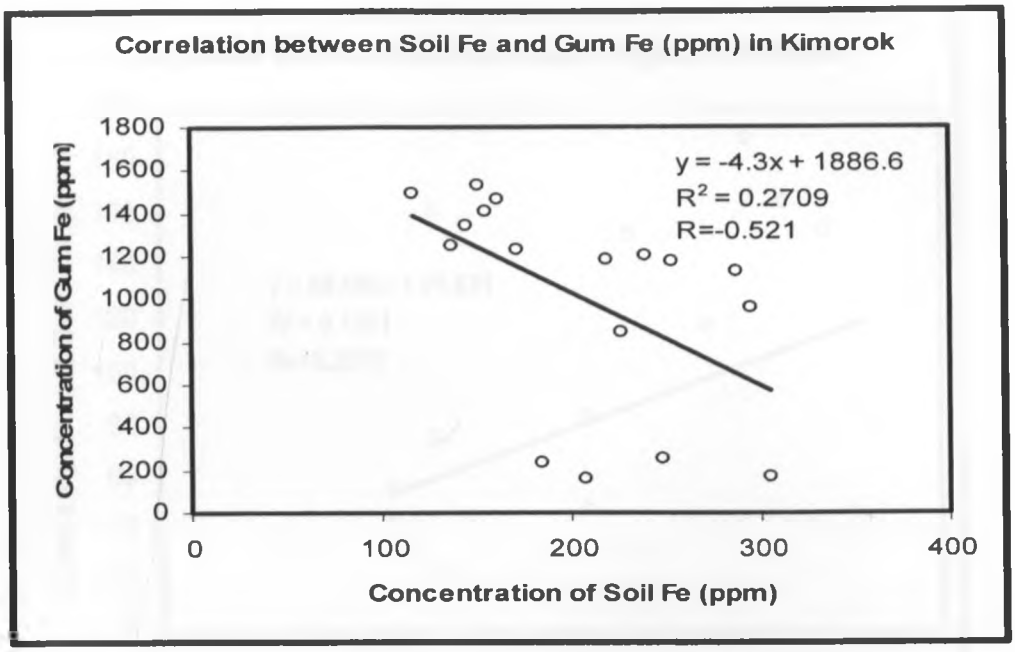

Figure 13 Correlations between Soil Fe and Gum Fe in Kimorok

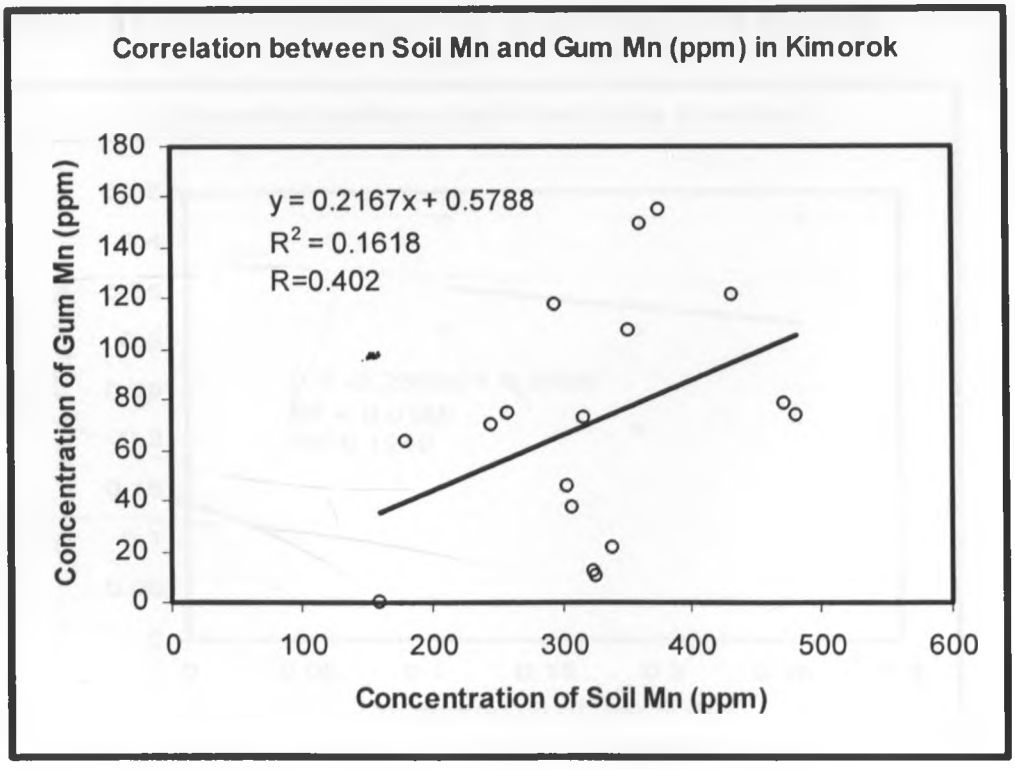

Figure 14 Correlations between Soil Mn and Gum Mn in Kimorok

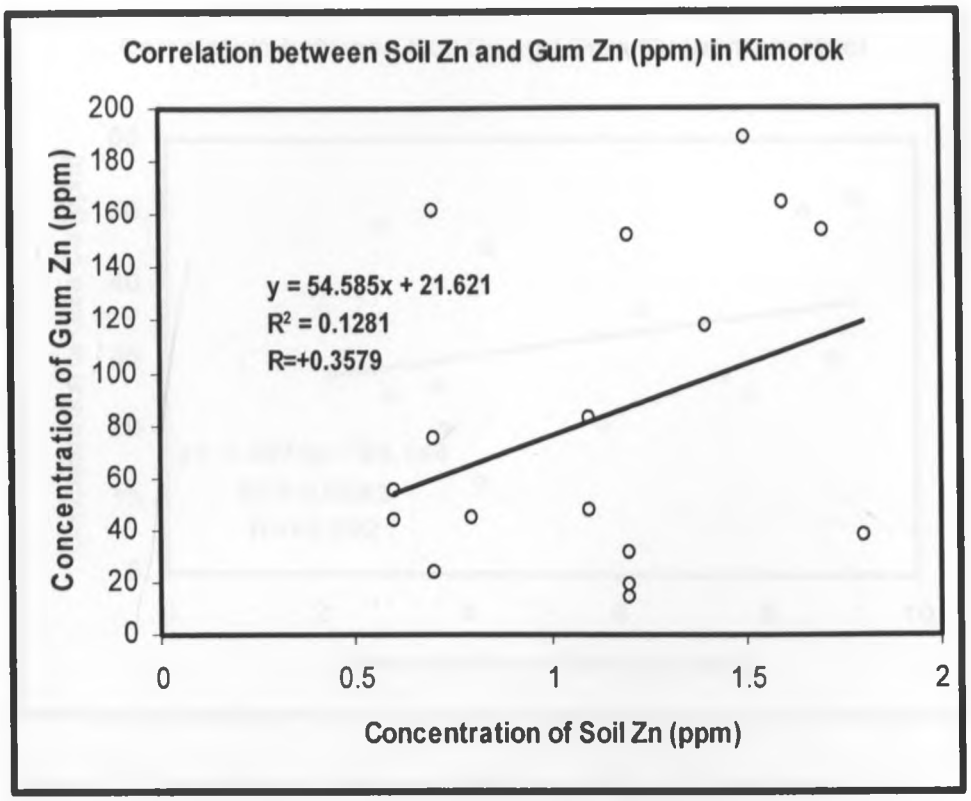

Figure 15 Correlations between Soil Zn and Gum Zn in Kimorok

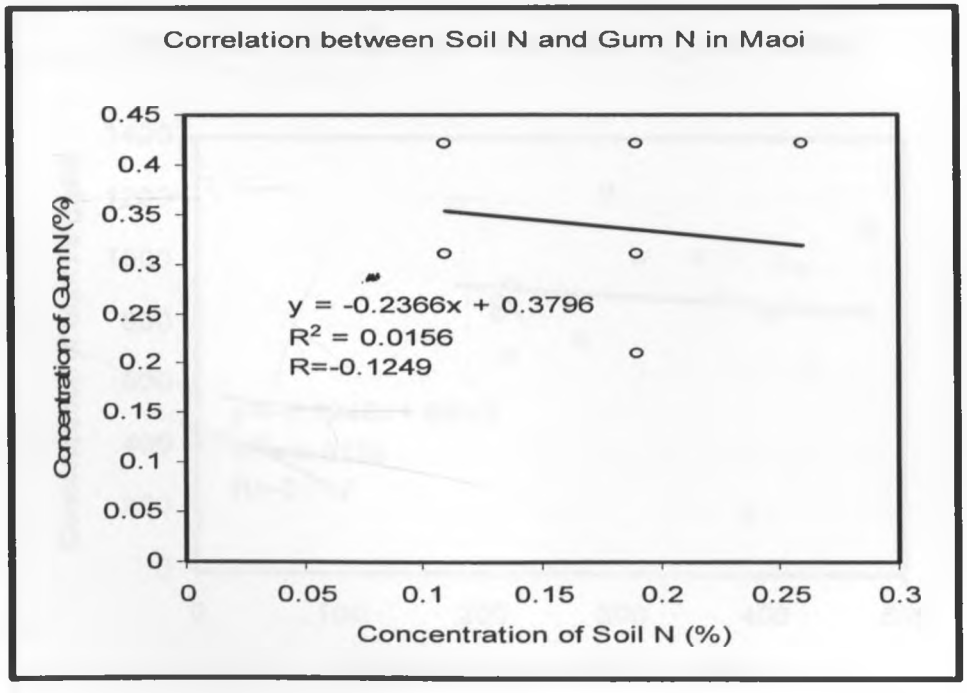

Figure 16 Correlations between Soil N and Gum N in Maoi

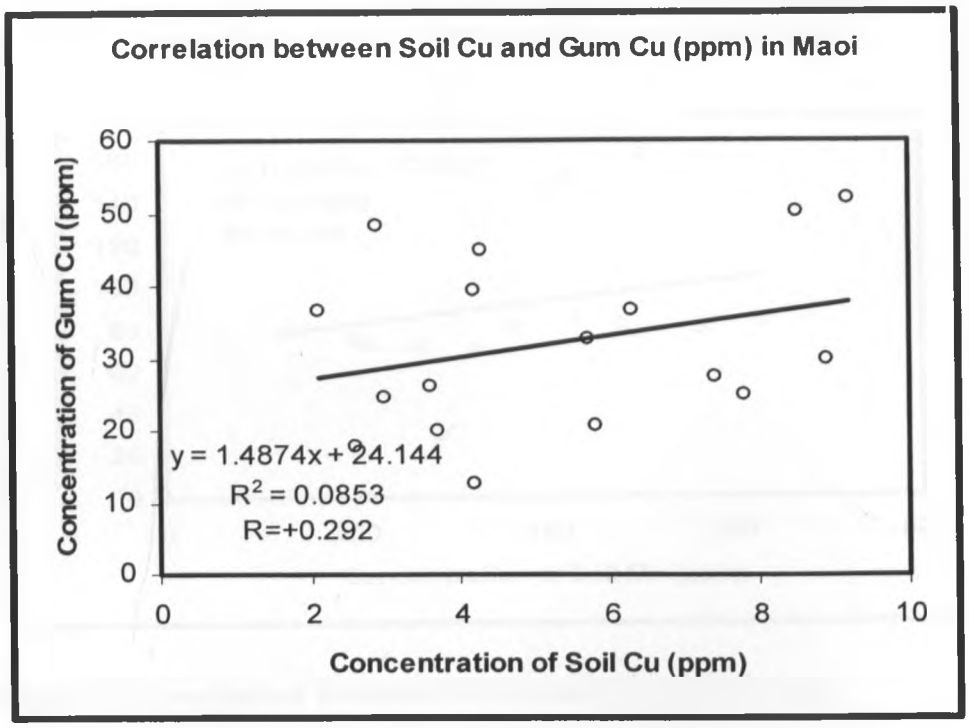

Figure 17 Correlations between Soil Cu and Gum Cu in Maoi

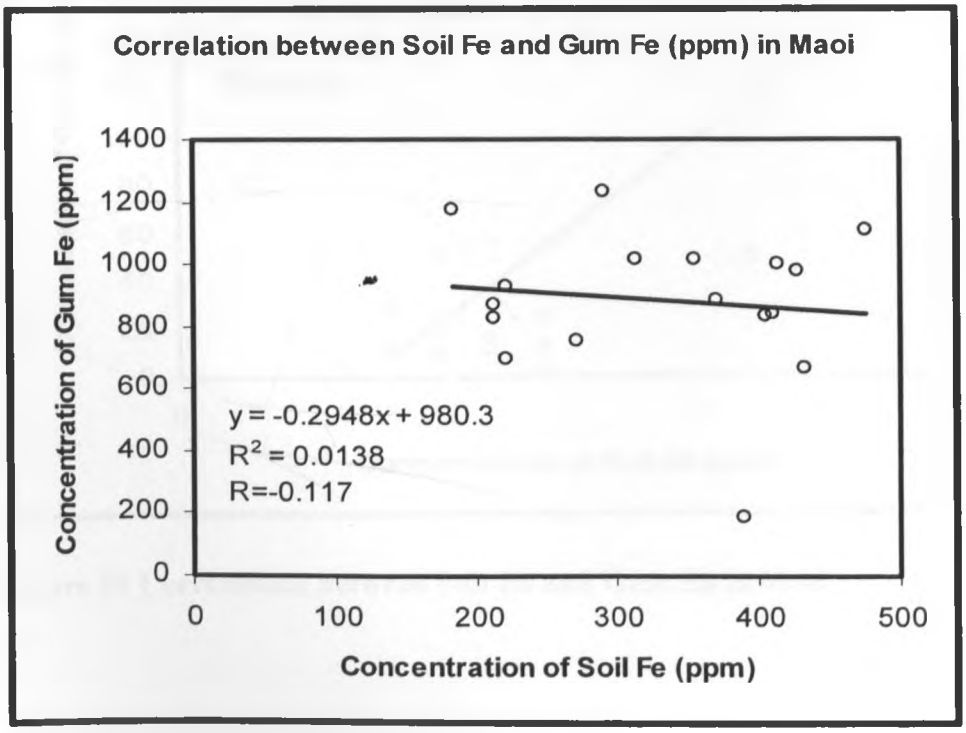

Figure 18 Correlations between Soil Fe and Gum Fe in Maoi

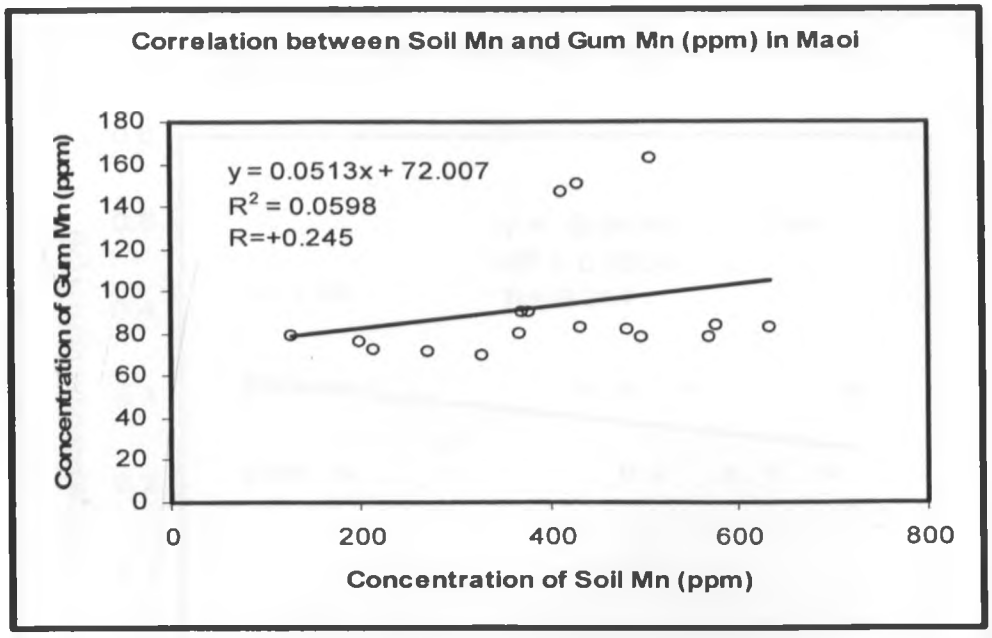

Figure 19 Correlations between Soil Mn and Gum Mn in Maoi

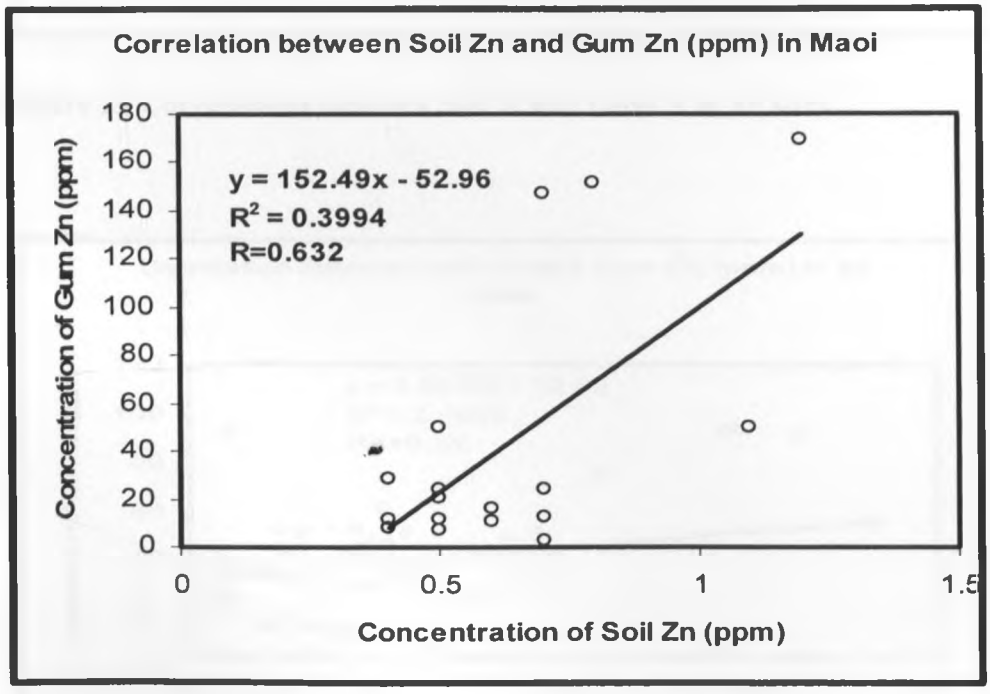

Figure 20 Correlations between Soil Zn and Gum Zn in Maoi

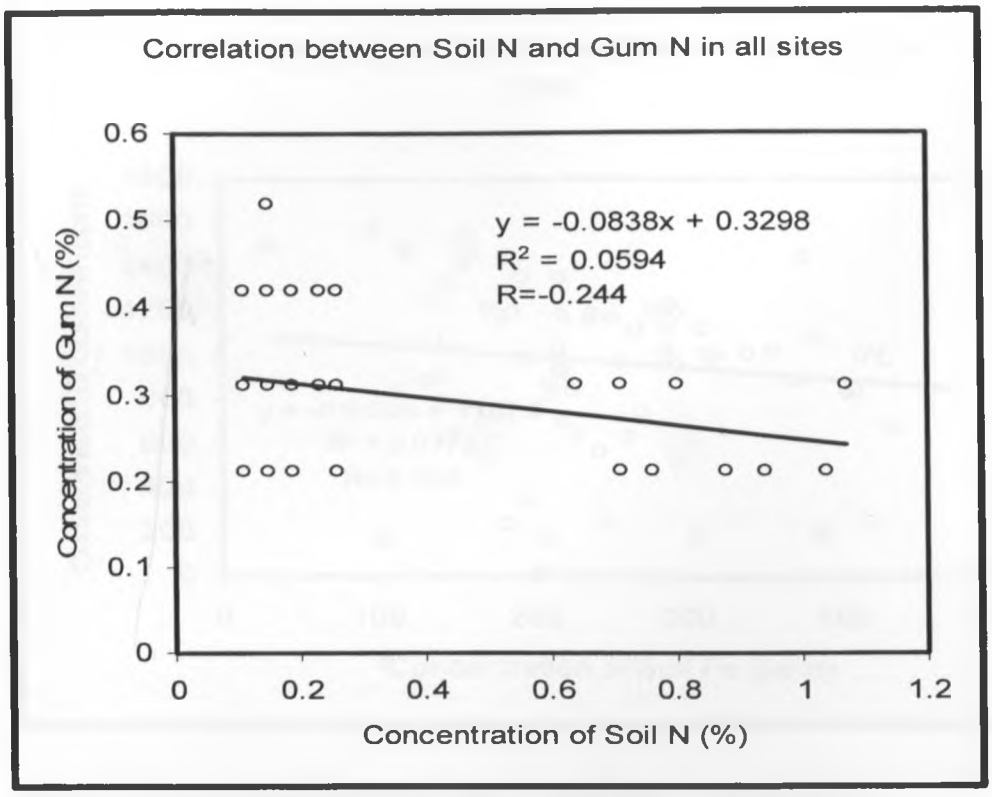

Figure 21 Correlations between Soil N and Gum N in all sites

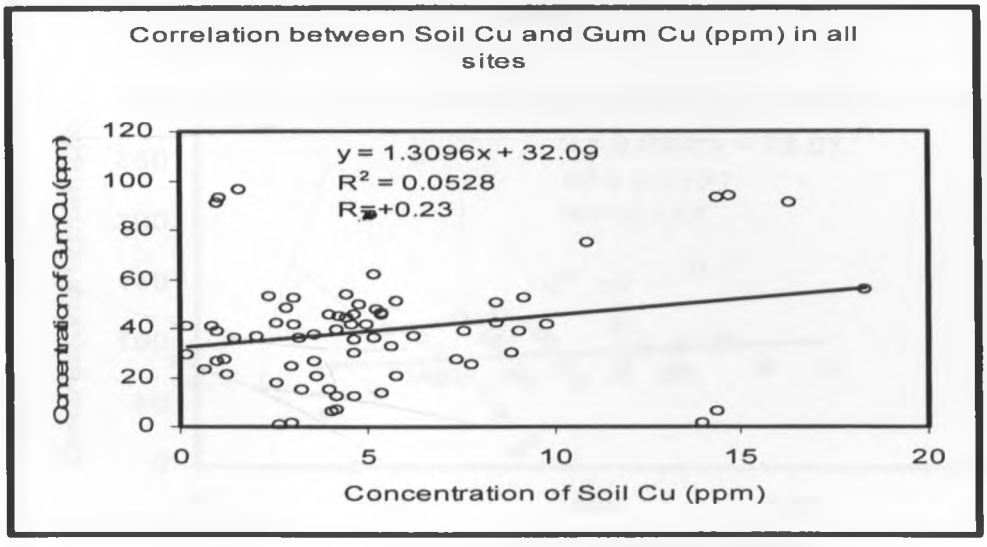

Figure 22 Correlations between Soil Cu and Gum Cu in all sites

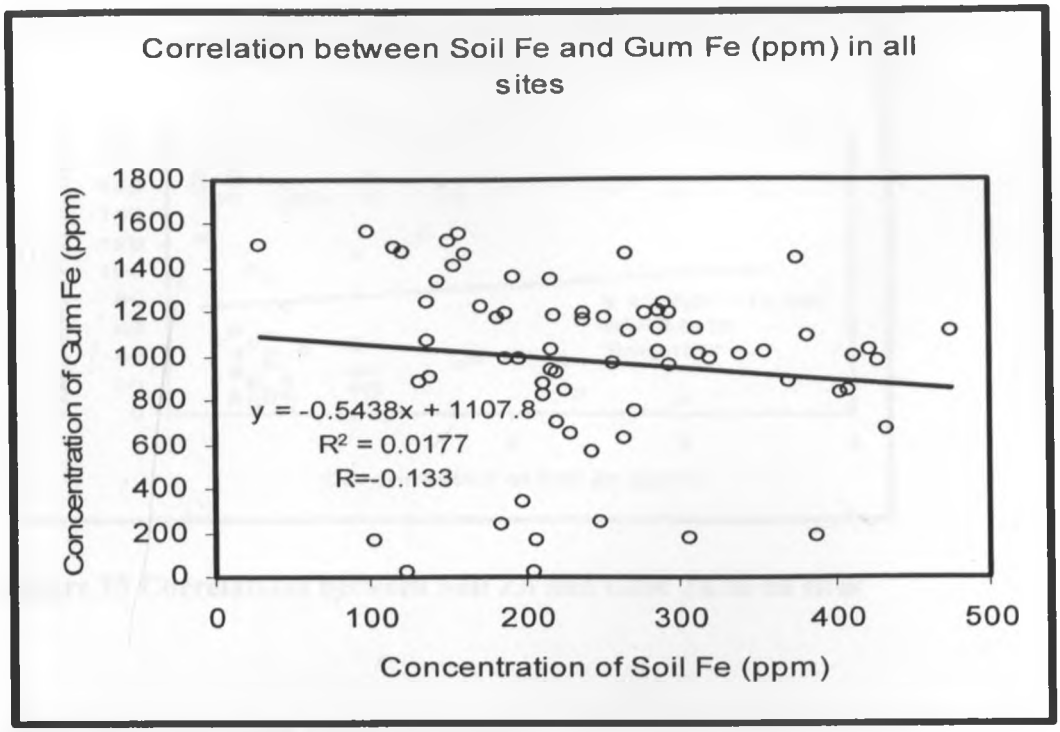

Figure 23 Correlations between Soil Fe and Gum Fe in all sites

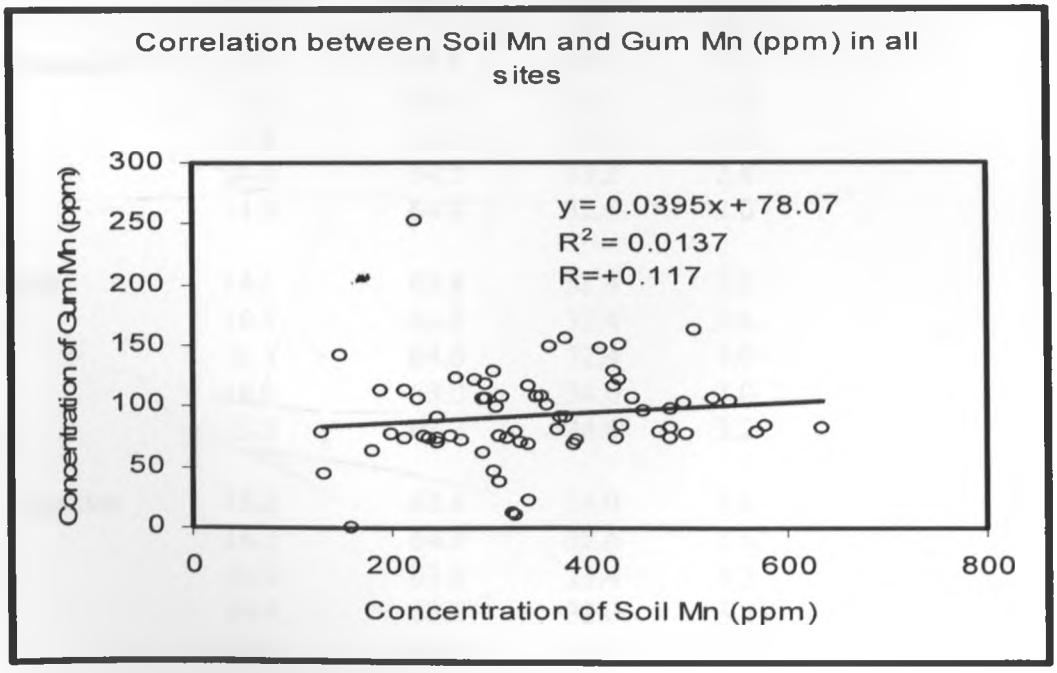

Figure 24 Correlations between Soil Mn and Gum Mn in all sites

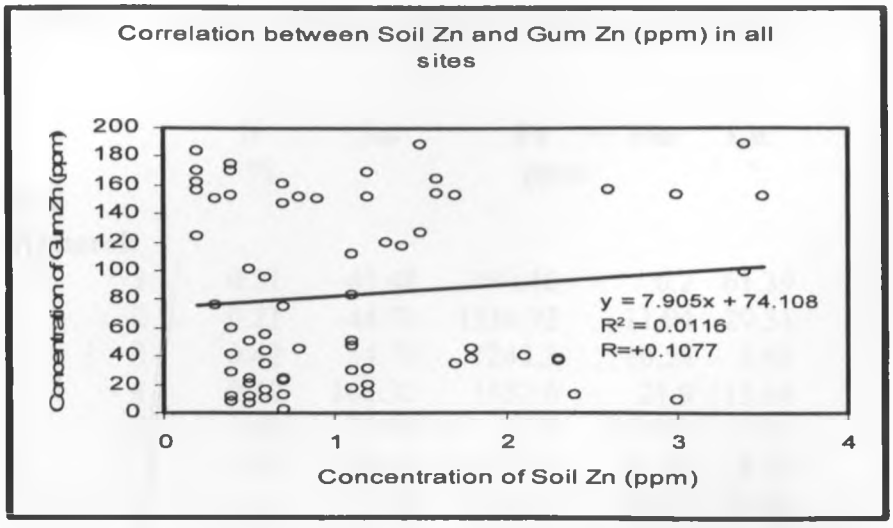

Figure 25 Correlations between Soil Zn and Gum Zn in all sites

APPENDIX IV: Gum arabic Analysis

Physical properties of Gum arabic of the four Study sites

	Moisture content %	Volatile matter %	Internal energy %	Ash content %
Kimorok	16.0	62.8	34.2	3.0
	15.2	64.0	33.2	2.8
	16.8	63.4	33.8	2.8
	24.6	64.0	33.2	2.8
	14.9	64.4	32.6	3.0
Solit	14.6	65.4	31.4	3.2
	16.8	65.0	32.4	2.6
	16.5	64.6	32.4	3.0
	16.0	63.0	34.0	3.0
	15.5	63.2	34.6	2.2
Kapkun	15.2	63.4	33.0	3.6
	16.3	64.8	32.6	2.6
	16.0	63.4	33.4	3.2
	14.4	63.6	33.0	3.4
	17.4	63.8	33.2	3.0
Maoi	16.3	61.8	35.4	2.8
	14.2	64.2	33.4	2.4
	15.2	64.4	32.2	3.4
	15.7	63.8	33.8	2.4
	15.7	63.8	34.0	2.2

Chemical properties of Gum arabic of the four Study sites

Site Kimorok	N %	Zn	Fe ppm	Mn	Cu
1	0.31	43.48	1490.46	0.2	61.39
2	0.21	44.73	1336.92	11.94	29.51
3	0.42	54.79	1243.3	10.55	5.93
4	0.42	161.32	1552.6	21.9	13.64
5	0.42	23.49	1228	37.053	12.01
6	0.42	74.44	1197.42	45.99	14.98
7	0.21	47.32	1409.63	63.11	14.83
8	0.21	31.13	249.66	107.1	35
9	0.31	14.12	236.24	117.1	35.74
10	0.21	82.48	846.96	154.88	45.23
11	0.31	19.09	169.77	120.84	45.52
12	0.31	117.75	159.78	148.91	55.9
13	0.21	188.87	1461.13	75.01	90.98
14	0.42	151.56	1121.44	74.09	92.61
15	0.31	153.31	1168.31	72.9	93.43
16	0.31	164.13	953.69	78.58	6.38
17	0.31	38.12	1180.4	70.13	1.09

SOLIT	N %	Zn ppm	Fe ppm	Mn ppm	Cu ppm
1	0.42	34.41	1504.5	44	29.21
2	0.31	17.57	1560.05	61.12	21.2
3	0.21	37.65	1470.17	78.04	52.79
4	0.31	36.49	1551.62	67.69	27.43
5	0.21	45.29	23.41	73.66	23.28
6	0.42	34.11	22.47	72.66	26.25
7	0.42	39.68	343.9	107.9	35.88
8	0.21	12.69	644.43	113.08	40.93
9	0.21	9.76	563.76	252.83	40.63
10	0.21	98.28	625.71	106.08	38.55
11	0.21	188.87	1461.13	75.01	90.98
12	0.42	151.56	1121.44	74.09	92.61
13	0.31	152.58	933.96	70.92	96.41
14	0.21	153.68	910.28	68.41	0.81
15	0.52	156.49	1070.87	74.35	1.49
16	0.31	125.95	161.97	141.74	52.05
17	0.21	29.05	887.8	100.77	6.52

MAOI	N	Zn	Fe	Mn	Cu
	%	ppm	ppm	ppm	ppm
1	0.31	11.37	926.8	71.58	12.49
2	0.42	8.41	827.64	76.34	17.79
3	0.42	12.61	751.16	69.73	20.1
4	0.42	2.45	698.13	72.77	20.51
5	0.31	11.77	872.04	78.71	24.71
6	0.31	7.38	833.06	77.66	24.85
7	0.31	24.34	1234.18	82.81	26.21
8	0.42	20.9	1112.81	82.15	27.29
9	0.31	10.53	977.38	77.52	29.88
10	0.42	23.86	1012.65	80.17	36.66
11	0.31	50.29	1014.38	89.94	44.95
12	0.31	15.79	839.23	81.88	36.66
13	0.31	28.87	885.85	83.33	32.73
14	0.42	50.14	1174.23	90.2	39.38
15	0.21	169.13	666.9	149.9	52.05
16	0.21	146.85	188.18	146.52	48.19
17	0.31	151.86	997.7	162.25	50.17

KAPKUN	N	Zn	Fe	Mn	Cu
	%	ppm	ppm	ppm	ppm
1	0.42	30	1005.25	96.54	35.71
2	0.31	95.82	1440.9	103.01	42.23
3	0.31	41.48	1021.78	89.81	38.84
4	0.31	150.42	1207.78	115.3	74.82
5	0.31	60.3	1189.28	95.22	38.97
6	0.31	76.13	1345.68	112.92	37.48
7	0.31	100.76	1092.83	103.67	41.15
8	0.21	119.18	1027.45	106.45	41.69
9	0.31	111.76	984.78	99.71	44.27
10	0.21	124.37	987.98	105.92	42.23
11	0.21	155.76	1112.81	106.05	41.55
12	0.31	150.94	990.94	105.65	41.69
13	0.21	152.43	970.22	108.03	45.76
14	0.21	162.01	1030.41	115.69	46.44
15	0.31	170.3	1192.98	127.055	49.7
16	0.21	170.52	1356.04	120.31	53.23
17	0.31	174.54	1192.73	122.16	47.26
18	0.31	184.37	1162.4	128.11	50.92