THE INFLUENCE OF SELECTED CROPPING SYSTEMS ON SOIL PROPERTIES IN KWALEI VILLAGE, LUSHOTO, TANZANIA

CLEMENT T.K.G. MWINUKA

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN SOIL SCIENCE AND LAND MANAGEMENT OF THE SOKOINE UNIVERSITY OF AGRICULTURE, MOROGORO, TANZANIA

2001

ABSTRACT

A study was conducted in Kwalei village. Lushoto district to evaluate the influence of selected cropping systems on soil properties. The following cropping systems were identified through a transect walk, cropping systems on the slopes (monoculture tea, coffee/banana and maize/beans intercropping systems) and vegetable cropping systems in valley bottoms. Other cropping systems were woodlot systems (Eucalyptus, Grevillea, Wattle in a mixture of tree species) and fallows. Three soil profiles representing summits, slope and footslope areas were dug. According to World Resource Base (WRB) (FAO, 1998) classification system three soil levels were identified namely Lixisols (summit), Fluvisols (slope) and Lixisols (footslope). The corresponding USDA-soil classification at soil order levels were Alfisols (summits), Entisols (slopes) and Mollisols (footslopes). Soil samples were taken at a depth of 0-20 cm from each identified cropping system for physical and chemical analysis. Core samples from the same cropping systems were taken for bulk density determination. The results from cropping systems on the slopes showed that soils from monoculture tea had low levels of plant nutrients compared to coffee/banana and maize/beans cropping systems. However, the soil physical properties in all three cropping systems on the slopes were suitable for crop production. Soil pH was conducive for tea production. The DTPA extractable Fe was significantly higher (P=0.05) in monoculture tea than in other cropping systems and the opposite was true for DTPA extractable Mn. DTPA extractable Zn did not differ significantly (P=0.05) between the cropping systems while DTPA extractable Cu was higher in coffee/banana cropping system. Most of the plant nutrients in soils from vegetable growing area were adequate for vegetable production except for available P. DTPA extractable Fe and Zn were within the acceptable range while DTPA extractable Cu and Mn were above the critical level for vegetable production. Soil properties in four woodlot systems were variable. Except for Eucalyptus. other tree species showed superiority in one or more properties. Eucalyptus had the least effect on soil properties. which suggest that the tree have low potential for amelioration of soil fertility compared to other tree species. From the study it can be concluded that fallow systems did not improve the soil fertility of degraded soils in Kwalei village. This is possibly due to the young age of the fallow systems. It takes long time to restore soil fertility. It can be recommended from this study that. for optimum crop production. farmers should control soil erosion. use cover crops and organic fertilisers like composts. crop residues and farm yard manures.

DECLARATION

I, Clement Thomas Kalungu Gwerhino Mwinuka, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work and it has not been submitted for a degree award in any other University.

Signature.................................

Date 13 · 11 · 2001

COPYRIGHT

ACKNOWLEDGEMENTS

I do express my sincere gratitude to my supervisors. Dr F.B.R. Rwehumbiza and Dr J.J.T. Msaky for their guidance. constructive criticism. and encouragement throughout the study period. Special appreciation goes to the Norwegian Agency for Development Co-operation and Sokoine University of Agriculture for the sponsorship

I also give my heartfelt thanks to the head of Department of Soil Science. all academic and non-academic staff in the Department of Soil Science who in one way or another assisted me in this study. Special thanks goes to Dr Mtakwa for encouragement during the study. I gratefully appreciate the family of Mr. Madiga of Soni Secondary School and Mr. Kizinga, Hozza of Kwalei village for providing accommodation to the author during data collection. I thank all my colleagues for their moral and material support during the study. Special appreciation goes to Mr. Mwango, S.B and Mr. Kileo, E.P for helping the author to describe soil profiles and to classify soils. Isaac Bazugba is also acknowledged for his company and encouragement during the study

Last but not least my heartfelt appreciation are extended to my wife 'mama Emma' and my son Emmanuel for their prayers, understanding, moral support, encouragement and patience extended to me bountifully throughout my study.

DEDICATION

To the late my father Thomas Kalungu Gwerhino Mwinuka and my mother Alfonzia Mgeni who realised that, the best inheritance I could be given was to be sent to school.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

BS	Base saturation
Ca	Calcium
CEC	Cation exchange capacity
Cu	Copper
DTPA	Diethylenetriaminepentaacetic acid
FAO	Food and Agriculture Organisation of United Nations
Fe	Iron
GDP	Gross domestic product
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
NORAD	Norwegian Agency for Development Co-operation
OC	Organic carbon
SUA	Sokoine University of Agriculture
TEB	Total exchangeable bases
URT	United Republic of Tanzania
USDA	United States Department of Agriculture
Zn	Zinc

CHAPTER ONE

1.0 INTRODUCTION

Land is one of the most important resources for human existence. Arable land, the shallow mantle of the earth, is necessary for feeding, clothing and providing shelter for human being (Buol, *at el.*, 1980). Arable land is especially critical in countries where the economy is predominantly agriculture, like in Tanzania.

According to URT (1994) the agriculture sector accounted for nearly 60% of the GDP in 1990. Crop production is the largest subsection in agriculture, contributing around 63% to agriculture GDP. Agriculture is the main source of food supply, provides employment opportunities and raw materials for the industrial sector and accounts for more than 75% of the total export earnings (Amani, 1992).

One of the constraints to agriculture production in Tanzania is low productivity, which is associated with soil fertility depletion due to mismanagement of land and poor agronomic practices. Other problems include lack of capital, poor marketing facilities, fluctuation of output and input prices and land tenure system. Other constraints include inferior tools, poor storage facilities and unreliable weather condition (Akinsanmi, 1975).
These problems are widely spread in the country and Kwalei village (the study area). The village is in Lushoto district and it is an example of a highly populated area. Land is

scarce and can no longer sustain the population pressure in this village. A high population growth rate of both humans and domesticated grazing animals is a major cause of land degradation. In Kwalei village, soil erosion has led to low soil fertility, which is accelerated by cultivating along the steep slopes without using any conservation measures. The soil is highly weathered with continuous mining and export of nutrients without any replenishment.

There are inadequate management practices in these marginal lands; hence there is a great danger of losing soils through erosion processes. Soil losses and reduction in inherent soil fertility are therefore, increasingly severe constraints to crop production in the tropics (Gardner, 1986)

Farmers have cited declining soil fertility and land fragmentation as the major cause of low crop production in the village (Lyamchai *et al*, 1998). Low soil fertility problem is a product of deforestation, overgrazing, frequent burning of vegetation, continuous cultivation, nutrient export and poor agronomic practices. Farmers' efforts to restore soil fertility are inadequate since very few can afford to use inorganic fertilisers. Inorganic fertilisers are very expensive and smallholder farmers can hardly afford to buy them. These fertilisers are also not available when required due to bad condition of rural roads especially during the rain season. At the same time, the use of manure is also restricted as farmers have only a limited number of animals. The manures are bulky and expensive to transport them to the field.

To maintain soil fertility or soil productivity farmers are forced to adopt other strategies like a change in type of crops grown on the farm and cropping systems. This situation has made farmers in Kwalei village to adopt intensive cropping systems, which cater for their needs (Lyamchai *et al.*; 1998). Most of such intensive cropping systems involve mixing of trees and agricultural crops or mixing different crops in an intimate combination with each other. The common intercropping systems in Kwalei village are coffee intercropped with banana and maize intercropped with beans. Tea is grown as a monocrop. Vegetables like cabbages, potatoes, onions, tomatoes, eggplants and sweet pepper are grown in valley bottoms. Some farmers have woodlots on which Eucalyptus, Grevillea and Wattle tree species are mainly planted.

The intimate association between the components of mixed cropping system results in both negative and positive interaction, in both space and time. Intercropping increases the combined yields from the intercrops and do make efficient use of resources (Mango, 1999). One of the obvious influences of mixed cropping of genetically diverse crops is the change in the microclimate around the component plants and in soil properties in which the plants are growing. Nyambo *et al.* (1980) noted that physical shading by taller plants is presumed to reduce wind speed and amount of solar radiation reaching the shorter plants and soil surface. This may affect the vapour pressure, photosynthetic activity and thus productivity of the shorter plants. Other negative effects of these crop associations are competition for water, nutrients and air as well as causing allelopathic effect.

Crops in association have tremendous effects on soil properties. Investigations by Sanchez (1976) reported that cropping systems are a major cause of changes in soil characteristics. This is because crops in association have a direct influence on soil physical properties like soil structure, chemical and biological properties. Growing crops can for example affect the chemical properties of the soil by their different absorption capacity of nutrients and by their excretions. Consequently they affect the biological properties of that soil. The cropping systems that control the amount of organic matter added to the soil are very important in ensuring sustainable crop production. This is because organic matter has a great influence on physical, chemical and biological properties of soil.

With the need to produce greater amounts of food, and fibre for the world's population, the development of appropriate technologies to maintain and improve soil fertility is of paramount importance. This is so in tropical countries where population growth is the highest in the world and yet soils tend to be highly weathered and have low inherent fertility.

There is a need therefore to improve the existing cropping systems instead of introducing new ones so that they can alleviate soil fertility problems and increase crop yields. The improvement of these cropping systems in these areas with harsh climatic conditions must be based on a thorough understanding of the soil properties, if they are to be successful.

This information on soil properties and their relation to management in Lushoto including Kwalei village is not available.

It is important to obtain basic data related to changes in soil properties, which occur due to the effect of intercropping of genetically diverse crops. The proposed study will provide information required by stakeholders to make sound advice to farmers aimed at improving specific cropping systems. This information is necessary so as to alleviate soil fertility problems and to increase crop yields. It is within this context that the study was conducted to investigate the influence of selected cropping systems on soil properties at Kwalei village. Specifically the study was aimed at:

- Evaluating the effect of selected cropping systems on soil physical properties
- Determining the effect of selected cropping systems on soil chemical properties
- Assessing the availability of some micronutrients in the selected cropping systems.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Factors which influence crop production

Maximum production potential of a particular crop depends on genetic factors, environmental factors, the interaction between genetic and environmental factors and the skills of the farmer to control or eliminate unfavourable factors (Marshner, 1986). Environmental factors include temperature, moisture supply and soil properties. Soil properties include biological, physical and chemical characteristics. Soil temperature, soil moisture content, water retention and plant nutrients are very much affected by these soil properties.

2.1.1 The role of soil physical properties on crop production

The final crop yield is the result of all factors, which influence growth during that season, soil physical factors inclusive (Lal *et al.*, 1975). Soil physical factors per se are not a crop growth factor, but they control the environment in which the plant roots develop. Davies (1982) identified some agriculturally important properties, which are influenced by soil physical characteristics. These are:

- Rainfall acceptance by the soil (infiltration rate) and the ease with which excess water is shed from the soil.
- Storage of available water and ease with which roots can absorb this water.
- Mineralisation of organic matter that involves temperature, oxygen supply and moisture supply.

Thus improving the soil physical properties ultimately increases crop yield by creating favourable environment for plant roots to grow and to develop under a given cropping system. Fertilisers alone, or even in conjunction with improved crop varieties and introduction of measures to control pests and diseases will not preserve productivity if significant deterioration of soil physical condition occurs (Sanchez, 1976).

2.1.1.1 Soil texture

Soil texture refers to the size range of particles in the soil, that is whether the particles of which a particular soil is composed are mainly large, small or of some intermediate size or range of sizes (Hillel, 1982). In coarse textured soils, like sandy soils, air and water can easily slip into the gaps between the particles and roots can penetrate without any difficulty. Fine textured clay soils are rich in plant nutrients but the plant roots find it hard to penetrate because there is hardly any room between the clay particles (Uriyo *et al.;* 1979)

Soil texture is known to affect plant growth through its influence on water infiltration, the capacity to hold water in a condition available to plant, aeration and nutrient supply. For example Woomer, *et al.*, (1994) reported that the availability of nitrogen supply to plants usually increases as a texture become finer. Soil texture also influences the soil temperature. Root penetration and the workability of the soil depend on soil texture. For example soils with high silt and clay contents usually retard root growth and its extent of branching. The machines can work easily to loose-textured soils than to the soils with high silt and clay contents. VanDyk, (1999) revealed that soil texture affects the occurrence of *Phytophthora* disease on soyabeans. The higher the clay content, the greater the disease risks. Fields with sandy loam soil had lower disease risk than clay soils.

2.1.1.2 Soil structure

Soil structure pertains to how the particles of sand, silt and clay are bound together into aggregates by organic matter and clay. The soil pores between and within the aggregates contain air and water and provide networks through which plant roots move.

Good structure is essential for the production of optimum soil tilth. Well aggregated soils provide stable traction for farm implements, adequate physical condition for the penetration, growth and anchorage of plant roots and free drainage with moderate retention of rain water (Davies, 1982). These conditions facilitate the existence of an air-moisture regime favourable for crop growth and microbial activity.

2.1.1.3 Soil bulk density

The composition and stability of the soil separates and peds, their volume and weight, determine the soil physical properties. The space not occupied by soil solids is called pore space and is occupied by air and water. Thus soils with a high proportion of pore space to solids have lower bulk densities than those which are more compacted and have less pore space. Bulk density is the indicator of porosity and compaction of the soil (Helalia, 1993). The bulk density has an effect on soil air, soil water movement and invariably pores affect root growth and development. When a soil is compacted the soil structure is destroyed, partially or totally, depending upon the degree of compaction. Bulk density of a compacted soil is light and water retention and movement are significantly reduced.

The cropping systems and soil management employed on a given soil is likely to influence its bulk density, especially of the surface layers (Alegre and Cassel, 1986). Addition of crop residues or farmyard manure tend to lower the weight of the soil, hence lowering its bulk density (Tester, 1990). Dao, (1996) observed an increase in bulk density due to removal of crop residues in the field. When crop residues are incorporated into the soil, after decomposition increases porosity through granulation. Intensive cultivation makes the soil more compact and increases the weight per unit volume. Alegre and Cassel, (1996) in their study on dynamics of soil properties under alternative systems of slash and burn noted that bulk density was lower after 4 years for the systems with trees and cover crops. The implication is that soil management and cropping practices can alter bulk density.

2.1.1.4 Soil porosity

The sum total of spaces not occupied by solid matter in the soil is called porosity. These spaces are filled with water and air (Hillel. (1982). Soil porosity is affected by all factors. which affect soil density. These factors include texture. shape of the individual particle. structure. organic matter content and compactness of the soil (Pagliai and Antisari. 1993). The distribution of these pore spaces is more important in crop production than total pore spaces in the soil. The distribution of pore size affects other soil properties like soil air, soil temperature and soil water (Thiessen and Stewart, 1983). These properties are more important in crop production because they affect chemical and biological processes in the soil and in the plants (Tester, 1990).

2.1.1.5 Soil air

Adequate aeration is needed for successful crop production. Air is an important factor for crop growth and soil microbial growth, development and their activity. Oxygen is required for respiration of plant roots, microbes and other fauna. Carbonic acid helps to dissolve the plant nutrients from rocks and minerals. Soil air is affected by soil properties like soil texture, structure, organic matter content and soil moisture content. These factors affect air capacity and permeability in the soil. The presence of growing plants tend to reduce oxygen content and increase the amount of soil carbon dioxide due to respiration (Renault *et al.;* 1994). Soil air can be managed by improving soil physical properties, through addition of organic matter and by adjusting the plant density (Leffelaar, 1993).

2.1.1.6 Soil temperature

Soil temperature affects plant growth and it influences moisture content, aeration, soil structure, microbial and enzyme activity (Bussiere and Cellier, 1994). The decomposition of organic matter and the availability of plant nutrients are also affected by soil temperature (Stott *et al.;* 1986). Mulching, addition of organic matter and vegetation keeps the soil relatively cool (Grant *et al.;* 1995). Some of the cropping systems like intercropping also reduce soil temperature (Olasantan *et al.;* 1996).

2.1.1.7 Soil water

Soil moisture deficiency is one of the primary limiting factors to crop production in many of tropical countries. Water plays an important role in the soil-plant system. According to Brady, (1984) water is involved in physical, chemical and biological activities, which are taking place in the soil. Water is a solvent and carrier of plant nutrients. Water is essential for photosynthesis and is part of protoplasm (Marshner, 1986). Thus moisture deficiency retards plant growth and hence lowers crop yield. Soil formation through weathering processes mostly depends on water. Weathering and decomposition is one of the sources of plant nutrients in the soil. Microbial activity in the soil also depends on availability of water in the soil (Friedel *et al.*: 1996, Stott *et al.*: 1986). The capacity of the soil to store water depends on its depth, texture, structure, clay type and amount of organic matter (Parvathappa and Murthy 1994).

Soil texture for example can have an effect on the availability of water and holding capacity. The type of clay for example influences water holding capacity through influencing soil structure and expansion of the clay on which water is absorbed internally. Emerson, (1995) reported that organic matter content has great influence in water holding capacity of the soil through influencing soil structure.

2.1.2 The role of soil chemical properties in crop production

Chemical properties affect soil-plant relationship mainly by exerting influences on root environmental conditions and nutrient availability to plants (Tester, 1990). Similarly, chemical properties influence the type, population and activity of soil organisms responsible for several useful transformations between organic and mineral constituent (Brady, 1984). Some of soil chemical properties, which have influence on crop yields, are availability of plant nutrients, soil reaction (soil pH) and cation exchange capacity. These chemical properties are affected by soil physical and biological properties (Juma, 1993). Roles of some soil chemical properties on crop production are briefly discussed below.

2.1.2.1 Soil reaction

Soil reaction (pH) is an indication of the acidity or alkalinity of the soil (Bickelhaupt, 1993). Soil pH provides various clues about soil fertility. The effect of soil pH is great on the solubility of minerals or nutrients (Motavalli *et al.;* 1995). Extremely and strongly acidic soil can have concentration of soluble Al, Fe and Mn, which may be toxic to growing of some plants. A soil pH range of approximately 6 to 7 promotes the most ready availability of plant nutrients (Marshner, 1986). Oborn *et al.*, (1995) studying the influence of soil pH on nutrients, established that soil pH affects the growth of plants, microbial growth, population and activity. The pH tolerance limits of different crops vary greatly, but most crops have a neutral range of between pH 6 to 7 (Landon, 1991). The soil pH can also influence the plant growth by its effect on the activity of beneficial micro-organisms (Beyer, 1994). Bacteria that decompose organic matter are hindered in strong acid soils (Parr and Papendick, 1978). This prevents organic matter from breaking down, resulting in accumulation of organic matter and the tie up of nutrients, particularly nitrogen that is held in the organic matter (Barrios, *et al.;* 1996).

2.1.2.2 Cation exchange capacity

The cation exchange capacity (CEC) is a measure of the soil's ability to retain cationic nutrients. It is also an index of clay activity and mineralogy which is important in calculating mineralisation rates, leaching rates and interaction with pollutants. The CEC measures the quantities of sites on soil surfaces that can retain positively charged ions by electrostatic forces (Riffald, *et al.*, 1994). The positively charged ions include Ca^{2+}, Mg^{2+}, K^{2+}, Na^{+}, H^{+}, Al^{3+}, NH^{4+} and Mn^{2+}. The cations retained electrostaticaly are easily exchangeable with other cations in the soil solution and thus readily available for plant uptake. Therefore CEC is important for maintaining adequate quantities of plant nutrients in the soil (Khanna *et al.;* 1994). CEC is made as part of the overall assessment of the potential fertility of the soil and their response to fertiliser application (Russell, 1973).

Soil texture, soil structure, organic matter content, clay type and soil reaction can affect the CEC of the soil. For example fine textured soil tends to have higher CEC than coarse ones. Motavalli et al.. (1995) found out that CEC increased with increase in soil pH. The higher the CEC the more the fertile and productive the soil is (Landon, 1991).

2.1.3 The influence of biological properties on crop production

Microorganisms occur in soil, water, air and various organic and inorganic substances. Also can occur on or within the bodies of other organisms. Microbial activity in the soil to a certain extent regulates the supply of nutrients (Beyer, 1994). They influence soil properties that affect plant growth. Brendecke *et al.,* (1993) observed that soil bulk density, nitrogen mineralisation rate and water regimes were the first parameters that exhibited a significant change following earthworm inoculation. The activity of microorganisms and soil fauna serves to promote soil aggregation (Marterns *et al.;* 1992) leading to reduced erosion and greater water infiltration.

Soil from termitaria is sometimes used as fertiliser in tropical cropping systems. Costantin *et al.*.(1996) indicated that maize production was significantly increased using soils from the mound. Plant materials particularly roots. produced in the presence of earthworms had higher nitrogen and phosphorous concentration (Ghodrat. 1995).

2.1.4 Effect of soil erosion on soil properties and crop yield

Soil erosion is defined as the wearing away, detachment or physical removal and transportation of top soil (soluble and insoluble materials) from one place and its deposition to another by various agents, including water. wind and gravitation force (Lal. 1990). Dregne (1990) reported soil erosion had an adverse effect on crop yield. Soil erosion being self-accelerating process, results in reduced plant cover, which in turn increase surface runoff and nutrient loss (Morgan, 1995). Stocking (1994) summarised the effect of soil erosion on soil physical properties as reduced rooting depth, reduced infiltration, increased surface runoff, loss of soil water holding capacity, crusting and soil compaction. Macharia *et al.*, (1996) observed other physical effects caused by soil erosion as increased bulk density, changes in soil texture due to the preferential removal of fine particles and organic matter. These structural effects may adversely affect seedling emergency, leading to low crop yield. Soil erosion can expose subsoils which are mostly less productive as they are associated with low CEC, low inherent fertility and nutrients, toxicity of aluminium and manganese and high soil acidity (Macharia *et al.;* 1996, Stocking, 1994).

2.2 Factors influencing soil properties

2.2.1 Weathering

Weathering is the physical and chemical disintegration and decomposition of rocks and minerals. which take place because the minerals contained in them. are not at equilibrium under the temperature. pressure and moisture conditions of atmosphere-lithosphere interface (Buol *et al.*. 1980). The kind of parent material determines the physical and chemical properties of the resulting soil. For example. acid igneous rocks and sandstone usually weather to form coarse sandy soils with low base status. On the other hand most of the basic igneous and sedimentary rocks weather to fine-textured soils. which have high bases status dominated by montmorillonitic clays (Uriyo *et al.*, 1979). Physical and chemical weathering influences particle size distribution (texture) while decomposition of organic matter influences chemical and some of physical (eg soil structure) properties of the soil. The products of decomposition of organic matter bind soil particles together to form granular structures. which facilitate air and water movement. Soil chemical properties are also influenced by decomposition of organic matter because it increases the overall exchange capacity of the soil. Decomposition of organic matter increases plant nutrients and soil water holding capacity.

2.2.2 Cropping systems

Charterjee *et al.;* (1986) defined cropping system as a cropping patterns used on a farm and their interaction with farm resources. other farm enterprises and their available technology which determine their makeup. A cropping system is a major cause of changing soil characteristics because it influences directly the chemical and physical properties of the soil (Sanchez, 1976). Dalland *et al.*, (1993) suggests that some of the cropping systems may influence the whole hydrology and soil temperature regime which control soil organic matter balance, root development and plant nutrient availability.

Cropping systems alter soil structure and aggregate distribution. especially in the Ap horizon. through the type or duration of crops and the frequency and intensity of tillage (Low. 1972). Crops affect soil structure differently because of diverse rooting habits. rhizosphere processes, type of organic matter and amount of additions and providing surface soil. Sanchez (1976) reported that some crops like potatoes, maize and wheat when intercropped with others, lead to deterioration of soil structure.

The quantity and quality of organic matter depends on the cropping system and its management (Brendecke *et al.;* 1993). The presence of soil organic matter enhances nearly all soil properties. The absence of soil organic matter and the persistent use of practices, which diminish, deplete or destroy organic matter threatens to impair soil quality and sustainability (Koudokpon, *et al.;* 1994). Thus, enhancing the quality and quantity of soil organic matter should be the goal of all long-term soil management. The quality of organic matter is determined by its Carbon:Nitrogen (C:N) ratio. The organic matter with C:N ratio between 8 and 13 is termed as a good quality whereas above 20 is of poor quality (Kileo. 2000). Soil organic matter contributes to plant growth through its effect on the physical. chemical and biological properties of soil.

2.2.2.1 Effect of soil organic matter on physical condition, erosion and buffering of the soil

One of the products of decomposition of organic matter is humus. Humus has a profound effect on the structure of many soils. The deterioration of structure that accompanies intensive tillage is usually less in soil adequately supplied with humus (FAO. 1978). When humus is lost, soil tends to become hard, compact and cloddy (Hoffman and Carroll. 1995). Aeration, water-holding capacity and permeability are all favourably affected by humus.

The frequent addition of easily decomposable organic residues leads to the synthesis of complex organic compounds that bind soil particles into structural units called aggregates (Cogle *et al.;* 1995, Thiessen and Stewart, 1983). These aggregates help to maintain a loose, open, granular condition. Hence water can infiltrate and percolate downward through the soil. The roots of plants need a continual supply of oxygen in order to respire and grow. Larger pores permit better exchange of gases between the soil and atmosphere. Humus usually increases the ability of the soil to resist erosion (Lee *et al.;* 1993) as well as enabling the soil to hold more water. In soils with low clay content, organic matter functions as a buffer system that stabilises pH and the general ionic environment (Bohn *et al.;* 1985).

2.2.2.2 Effect of soil organic matter on soil biological properties

Organic matter serves as a source of energy for both macro and micro faunal organisms (Palm, *et al.*;2000). The population of bacteria, actinomycetes and fungi in the soil is related in a general way to humus content. Earthworms and other faunal organisms are strongly affected by the quantity of plant residue materials returned to the soil (Gupta *et al.;* 1994). Organic substances in the soil can have a direct physiological effect on plant growth. Some compounds such as certain phenolic acids have phytotoxic properties (Jones, 1994); others such as the auxins enhance plant growth.

2.2.2.3 The influence of Soil Organic Matter on availability of plant nutrients

Organic matter functions as a sorption or an exchange agent especially in kaolonitic soils with naturally very low CEC (Riffald *et al.;* 1994). In such soils, organic matter contributes considerably to storage and release of nutrient ions (Dalland *et al.;* 1993). On acidic, highly weathered soils, organic matter is responsible for almost the entire exchange capacity. Agboola (1975), found a high significant and a very close correlation between the content of organic matter in the soil and CEC (r=0.988) in a western Nigerian soil.

Organic matter (OM) influences the supply of nutrients from other sources. for example. OM is required as energy source for N-fixing bacteria (Hesse. 1984).

Organic matter also works as a slow-release source of nutrients. thereby reducing the risk of leaching. This function is very important as it reduces nutrient loss in region with high rainfall as well as on all permeable soils especially sandy soils (Karl and Johannes. 1994).

Humus plays an indirect role in soil through its effect on the uptake of micronutrients by plants and the performance of herbicides and other agricultural chemicals. The organic matter reduce the toxicity of heavy metal by forming stable complexes with a high molecular weight and therefore less available to plants (Allison. 1973).

Growing crops in an association can affect the biotic condition in the soil by their different absorption of nutrients from it and by their excretion into it. Crops in single or association may cause a shift in pH of the soil; for example, a fall in pH was reported when jute was grown as a monocrop in India (Chalterjee *et al.*, 1986)

2.2.2.4 Limitations of soil organic matter as a source of plant nutrients

Organic resources have a number of shortcomings, which limit their use as sole source of nutrients for sustaining high crop yield. The organic matter contain very low amount of nutrients per unit weight, and thus, large quantities are needed to satisfy the requirement of crops (Kasembe, *et al.;* 1983)

The application of organic material with wide C:N ratios (>30:1) can cause immobilisation of nutrient elements from soil, thus making them unavailable to plants (Parr and Papendick 1978). Nutrient imbalances are often encounted in organic matter. The element frequently quoted as being out of balance is phosphorous and, this is due to low amount of element present in organic materials and slow rate of its release from the organic forms (Kasembe *et al.;* 1983)

There is a competing need for crop residues. A variety of crop residues are used in many places as animal feed and as building materials. Many smallholder farmers consider crop residues more as animal feeds and building materials than as soil amendment resource (Mabula, 1999).

Low rate of decomposition in arid and semi-arid areas is caused by unavailability of adequate soil moisture. This factor makes organic materials incorporated into the soil decompose slowly and hence, a slower release of nutrient contained in them (Franzluebber and Arshad, 1996).

The use of some of contents of organic materials may cause health problems to mankind. Some of the crops like wheat, barley, maize, vegetables and rice can absorb heavy metals which are released by organic materials (Bingham *et al.;* 1975)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site characteristics

Kwalei village is located in Mamba ward, Soni division in the southern part of Lushoto District, about 12 km south of Soni town. According to 1988 census the village is estimated to have about 4120 people. The village stands at an elevation ranging from 1290 to 1395 m a.s.l., with hilly steep slopes and medium tall mountains with narrow valley bottoms. It is in the humid warm agro-ecological zone with an annual rainfall ranging from 1000 to 1600 mm (Lyamchai, *et al.*, 1998). The rainfall pattern is described as unimodal. The annual mean temperature ranges from 17 to 23 °C but sometimes during cooler months the temperature can be below 17 °C and higher than 23°C during the dry season. Relative humidity is very high during the rain season. Wind speed is moderate having no effect on crop development. The indigenous trees have been replaced to a lesser extent by exotic tree species including *Eucalyptus sp.*, *Grevillea sp.* and black wattle.

3.2 Land use

One of the dominant land uses in the village is the permanent cultivation of coffee and tea. Coffee receives much more attention than any other cash crop in the village due to higher economic returns. Other crops grown in the village include maize, beans, wheat, potatoes and cassava. Vegetable production is also an important business and is practised in the valley bottoms. Livestock keeping is also practised in the village. The animals kept include sheep, goats, cattle, poultry and pigs.

Six main cropping systems were identified in the village through observations made during a transect walk from the southern part of the village to the north (Lyamchai, *et al.*; 1998) The cropping systems are described below:

3.2.1 Coffee-banana cropping system

The system is based on perennial crops which are intercropped. This cropping system is found in sloping physiographic units. A hand hoe is used to perform cultivation activities in the field. The system is also found in other densely populated areas of Tanzania like Arusha, Kilimanjaro, Mbeya, Ruvuma and Kagera regions. Soil fertility in this system is maintained with mulch from crop residue. Inorganic fertilisers are not used because most of the farmers are unable to purchase them. The poor infrastructure makes transportation difficult especially during the rainy season and therefore makes the price of the fertilisers to be high.

Soil samples for soil fertility evaluation were taken as described in section 3.4. The soil samples were taken from fields which had not previously received inorganic fertilisers.

3.2.2 Maize-beans cropping system

Maize is intercropped with beans. This system is found along the slopes and sometimes in valley bottoms especially during the dry season. All field operations are done by hand hoe. There are no soil conservation practices which are carried out in these areas although the slope varies from 25 to 35%. Very few farmers intercrop maize with cowpeas. The system is very common in highlands. In this system sometimes few scattered banana, fruit and other trees can be seen. Some farmers use crop residues from this system to feed their animals. Others leave it to decompose or burn it. Inorganic fertilisers are not used in this cropping system.

Soil samples for soil fertility evaluation were taken from fields which were continuously under maize beans cropping system as described in section 3.4.

3.2.3 Tea cropping system

Tea is grown as a monocrop. The system is found in sloping land with a slope of more than 20%. Land preparation and weeding are done by hand hoe. Very few farmers are growing tea in this village because the price is low and the market is not reliable. The farmers sell their tea leaves to the nearby private estate. No inorganic fertilisers application is practised in this system.

Soil samples for soil physical and chemical properties determination were taken from three selected tea fields which had not previously received inorganic fertilisers.

3.2.4 Vegetable cropping system

Valley bottoms are used by many farmers for growing vegetable crops, which fetch a good price. They sometimes apply manure or inorganic fertilisers depending on the type of vegetables grown. The main vegetable crops are cabbages, tomatoes, spinach, egg plants, sweet pepper, carrots and onions. During the dry season some farmers also grow maize or beans in these valleys using traditional irrigation system.

Soil samples were taken from four valleys, which were continuously under vegetable production for soil physical, and chemical analysis as described in section 3.4.

3.2.5 Woodlot and agroforestry systems

Farmers grow both indigenous and exotic types of trees. However most of them prefer exotic type of trees because they grow faster compared to indigenous type of trees. Some of the indigenous trees grown in the village include Albizia species, Dracaena species and Rauvolfia species. The most popular exotic trees are Eucalyptus, Grevillea and Acacia species.

These trees can be intercropped with crops or planted in small woodlots. Woodlots are not a very common practice in the village due to land shortage. Eucalyptus species woodlots are emerging due to new fuelwood market in the nearby Herkulu tea factory. Acacia species is used mainly for building poles and fuelwood. Occasionally it is used as fodder for goats and their barks are sold at Lushoto wattle factory. Grevillea species are mainly used for timber and fuelwood, but are also perceived to improve soil fertility.

The soil samples for soil physical and chemical analysis were taken from eucalyptus, grevillea, wattle and a mixture of woodlot systems. The woodlot systems used in the study were about 5 years old.

3.2.6 Fallow systems

Due to increased population growth in the village, the fallow system is becoming impossible to practice. However some farmers do leave the land under fallow for few years because it is infertile and they harvest nothing from that particular land. Most of the land left as fallow is that which was affected mostly by erosion or was under continuous cultivation for a long time. Two fallow systems were used in the study. The selection was based on the physiogragraphic units. In this study one fallow system was on summit and another on sloping land. Both fallow systems were 3 years old. These fallow systems were covered with grass, shrubs and indigenous tree species.

Soil samples were taken from both fallow systems for soil physical and chemical determination as described in section 3.4.

3.3 Soil profile description

Three representative soil profiles were dug to a depth of at least 100 cm. Each soil profile represents a physiological unit (Summit, slope and footslope). Soil samples were collected from each horizon for soil physical and chemical analysis. Core samples were taken from different depths in all three soil profiles for bulk density determination. The morphological characteristics of the profile were described in detail using guidelines for soil profile description (FAO. 1990). Soil colour was determined using the Munsell Soil Colour Chart (Munsell Colour Company, 1975). Based on both field and laboratory data. the soils were classified to the subgroup level according to USDA Soil Taxonomy System (Soil Survey Staff. 1998) whereas according to World Resource Base (FAO.1998) soil classification system, the soils were classified to level-three.

3.4 Soil sampling and processing

3.4.1 Undisturbed soil samples

The undisturbed surface soil samples for bulk density were randomly taken from each cropping system using cylindrical metallic cores at a depth of 0-5 cm. Fresh weight of soils was taken before oven drying. The cores were removed from the oven after 48 hours and the cooling process was done using dessicators. Oven drying was done at a temperature of 105°C until constant weight was reached. Oven dry weight was determined by weighing the already cooled samples. Before calculating the bulk density, the volume of the cores was determined by measuring the diameter and height of cores.

3.4.2 Composite soil sample

Random composites sub-samples were taken from each cropping system at 0-20 cm depth. The composite samples were air-dried and ground to pass through a 2 mm sieve. The prepared samples were used for physical and chemical soil analysis.

3.5 Soil analysis

3.5.1 Soil physical analysis

Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986). The textural class was arrived at by using USDA textural class triangle. Soil bulk density was determined using the core method (Okalebo *et al.*, 1993). Water retention was determined by equilibrating the samples with water at various suction levels using a ceramic plate extractor as described by Peters (1986).

3.5.2 Soil chemical analysis

Soil pH was measured potentiometrically in water using 1:2.5 soil: water ratio (Maclean, 1982). Total nitrogen was determined by the semi-micro-Kjeldahl digestion method followed by ammonium distillation titrimetric method (Bremner and Mulvaney, 1982). Organic carbon was determined by wet-acid dichromate digestion method of Walkley and Black (Nelson and Sommers, 1982). Extractable P was determined following the Bray and Kurtz 1 procedure for soils with pH < 7 (Olsen and Sommers, 1982). Cation exchange capacity and exchangeable bases of the soils were determined by saturating soil with neutral 1M ammonium acetate extraction and the bases determined by atomic absorption spectrophotometry (Okalebo *et al.*; 1993). DTPA extractable micro-nutrients (Cu, Zn, Mn and Fe) were determined by extraction with 0.005M DTPA and quantified using atomic absorption spectrophotometry method (Lindsay and Norvell 1978).

3.6. Statistical analysis

The means of all soil properties from all identified cropping systems were separated using Duncan's New Multiple Range Test. MSTATc computer software was employed to analyse the data.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Classification of the studied soils

Information on soil profile description and analytical data are presented in appendices 1. 2 and 3. Table 1 gives a summary of morphological and diagnostic features while Table 2 presents the classification of the studied soils according to both World Resource Base (FAO,1998) and USDA-Soil classification (Soil Survey Staff. 1998) systems. Three soil levels namely Lixisols, Phaeozems and Fluvisols were identified according to World Resource Base (WRB) (FAO. 1998). Lixisols were dominant in the summit physiographic unit. Fluvisols were found on sloping areas while Phaeozems were dominant in footslope areas. The corresponding USDA-soil classification at soil order levels were Alfisols (Summits), Entisols (Slopes) and Mollisols (Footslopes).

The average percentage of Base Satutaion (%BS) for soils in summit, slope and footslope were 49, 72 and 80%, respectively (Appendices 7,8 and 9). Percentage base saturation is a good index for evaluation of soil fertility. The soils in slope and footslope were fertile because they had %BS were above 50% which is the critical value. This may be attributed to the deposition of materials from the summit. The soil in the summit has %BS below the critical value and is an indication that Alfisols have low capacity to store plant nutrients. The low soil fertility in summit may be attributed to the leaching of exchangeable bases and erosion processes, which occur during the rain season. The exchangeable bases increased with the depth (Appendix 7) which is an indication that leaching is active. It is therefore concluded that addition of plant nutrients from external sources may be required for improvement of crop production in the summit.

Table 1: Summary of soil profile morphological and diagnostic features

PROFILE LOCATION	DIAGNOSTIC HORIZON	OTHER DIAGNOSTIC FEATURES/PROPERTIES
PFK1 Summit	Argillic horizon, Umbric horizon, *Umbric epipedon	Ferralic, Endoleptic, Umbrihumic, Profondic, Rhodic *Udic soil moisture regime . *isothermic soil temperature regime
PFK2 Slope	Ferralic horizon, Ochric horizon, *Ochric epipedon	Ferralic, Fluvic, Orthieutric, Humic *Udic soil moisture regime . *isothermic soil temperature regime
PFK3 Footslope	Cambic horizon, Mollic horizon, *Mollic epipedon	Chromic, Hypereutric, Mollihumic, *Udic soil moisture regime . *isothermic soil temperature regime Mollic, Pachic

Note: * diagnostic horizons and other diagnostic features according to USDA -Soil classification system (Soil Survey Staff, 1998).

Table 2: Classification of the studied soils.

	FAO classification systems			USDA-Soil Taxonomy			
Profile	Level-1	Level-2	Level-3	Order	Suborder	Greatgroup	Subgroup
PFK1 Summit	LIXISOLS (LX)	Endoleptic Lixisols	Umbrihumi-Endoleptic Lixisols (Ferralic,Profondic, Rhodic)	ALFISOLS	Udalfs	Rhodudalfs	Typic Rhodudalfs
PFK2 Slope	FLUVISOLS (FL)	Humic Fluvisols	Orthieutri-Humic Fluvisols (Ferralic)	ENTISOLS	Fluvents	Udifluvents	Mollic Udifluvents
PFK3 Footslope	PHAEOZEMS (PH)	Pachic Phaeozems	Chromi-Pachic Phaeozems (Hypereutric, Mollihumic)	MOLLISOLS	Udolls	Hapludolls	Pachic Hapludolls

4.2 Soil physical and chemical properties under the cropping systems on the slopes

4.2.1 Tea monoculture system

The data on soil physical and chemical properties from monoculture tea are presented in Table 3 and Appendix 1. The soils have bulk densities ranging from 1.09 to 1.19 g/cm3. The total porosity ranged from 47.78 to 57.65%. The observed bulk density and total porosity are conducive to good soil physical properties and hence suitable for tea production. It has been demonstrated that high bulk density imposes many problems such as mechanical resistance. poor aeration and reduced permeability to plant rooting systems (Marshner, 1986). The soils of Kwalei village under monoculture tea system are thus free from problems associated with compaction. The soils are well drained sand clay loams.

The soil pH ranged from 4.64 to 5.09 and it was rated as very low to low according to Landon (1991). Wilson. (1969) reported that the soil pH range of 5.3 to 5.6 was optimal for the availability of exchangeable bases and available P for tea plants. Therefore, the soil in this cropping system is likely to be deficient in exchangeable bases and available P. Results in Table 3 indicate low levels of exchangeable bases and available P. Observations made by Lieffering *et al* (1996) on the effect of soil pH on cation exchange capacity of the soils also found that soil pH has great influence on the capacity of the soil to retain plant nutrients. There is a possibility that, the growth and activity of microorganisms will be reduced due to the observed low soil pH. This is further supported by Beyer (1994) who found that strong acid soils have a negative effect on the activity of beneficial microorganisms which decompose organic matter, leading to reduced availability of plant nutrients.

The low soil pH may be due to leaching of exchangeable bases and soil erosion. Increased soil erosion can be attributed to lack of soil conservation practices in this village. Macharia *et al* (1996) in a study on the relationship between some chemical properties and soil erosion in Western Kenya also observed that soil erosion increased the acidity of the soils. However, the low soil pH observed in this study is conducive for tea production because the crop requires an acidic environment. Mabbett (1999) found that tea requires acid soils with a pH values between 4.5 and 5.5 and perform poorly in soils which are alkaline.

Soil organic carbon ranged from 2.01 to 2.46% and was classified as low according to the rating system by EUROCONSULT (1989). The Low level of soil organic carbon is a reflection of low soil organic matter. The low soil organic carbon may be attributed to low input of crop residues because the tea leaves are harvested and processed for human consumption. The low organic materials returned to the soils will likely affect the capacity of the soil to supply plant nutrients. The low level of cation exchange capacity in the soils supports this observation. However, the results are contrary to the observation made by Wilson (1969) that well maintained tea plants generate a lot of organic matter from leaf fall and pruning, leading to high percentage soil organic carbon content. These contrasting observations could be probably due to the small quantity of organic matter present and its slow rate of decomposition.

The cation exchange capacity of the soil ranged from 9.73 to 11.80 Cmol(+)kg^{-1} and this range was rated as low according to Landon (1991). These values indicate that the soils are probably dominated by kaolinite which is commonly in highly weathered, well drained soils. Such soils are fragile and easily degraded if are mismanaged. The results suggest that the soils have poor inherent fertility status, as their ability to retain cations is low. Othieno, (1992) reported that in intensively leached soils in which tea grows best the predominated clay minerals are kaolinite. These type of clay minerals are low in CEC, and have low ability to retain plant nutrients. Tandon, (1991) concluded that the CEC of such soils mainly depends on the organic matter content because these are highly weathered and contribution of the clay fraction to the CEC is very limited. Therefore, the low CEC is attributed to low organic matter content in the soils.

Soil organic matter is an important component of a productive soil. Therefore, the low soil organic matter together with low cation exchange capacity of the soils are a reflection of poor soils in terms of nutrient supplying power. Thus inorganic fertilisers must be applied to supply plant nutrients, and if possible organic sources should be identified and spread on soil surface as a mulch. This will not only be a source of plant nutrients but also a conditioner to improve on soil physical properties and conserve soil moisture.

The level of exchangeable bases varied from very low to low (Ca ranged from 1.10 to 2.62, Mg ranged from 0.32 to 0.47 and K ranged from 0.11 to 0.16 Cmol(+)kg^{-1}). The low level of exchangeable bases may be due to leaching and washing by runoff due to lack of soil conservation practices. This argument is similar to that of Macharia *et al.*; (1996) who studied the relationship between some chemical properties and soil erosion in western Kenya. The low exchangeable bases may also be due to low crop residue incorporated into the soil and exportation of nutrients through harvesting of the tea leaves. The argument is similar to that put forward by Wilson, (1969) who observed that plucked tender shoots are highly concentrated in nutrients.

Percentage base saturation is a good index for soil fertility evaluation. The average percentage base saturation for the soils in tea cropping system is 20.1%. This is far below the 50% critical level, indicating that the soil fertility status is very low. This is an indication that a serious intervention is required to improve on tea production in the village.

The available P ranged from 2.41 to 6.00 $mgkg^{-1}$ which is low according to Baize, (1993) classification system. Phosphorous is very important in division of plant cells and its growth as well as root growth and crop maturity. The low level of available P will generally affect plant growth and development. This low level may be attributed to long-term P mining by plants, nutrient export and low inherent P levels. Othieno (1992) found that tea plant takes about 4 to 5 kgP/ha/year to yield about 2000 kg of made tea. Loss of P in soils through leaching is virtually non-existent because of its low mobility. The observed low P status may also be due to low levels of organic matter content as a result of limited organic matter accumulation and slow decomposition, high activities of Al and Mn in the soils which form insoluble complexes with phosphorous. Similar observations were also made by Sandanam et al.; (1978) in tea fields in Sri Lanka. Other contributing factors are lack of addition of phosphatic fertilisers and soil erosion. The soils in this village could be inferred to as having a serious limitation of phosphorus.

The total nitrogen content in the soils ranged from 0.10 to 0.21% and was categorised as low according to EUROCONSULT (1989). Other workers have reported almost similar results of total nitrogen in tea growing areas of the world (Dey, 1969, Sandanam et al.; 1978). The low level of total nitrogen in this cropping system may be due to low level of organic matter which is attributed to low amount of crop residues returned to the soils. This argument is supported by the observation made by Heenan, *et al* ;(1995) who found that a cropping system with a high amount of crop residues returned to the soils reduced the loss of nitrogen. Othieno (1992) observed that the low level of total nitrogen was due to nutrient mining as a result of frequent plucking of the tender succulent shoots and leaching due to high rainfall. Nitrogen being the major nutrient element is needed in very high amounts and hence, it has to be applied adequately to meet the demand.

The low level of exchangeable bases, available P and total nitrogen is a reflection of low soil fertility status which can only lead to a low tea yield. In order to increase the production level of tea, there is a need to apply fertilisers which will supply these plant nutrients.

The mean values of DTPA-extractable Fe and Mn for monoculture tea soils are 36 and 56 mg/kg respectively. These are above the normal range suggested by Sims and Johnson (1991). The DTPA-extractable Zn and Cu mean values were 0.53 and 1.89 mg/kg which were within the acceptable range for normal plant growth and development. The critical values are 0.2 to 2.0 mg/kg and 0.1 to 2.5 mg/kg of soil for Zn and Cu respectively, based on Sims and Johnson (1991). Soils with high levels of available Fe and Mn could be due to low soil pH, which favours the dissolution of Fe, and Mn compounds in the soils (Alloway and Ayres, 1990)

From this study, it can be concluded that soil physical conditions in this cropping system allow for both good rooting and aeration. However, the soils have low capacity to retain plant nutrients. The levels of available macro-nutrients are also very low to low. This system can only be utilised optimally if good soil management practices are adopted including soil erosion control and incorporating organic materials into the soils. Use of inorganic fertilisers will be necessary as the levels of plant nutrients are low in the soils.

Table 3: Comparison of soil properties among the cropping systems on the sloping land

Parameter	Cropping system			CV %	LSD	SEM
	Tea	Coffee banana	Maize beans			
pH (water)	4.7[b]	5.8[a]	5.9[a]	7.05	0.67	0.22
%OC	2.19[b]	4.64[a]	3.93[a]	19.02	1.18	0.39
CEC Cmol(+)/kg	11.42[b]	23.62[a]	24.20[a]	13.21	4.51	1.41
Ca Cmol(+)/kg	1.61[b]	9.08[a]	8.33[a]	26.68	2.93	0.98
Mg Cmol(+)/kg	0.57[b]	2.09[a]	2.12[a]	33.83	0.93	0.31
K Cmol(+)/kg	0.23[a]	0.53[a]	0.21[a]	58.40	0.34	0.11
Na Cmol(+)/kg	0.02[a]	0.10[a]	0.04[a]	114.10	0.09	0.03
%BS	20.10	51.65	46.76			
%TN	0.15[b]	0.29[a]	0.26[a]	14.82	0.05	0.02
P mg/kg	3.66[a]	4.72[a]	2.21[a]	43.10	2.63	0.88
Fe mg/kg	35.77[a]	29.08[b]	8.17[c]	10.16	5.61	1.43
Mn mg/kg	56.26[b]	125.50[a]	113.20[a]	23.35	52.02	13.25
Zn mg/kg	0.53[a]	1.33[a]	0.56[a]	43.59	0.79	0.20
Cu mg/kg	1.89[b]	3.62[a]	1.33[b]	18.56	0.96	0.24
Bulk density g/cm^3	1.18[a]	0.95[a]	0.83[a]	6.92	0.12	0.04

Note: within each row means carrying the same letter(s) are not significantly different at P=0.05

CV means coefficient of variation

LSD means least significant difference

SEM means standard error of means

4.2.2 Coffee/banana mixed cropping system

The data on soil physical and chemical properties from coffee/banana growing fields are presented in Table 3 and appendix 2. The soil bulk density ranged from 0.92 to 0.96 gcm^{-3} and the total porosity ranged from 62 to 66%. This is an indication that the soils are suitable for coffee and banana production due to conducive soil physical properties. The soils are well drained sand clay loam.

The soil pH ranged from 5.63 to 6.96 and the range was rated as medium according to the classification system established by Landon. (1991). Soils with such a pH range are likely to have satisfactory plant nutrients for coffee and banana production. This is supported by the observed medium capacity of supplying plant nutrients in this study. Also the medium soil pH range may create conducive condition for the growth and microbial activity. Parr and Papendick (1978) observed that bacteria are responsible for decomposition of organic matter were hindered in strong acid soils, thus preventing the break down of organic materials. This resulted in accumulation of organic matter and tie up of nutrients, particularly nitrogen that is held in the organic residues.

The soil organic carbon ranged from 7.24 to 8.72% and it was rated as medium according to Baize (1993) rating system. The cation exchange capacity of soils ranged from 20.40 to 27.47 Cmol(+)kg^{-1} and this range was classified as medium (Landon, 1991). The exchangeable bases were rated as medium to slightly high. Their ranges were as follows. Ca^{2+}, from 8.39 to 10.18, Mg^{2+} from 2.35 to 2.56 and K^{+} from 0.39 to 0.69 Cmol(+)kg^{-1}. The medium levels of both soil organic carbon, cation exchange capacity of the soil and exchangeable bases may be due to relatively high amount of organic residues produced in this cropping system and returned to the soil. Banana and coffee leaves together with coffee prunings and coffee husks are returned into the soil and contributed to an appreciable amount of organic matter in the soils. The quantity and quality of organic matter is influenced by the nature of the above and below-ground litter inputs (Palm. *et al.*; 2000). Soil organic matter constitutes both a sink and a source of plant nutrients and hence acts as a regulator of temporal and spatial pattern of nutrient availability. This can be supported by the amount of soil organic matter in the soil which ranged from 4.21 to 5.07% and it was rated as medium (Landon. 1991). Another factor may be micro-climatic condition created by these perennial crops. which favoured the growth. and activities of micro-organisms. hence enhanced the decomposition of organic matter. The decomposition of organic matter results into release of plant nutrients (Dalland *et al.*; 1993). The decomposition of organic matter produces humus which increases the ability of the soil to resist erosion (Lee *et al.*; 1993) as well as enabling the soils to hold more water for plants.

The average percentage base saturation for the soils in coffee/banana cropping system is 52%. This is slightly higher than 50%, which is a critical level. indicating that the soil fertility status is adequate. It is an indication also that the soil is suitable for coffee and banana production.

The total nitrogen ranged from 0.32 to 0.35% and was rated as medium according to the rating system was established by Baize, (1993). The medium level of nitrogen in this system may be due to adequate amount of organic residues produced by coffee and banana crops.

This can be supported by the observed medium level of soil organic carbon which is a reflection of organic matter content.

The available P ranged from 3.66 to 6.47 $mgkg^{-1}$ and according to Singh *et al.*(1977) rating system, this range was rated as low. This level is an indication that there is P-deficiency in this cropping system. The argument is related to that put forward by Le Mare (1991) who observed that many soils in the tropics lack sufficient amount of P in a form that is available to plants to ensure satisfactory growth. The low level of P may be due to nutrient mining. Since P is accumulated in the reproductive portion of the plant which is usually harvested, then the crop residues returned to the soil often have a low level P. The soil is medium acidic, therefore P can be fixed by exchangeable Fe/Al Mn and their oxides

It can be concluded from this study that the medium level of soil organic carbon and cation exchange capacity of the soils is an indication that the soil can retain a satisfactory amount of plant nutrients for coffee and banana production while the medium level of exchangeable bases and total nitrogen implies that the soils have satisfactory amounts of plant nutrients for the same purpose. Addition of phosphatic fertilisers is highly required.

DTPA extractable Fe, Mn and Cu levels in the soils were 29, 126 and 3.62 mg kg respectively. These were above the normal range according to Sims and Johnson (1991) while extractable Zn (1.33 mg/kg) was within the acceptable range. The high level of available Cu may be due the use of pesticides (mainly Cu fungicides) in controlling pests and diseases, which affect coffee. These results are supported by the findings made by Mkindi (1990) who found that Cu contents were higher in the coffee cropping systems which were sprayed with Cu fungicides like copper oxychloride (cupric chloride 50% wettable powder) and cupric hydroxide 50% wettable powder in Moshi district than non sprayed farms.

4.2 3 Maize/beans mixed cropping system

Data on physical and chemical soil properties in soils from maize/beans cropping systems are presented in Table 3 and Appendix 3. The bulk densities ranged from 0.79 to 0.88 g cm^{-3} while total porosity ranged from 62 to 73%. The low level of bulk density and the high level of total porosity suggest that the soils do not have a serious problem of compaction. The soils are well drained sand clay loams which are suitable for maize and beans production. The soil pH ranged from 5.75 to 6.26 and it was classified as medium according to classification system established by Landon, (1991). The level suggests that the soils have satisfactory plant nutrients for maize and beans production. This is supported by the medium level of cation exchange capacity and medium to slightly high level of exchangeable bases observed in the study. The soil pH range is also conducive for microbial activity. Beans are also likely to contribute to the N pool through biological nitrogen fixation.

The soil organic carbon ranged from 6.56 to 7.20% and it was classified as medium. The cation exchange capacity of the soils ranged from 22.2 to 24.52 Cmol(+)kg^{-1} and the range was classified as medium (EURONCOSULT, 1989). These levels indicates that the soils can supply adequate amounts of plant nutrients for maize and beans production. The exchangeable bases were classified as medium to slightly high except exchangeable Na which was classified as very low according to Baize (1993) classification system.

The medium level of soil organic matter, cation exchange capacity and some of exchangeable bases (Ca, Mg and K) may be due to appreciable amount of crop residues incorporated into the soil. Incorporation of organic residues is a normal practice in this cropping system. The incorporated organic materials contribute considerable to storage and release of nutrient ions. This is supported by the observation made by Riffald, *et al.*; (1994) who found that the amount of crop residue incorporated in the soils has considerable effect on chemical properties of the soils. Another contributing factor is that the cropping system has favourable conditions for the growth and activity of microorganisms, which are responsible for decomposition of incorporated crop residues.

The average percentage base saturation for the soils in maize/beans cropping system is 47%. This is slightly below the 50% critical level, indicating that the soil fertility status is slightly low. This is an indication that intervention in form of soil fertility improvement is required to improve on maize and beans production in the village.

The total nitrogen in the soils ranged from 0.25 to 0.29%. This range was rated as medium according to Baize (1993) rating system. Nitrogen is the most limiting nutrient in plant growth and is a constituent of chlorophyll, plant protein and nucleic acids (Marshner, 1986). The medium level of total nitrogen in the soils indicates that the soil can supply moderate amounts of nitrogen to the plants. This medium level is probably due to the amount of crop residues returned to the soil and the good quality of some of the crop residues (bean crop residues). This is supported by the observation made by Palm, (2000) who found that the quantity and quality of organic matter is influenced by the nature of the above and below-ground litter inputs. The medium level also is probably due to biological nitrogen fixation processes in the soils because beans are one of the main crops in this system which are capable in fixing nitrogen. Soil pH was optimal for biological nitrogen fixation.

The available P in the soil ranged from 1.01 to 2.72 mg/kg. According to Singh et al (1977) classification system, this range was classified as low. Low P value indicating low P supplying power of the soils. Such low values are likely to lead to very poor crop performance. The low level of available P will reduce the growth and delay the maturity of the crop (Miller and Donahue, 1992). The low level of available P might be due to nutrient mining because the phosphorous is accumulated in the reproductive portion which is usually harvested.

In the maize/beans cropping system the means of the DTPA extractable Fe, Mn, Zn and Cu were 8.17, 113.20, 0.56 and 1.33 mg/kg of soil respectively. These means were rated as out of normal range for the DTPA extractable Fe and Mn while the rest were within the acceptable range for normal plant growth and development. The high level of extractable Fe and Mn may be due to parent materials, and the acidic pH level which favours their solubility.

4.3 Comparison of soil properties among cropping systems on sloping land

Data on the comparison of soil properties between cropping systems on sloping land are presented in Table 3. The soil pH in tea cropping system was significantly ($P=0.05$) lower than values from coffee/banana and maize/beans cropping systems. The percentage soil organic carbon and cation exchange capacity of the soils in tea cropping system were significantly (P=0.05) lower than those from coffee/banana and maize/beans cropping systems. The organic matter and CEC from soils in coffee/banana and maize/beans cropping systems were twice as much when compared with the values in the tea system. The exchangeable calcium and magnesium in tea cropping system were significantly (P=0.05) lower than from other cropping systems. Exchangeable potassium and sodium did not differ significantly (P=0.05) between the cropping systems. However, the exchangeable potassium in coffee/banana was slightly higher compared to other cropping systems.

The available P was significantly (P=0.05) higher in maize/beans cropping system than in other cropping systems while total nitrogen in tea cropping system was significantly (P=0.05) lower than that of maize/beans and coffee/banana cropping systems. The available Fe in tea cropping system was significant higher (P=0.05) than in other cropping systems and the opposite was true for available Mn. The extractable Zn did not differ significantly (P=0.05) between the cropping systems. Extractable Cu was significantly higher (P=0.05) in coffee/banana cropping system than in other systems.

From the above information, the low levels of soil pH, soil organic carbon, CEC, exchangeable Ca, Mg and percentage total nitrogen in tea monoculture compared to other systems may be due to low organic matter which is attributed to low input of crop residues in the soil. The low level of crop residues returned to soil is attributed to frequently plucking of tea leaves and lack of frequent prunning of tea plants. Other reasons may be due to increased soil erosion, which is attributed to lack of soil conservation measures and exportation of nutrients through harvesting of the tea tender leaves which are highly concentrated in nutrients.

According to percentage base saturation values from all cropping systems, the soil fertility status from coffee/banana cropping system was moderate while in maize/beans was slightly moderate and in tea cropping system was very low. This is
an indication that, soil from maize/beans and tea cropping systems needs extra addition of plant nutrients from other sources like farmyard manure and composts.

The high level of DTPA extractable Fe in tea monoculture may be due to low level of soil pH which favours the dissolution of Fe compounds in the soils while the high level of Cu in coffee/banana cropping system may be due to the use of Cu-fungicides like cupric hydroxide 50% wettable powder in controlling pests and diseases which affect coffee.

4.4 Soil physical and chemical properties in the valley bottoms under vegetable production

The mean values of physical and chemical soil properties for the valleys, which are used for vegetable production, are given in Table 4 and Appendix 4. The soils are well drained sand clay loams, and are good for vegetable production because the soils are not compacted. This is supported by low bulk density and high total porosity, which were observed to range from 0.86 to 0.92 g/cm3 and 62 to 69% respectively

The soil pH ranged from 5.30 to 5.97 and was rated as medium according to Landon (1991) rating systems. Knott, (1980) suggested that soil pH between 5.0 and 6.8 is suitable for vegetables such as beans, tomatoes, peppers, potatoes and cabbages. Therefore the soil pH values observed from the study area are favourable for production of most vegetables. The soil pH is thus likely to favour the activity of microorganisms and availability of essential plant nutrients. The results are supported by the amount of total nitrogen and cation exchange capacity of the soil

Table 4: Mean values of some physical and chemical properties of soils from four valley bottoms under vegetable production

Parameter	Mean value	CV%	SEM
pH (water)	5.7	7.2	0.24
%OC	4	37.3	0.9
CEC Cmol(+)/kg	20	14.5	1.5
Ca Cmol(+)/kg	6.2	8.1	0.3
Mg Cmol(+)/kg	2	15.5	0.2
K Cmol(+)/kg	0.2	77.2	0.1
Na Cmol(+)/kg	0.2	30	0.04
%BS	42		
%TN	0.3	33.7	0.1
P mg/kg	5.6	28	0.9
Fe mg/kg	8	14	0.8
Mn mg/kg	103	1.7	1.3
Zn mg/kg	2	5	0.1
Cu mg/kg	7.7	12	0.7
Bulk density g/cm^3	0.9	7	0.04

CV means coefficient of variation and SEM means standard error of means.

which were also rated as medium. The observed soil pH values could enhance the solubility of some micro-nutrients (Fe, Mn, Cu and Zn) as supported by the high amounts of these nutrients and subsequently may be taken up in excessive amounts by the plants..

The soil organic carbon ranged from 3.63 to 4.31%. This range was rated as low to medium according to EUROCONSULT (1989) rating system. This implies that the amount of organic matter returned to the soil is low. The leaves of most of the crops grown in these valleys are harvested and consumed by human beings. Some of the leaves which are not suitable for human consumption are used to feed animals especially during the dry season. The amount of crop residues returned to the soil is thus not as much as compared to other systems in which the leaves are not used either as a source of human food or animal feed. The low level of soil organic carbon observed can therefore be associated with continuous cultivation of vegetable crops on the same piece of land.

The Cation exchange capacity of the soils in all valleys ranged from 18 to 23 Cmol(+)kg^{-1} and are categorised as medium according to Landon (1991). This implies that the soil can moderately retain plant nutrients for vegetable production. According to Baize (1993) satisfactory level of CEC for most crops ranges from 15 to 25 Cmol(+)kg^{-1}. The CEC in the soils is attributed to the content of soil organic matter and the amount of clay in the soil. The organic matter in the soils was found to be low thus, the medium CEC may due to the amount of clay content in the soils.

Exchangeable bases except Na in all valleys were categorised as low to medium according to Baize (1993). The Na ranged from 0.09 to 0.36 Cmol(+)kg^{-1} and the range was classified as very low. Hence, the range is not expected to interfere with the nutrition of most field crops. The soils are thus not saline at the moment. Na in particular circumstances may be utilised by some crops as a partial substitute for K but it is not an essential plant nutrient. Knott (1980) found that its absence or presence in only very small quantities is therefore not usually detrimental to vegetable nutrition.

The low to medium level of exchangeable bases (Ca 5.98-7.33, Mg 1.63-2.25 and 0.13-0.35 Cmol(+)kg^{-1}) may be due to low amount of organic matter incorporated in the soil, because the crop residues returned is low. Another factor for low to moderate exchangeable bases may be due to nutrient mining by vegetables. The critical level of exchangeable K is 6 Cmol(+)kg^{-1}, while the deficiency level of Mg occurs at a level less than 1.25 Cmol(+)kg^{-1} for most vegetables.

The average percentage base saturation for the soils in maize/beans cropping system was 42%. This is slightly below the 50% critical level, indicating that the soil fertility status is slightly low. This is an indication that intervention is required to improve on vegetable production in the village.

The total nitrogen ranged from 0.27 to 0.28% and was categorised as slightly medium according to Singh *et al* (1977) classification system. The observed level of total N could be partly attributed to nutrient mining by vegetables and low organic matter content in the soil. Nitrogen is an important nutrient for vegetable production (Tindall, 1983). Therefore, for optimum production of vegetables in the village, N containing fertilisers such as urea and calcium ammonium nitrate should be applied.

The available P in the soils ranged from 4.9 to 6.7 mg/kg and was rated as low according to Singh, *et al.;* (1977) rating system. Magoggo *et al* (1996) found that an average P level of more than 7 mg/kg is considered to be optimum below which P-deficiency symptoms are likely to occur in many crops including vegetables. These results indicate that vegetables grown in the village may require application of P-fertilisers in the soils. The low P observed could be probably due to the inherent low P content in the soil. Moreover low pH may be responsible for high phosphate fixation. Nutrient mining by vegetables may be another factor for low P in the study area (Miller and Donahue 1992).

The DTPA extractable Fe, Mn and Cu were rated as out of range for normal plant growth and development, according to Sims and Johnson (1991) rating system where as Zn was within the acceptable range. The high level of available Cu and Mn may be attributed to spraying of Cu and Mn containing pesticides. Some of the pesticides which contain Cu are Blitox and Kocide while pesticides which contain Mn are Ridomil and Dithane M45 which are used to control pests and diseases in vegetables. This is in agreement with the observation made by Mwalilino (1997) who assessed the heavy metal accumulation in soil of vegetable growing area in Mbeya district. The high level of Fe found in these soils are most likely due to the nature of the parent materials. Thompson and Troeh, (1985) found that igneous rocks were rich in iron.

4.5 Soil physical and chemical properties under woodlot systems

4.4.1 Woodlot systems in summit

The data on soil properties within woodlot systems in summit areas are presented in Table 5 and Appendix 5. Only one woodlot system was identified in summit areas. The woodlot system had a mixture of Eucalyptus. Grevillea. Wattle and very few indigenous tree species. The bulk density for soils from mixed trees ranged from 0.85 to 1.03 g/cm^3 and total porosity was 64%. The bulk density is a reflection of compactness of the soils. The low level of bulk densities implies that the soil is not compacted at the moment, and hence it is free from the problems associated with compaction. The soils were sand clay loams in mixture woodlot systems.

The soil pH ranged from 4.57 to 5.40 in mixed woodlot system. This range was rated as low according to a classification system by Baize (1993). The low soil pH value may be due to great lignification or acidification by tree litter. The observation is supported by other studies (Chavan *et al.* 1995, Alexander, 1986, and Greenland and Nye, 1959), which reported tree litter to increase acidity of the soils.

Soil organic carbon from mixed woodlot system ranged from 4.86 to 5.25% and was rated as medium according to the classification system established by Landon. (1991). Soil organic carbon is a reflection of soil organic matter. Therefore, the medium level of soil organic carbon implies that there is a satisfactory amount of organic matter in the soil, which is attributed to turnover of organic materials in the soils.

The cation exchange capacity of the soils from mixture woodlot system ranged from 15 to 23 Cmol(+)/kg of soil. According to EUROCONSULT. (1989) classification system. this range was classified as medium. The medium level of CEC implies that the soils from these woodlot systems can moderately retain plant nutrients. The medium level of CEC may be due to an adequate amount of organic matter in a mixed woodlot system which is attributed to leaf fall.

Exchangeable Ca, Mg, K and Na in mixed woodlot system were 4.86, 1.12, 0.16 and 0.05 Cmol(+)/kg of soil, respectively. According to a classification system established by Landon (1991) these values were classified as low to medium for exchangeable Ca and Mg while K and Na were classified as low. The low to medium levels of some exchangeable bases in soil from a mixed woodlot system suggests low to medium transfer of the ions from deeper horizons by the tree species to the surface of the soil layer. The low level of exchangeable Na suggest that the soil from mixed woodlot system is free from salinity and other problems related to high amount of Na in the soils.

The average percentage base saturation for the soils in mixed woodlot system was 26%. This is far below the 50% critical level, indicating that the soil fertility status is very low.

Total nitrogen for mixed woodlot system ranged from 0.22 to 0.29%. This range was classified as medium according to a classification system by Singh *et al.;* (1977). The observed medium level of total nitrogen may be due to appreciable input of organic matter and possibly the biological nitrogen fixation of some of these tree species.

The available P in soils from mixed woodlot system ranged from 1.69 to 2.33 mg/kg of soil. This range was classified as low according to Singh, *et al.:* (1977) The observed low level of available P may be due to the slow rate of its release from organic form (Kasembe, et al.: 1983). It may also be due to P-fixation by Fe^{2+}, Mn^{2+} and Al^{3+} and the oxides of Fe, Mn and Al.

In this study the DTPA extractable Fe and Zn from mixture woodlot system were within the acceptable range for plant growth while DTPA extractable Mn and Cu were above the acceptable range as suggested by Sims and Johnson (1991). The high levels of the DTPA extractable Mn and Cu in mixture woodlot system may be due to accumulation of organic matter in the soil surface which provided a favourable condition for availability of these elements. This is further supported by Bhandari and Rwandhawa (1985) who found that accumulation of organic matter and the decrease in soil pH were responsible for promoting the availability of micro-nutrients in the soils.

4.4.2 Woodlot systems on sloping land

The data on soil properties from three woodlot systems, which were identified on the sloping area, are presented on Table 5 and Appendix 6. Bulk density in Eucalyptus, Grevillea and

Wattle woodlot systems were 0.73, 1.13 and 0.9 g/cm^3, respectively. Total porosity in Eucalyptus, Grevillea and Wattle woodlot systems were 72, 54 and 63%, respectively. The bulk density is a reflection of compactness of the soils. Therefore, the low level of bulk density implies that the soil is not compacted at the moment, and hence it is free from the problems associated with compaction. The soil total porosity indicates that the soils are well aerated and well drained. The soils ranged from sandy clay to sandy clay loams in Eucalyptus, sandy clay loams in Grevillea and sandy clay in Wattle.

Soil pH from soils in eucalyptus, grevillea and wattle woodlot systems were 4.8, 5.2 and 4.5, respectively. According to Baize (1993) classification system, the soil pH in these three woodlot systems was classified as low. The low soil pH values in these woodlot systems may be due to great lignification or acidification of tree litter. Chavan *et al.* (1994) investigated the effect of forest tree species on soil properties and observed that tree litter reduced soil pH.

Organic carbon of soils from Eucalyptus, Grevillea and Wattle woodlot systems were 6.0, 2.9 and 4.9, respectively. The values were classified as medium (Landon, 1991). Soil organic carbon is a reflection of soil organic matter. Therefore, the medium level of soil organic carbon implies that there is an adequate amount of organic matter in the soil, which is attributed to the amount of leaf fall. The results are similar to those reported by Jaiyeoba (1996) who found that the high percentage soil organic carbon in the woodlots was due to the appreciable amount of organic matter in the soil which is attributed to leaf fall.

Cation exchange capacity of the soils from Eucalyptus, Grevillea and Wattle woodlot systems were 21.5, 21.8 and 17.0 Cmol(+)/kg of soil respectively. They were classified as medium (EUROCONSULT, 1989). The medium level of CEC implies that the soils from these woodlot systems can retain a satisfactory amount of plant nutrients. The medium level of CEC may be due to a satisfactory amount of organic matter in these woodlot systems which is attributed to leaf fall.

Exchangeable Ca, Mg, K and Na in Eucalyptus woodlot were 2.34, 0.34, 0.13 and 0.03 Cmol(+)/kg of soil, respectively. The levels were classified as low (Baize, 1993). Exchangeable Ca, Mg, K and Na in Grevillea woodlot system were 3.61, 1.04, 0.16 and 0.03 Cmol(+)/kg of soil respectively. Exchangeable Ca, Mg, K and Na in wattle woodlot system were 2.67, 0.74, 0.16 and 0.06 Cmol(+)/kg of soil, respectively. The content of exchangeable Ca and Mg in soils from grevillea and wattle woodlot systems were medium while that for K and Na were low (EUROCONSULT, 1989).

The low to medium levels of some exchangeable bases in grevillea, wattle and mixture woodlot systems suggests low to medium transfer of the ions from deeper horizons by the tree species to the surface of the soil layer. The low level of exchangeable bases in eucalyptus woodlot system may be due to slow rate of decomposition of leaf-litter and low content of these exchangeable bases in the leaf litter. The small amount of exchangeable Ca in eucalyptus suggests a greater rate of immobilisation as was also observed by Greenland and Nye, (1959)

Table 5: Comparison of soil properties among woodlot systems

Parameter	Woodlot system				CV%	LSD	SEM
	Eucalyptus	Grevillea	Wattle	mixture			
pH (water)	4.8 ^{ab}	5.2^{a}	4.5^{b}	4.8 ^{ab}	5.69	0.55	0.16
%OC	6.01^{a}	2.98^{b}	4.96 ^{ab}	5.02 ^{ab}	24.01	2.27	0.66
CEC Cmol(+) kg	22 ^{ab}	22 ^{ab}	17.00^{b}	24.00^{a}	14.2	5.99	1.73
Ca Cmol(+) kg	2.34 ^{a}	3.61^{a}	2.67^{a}	4.86^{a}	47.97	3.23	0.93
Mg Cmol(+)/kg	0.34^{b}	1.04^{a}	0.74^{a}	1.12^{a}	25.64	0.41	0.12
K Cmol(+) kg	0.13 ^{a}	0.16^{a}	0.17^{a}	0.15^{a}	14.28	0.02	0.01
Na Cmol(+) kg	0.03 ^{a}	0.03^{a}	0.05^{a}	0.05^{a}	80.18	0.06	0.02
%BS	14	22	21	26	27	0.12	0.05
%TN	0.34 ^{a}	0.21^{a}	0.30 ^{ab}	0.29 ^{ab}	19.53	0.12	0.03
P mg/kg	2.41^{ab}	4.59^{a}	2.27 ^{ab}	1.72^{b}	37.10	2.11	0.61
Fe mg/kg	4.22 ^{a}	2.70^{b}	2.99 ^{ab}	3.32 ^{ab}	19.42	1.28	0.37
Mn mg/kg	86^{b}	88^{b}	202^{a}	34^{c}	10	20.11	5.81
Zn mg/kg	2.85^{a}	0.32^{c}	2.20 ^{ab}	0.91^{bc}	55.59	1.74	0.50
Cu mg/kg	1.77^{bc}	1.23^{c}	3.48^{a}	2.91^{ab}	32.59	1.53	0.44
Bulk density g/cm^{3}	0.73^{b}	1.13^{a}	0.90^{b}	0.97^{b}	8.41	0.15	0.04

Note: within each row, the means carrying the same letter(s) are not significantly different at P=0.05

CV means coefficient of variation. LSD means least significant difference and SEM means standard error of means.

Total nitrogen in soils from Eucalyptus, Grevillea and Wattle woodlots systems were 0.34, 0.21 and 0.30%, respectively. These values were classified as medium according to Singh *et al.:* (1977). The observed medium level of total nitrogen may be due to appreciable input of organic matter.

Available P in soils from eucalyptus, grevillea and wattle woodlot systems were 2.41, 4.59 and 2.27 mg/kg of soil, respectively. The mean values are low according to Singh, *et al.:* (1977). The observed low level of available P may be due to low content of element P present in the tree litter and the slow rate of its release from organic residues. A study by Kasembe, *et al.:* (1983) on organic farming in Tanzania observed that available P is influenced by the rate of decomposition of organic materials. P- fixation by Fe^{2+}, Mn^{2+} and Al^{3+} and the oxides of Fe, Mn and Al is also a possible explanation.

In this study the DTPA extractable Fe from eucalyptus, grevillea and wattle woodlot systems was within the acceptable range for plant growth while DTPA extractable Mn was above the acceptable range. Extractable Zn was within the acceptable range in grevillea while in eucalyptus and wattle woodlot systems it was above the acceptable range. The DTPA extractable Cu in Eucalyptus and Grevillea woodlot systems was in acceptable range while in wattle and woodlot system was above the acceptable as suggested by Sims and Johnson (1991).

The high levels of the DTPA extractable Mn in both eucalyptus, grevillea, wattle and mixture woodlot systems, Zn in eucalyptus and grevillea and Cu in wattle and mixture woodlots may be due to low soil pH and accumulation of organic matter on the soil surface which provided a favourable condition for availability of these elements. This is further supported by Bhandari and Rwandhawa (1985) who found that accumulation of organic matter and the decrease in soil pH were responsible for promoting the availability of micro-nutrients in the soils.

4.4.3 Comparison of soil properties among woodlot systems

Data on comparison of some soil properties between woodlot systems are presented in Table 5. Soil properties on land under different tree species showed a wide variation. Soil pH. percentage total nitrogen and available P were significantly higher (P=0.005) in grevillea than in other woodlot systems. This may be due to the different amounts of organic material produced by the tree species. Chavan, *et al* (1995) observed that tree litter increased total nitrogen and available P. They further observed that soils under Eucalyptus tree contained high available P and exchangeable Mg, however in this study the opposite was true. This may be due differences in the age of Eucalyptus studied, soil characteristics and the history of land use.

The CEC in mixed woodlot system was significantly higher (P=0.05) than in other woodlot systems. Exchangeable Ca, Mg K and Na did not differ significantly (P=0.05) between the woodlot systems while exchangeable Mg was significantly lower (P=0.05) in Eucalyptus woodlot system than in other systems.

The average percentage Base Saturation (%BS) for Eucalyptus, Grevillea, Wattle and mixed were 13, 22, 21 and 26, respectively. The %BS are far below the critical value which is 50%.

This is an indication that these tree species are not good to be used for amelioration of soil fertility. The Eucalyptus has very low potential for restoration of soil fertility. These observation is supported by studies from Jaiyeoba (1996) who found that Eucalyptus has low capacity of restoring soil fertility and often has a negative influence on soil properties like lowering water table.

4.6 Soil physical and chemical properties under the fallow system

In this section two fallow systems are discussed, namely fallow one which is on summit and fallow two which is on the sloping area. The data on soil physical and chemical properties are presented in Table 6. Bulk densities values for fallow one and two were 0.71 and 0.84g/cm^3 respectively. The means of total porosity for fallow one and two were 72.40 and 67.37%. These data imply that the soils are not compacted and are therefore, free from problems associated with compaction. The soils from fallow one were sandy clays while those from fallow two ranged from sandy clay to sandy clay loams. In both cases the soils are well drained.

The soil pH values from soils in fallow one and two were 5.32 and 4.89 respectively and were classified as low according to Baize (1993). The low level of soil pH is likely to be associated with low nitrogen and P content in the soils. Other associated problems are deficiency of exchangeable bases (like Ca, K) and reduced growth and activity of some beneficial micro-organisms which are responsible for decomposition of organic mater. Soil organic carbon in the soils from fallow one and two were 3.99 and 3.89% respectively and were rated as low according to EUROCONSULT (1989). The low level of soil organic carbon in these fallow systems implies that the soil organic matter is also low.

Both fallow systems were 3 years old, and therefore were not old enough to yield much organic materials. Similar observations have been reported by Juo *et al.*: (1995) who found that the low soil organic carbon resulted from low organic matter input when the bush regrowth was still small. Furthermore Msaky *et al* (1996) observed that, the amount of organic carbon increases with an increase in vegetation cover which is the function of time, indicating an important contribution from the litter upon decomposition.

Table 6: Influence of fallow systems on soil properties

Parameter	Fallow in summit	Fallow in slope	CV %	LSD	SEM
pH (water)	5.32^{a}	4.89^{b}	0.8	0.16	0.03
%OC	3.99^{a}	3.89^{a}	8.58	1.19	0.19
CEC Cmol(+)kg	19.1^{a}	19.8^{a}	14.9	10.20	1.68
Ca Cmol(+)kg	3.59^{a}	1.88^{b}	9.67	0.93	0.15
Mg Cmol(+)kg	1.34^{a}	0.62^{b}	12.9	0.44	0.07
K Cmol(+)kg	0.12^{a}	0.17^{a}	43.1	0.22	0.04
Na Cmol(+)kg	0.02^{b}	0.03^{a}	24.3	0.01	0.02
%BS	26.54	13.64			
%TN	0.23^{a}	0.24^{a}	7.5	0.03	0.01
P mg kg	1.69^{b}	2.59^{a}	23.6	1.78	0.29
Fe mg kg	3.13^{a}	3.09^{a}	63.97	6.99	1.15
Mn mg kg	72.77^{b}	106.4^{a}	5.75	18.08	2.97
Zn mg/kg	0.34^{a}	0.65^{a}	100.3	1.75	0.29
Cu mg kg	2.21^{a}	2.66^{a}	49.21	4.21	0.69
Bulk density g/cm^{3}	0.73^{b}	0.86^{a}	1.84	0.03	0.01

Note: Within the row, the means with the same letter(s) are not significantly different (P=0.05)

CV means coefficient of variation. LSD means least significant difference. SEM means standard error of means

The cation exchange capacity of the soils from fallow one and two were 19.1 and 19.9 Cmol(+)/kg and were rated as medium according to a classification system established by Landon (1991). This medium level of CEC implies that the soil can moderately supply plant nutrients.

Exchangeable Ca, Mg, K and Na for fallow one were 3.59, 1.34, 0.12 and 0.02 Cmol(+)/kg respectively while means of exchangeable Ca, Mg, K and Na for fallow two were 1.88, 0.62, 0.17 and 0.03 Cmol(+) kg respectively. According to the classification established by Baize (1993) exchangeable Ca, K and Na for both fallow systems were classified as low while exchangeable Mg was classified as medium. The low levels of most exchangeable bases implies that the soil fertility status is low. Also the low level of these exchangeable bases may be due to leaching, soil erosion and low content of these exchangeable bases in the organic materials returned to the soil. The exchangeable bases are very important for crop production especial cereals and the low level will definitely lead to a very poor crop performance if these fallows will be used to produced crops.

The percentage base saturation in fallow one and two were 27 and 14, respectively. This also is an indication that the soil is infertile because the values are far below 50% critical level. Total nitrogen for fallow one and two were 0.23 and 0.24% and are thus low according to the classification system established by Singh *et al.;* (1977). The low level of total nitrogen may be due to low level of organic matter in the soils from these fallow systems. The observed effect of low organic matter on the availability of N is similar to the observation made by Heenan *et al.;* (1995) who found that the amount of total nitrogen in the soil depend on the quantity and quality of organic materials produced by that system.

Available P for fallow one and two were 1.69 and 2.59 mg/kg of soil and were classified as very low according to Singh et al.: (1977). The low level of available P may be due soil erosion and low P in parent materials.

Soil organic carbon. CEC exchangeable K and total N did not vary significantly (P=0.05) between the two fallow systems. Soil pH. and exchangeable Ca and Mg in fallow one were significantly higher (P=0.05) than in fallow two. The opposite was true for exchangeable Na and available P.

In fallow one the DTPA extractable Fe. Mn. Zn and Cu were 3.13. 73. 0.34 and 2.21 mg/kg of soil while the means of DTPA extractable Fe. Mn. Zn and Cu from fallow two were 3.09. 106. 0.65 and 2.66 mg/kg of soil respectively. The DTPA extractable Fe. Zn and Cu for both fallow systems were within the acceptable range while available Mn was above the normal range for plant growth and development (Sims and Johnson 1991). DTPA extractable Fe. Zn. and Cu did not differ significantly (P=0.05) between the fallow systems while the DTPA extractable Mn was significantly lower (P=0.05) in fallow system one than in fallow system two. The high level of DTPA extractable Mn was due to low soil pH. which favour the dissolution of Mn compound in the soils. The high level of extractable Mn will affect the growth of most plants and sometimes interfere the uptake of other plant nutrients. for example uptake and translocation of Fe in plants.

It can be concluded from this study that the fallow did not improve the soil fertility of degraded land. This may be due to the fact that the fallows were young.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

On the basis of the present study and findings. the following tentative conclusions can be drawn:

1. Soils from all cropping systems were acidic with low to medium soil organic matter and nutrient supplying power. This was especially so for available P. total nitrogen. exchangeable Mg and K
2. Most of soil chemical properties were significantly ($p=0.05$) lower in tea monoculture cropping systems than in coffee/banana and maize/beans cropping systems.
3. The DTPA extractable Zn was within the acceptable range for crop growth and development on all cropping systems. Available Cu was within the range except in coffee/banana cropping system that was above the critical values. This may be due to continuous application of Cu containing fungicides. The DTPA extractable Fe and Mn were above the critical value for plant growth in all cropping systems in sloping land.
4. Extractable DTPA-Fe. Mn and Cu in the valley bottoms that are under vegetable production were above the critical level for plant growth except for Zn which was within the acceptable range. This situation may lead to toxicity if the amounts of Fe, Mn and Cu continue to accumulate.
5. Soil properties differed in the four woodlot systems but were not significantly different. Except for Eucalyptus, other tree species showed superiority in one or more soil properties. This may be due to the nature and amount of organic matter produced. The fate of decomposition and amount of plant nutrients released depended on the tree

species. Soils in the Eucalyptus had low levels of nutrients, which suggests that the tree has low potential for amelioration of soil fertility compared to other tree species.

5.2 Recommendations

From the study the following recommendations can be made

1. Soil erosion control practices are the most important aspect of land management in all systems which are found in sloping lands. It is therefore recommended that farmers should start adopting erosion control measures like the construction of contour bunds and terraces. The use of cut-off drains is recommended especially for coffee/banana and tea cropping systems.
2. The use of Cu fungicides in coffee and vegetable production should be done with caution and if possible an integrated pest management strategy be used.
3. The fallow period should be shortened by replacing bush or natural regenerated fallow with planted fallow systems. However, planted fallow systems should include several species with different rooting systems and growth rates in order to combine the advantage of rapid ground coverage with efficient biological N fixation and cycling of subsoil plant nutrients from deep rooted species.

REFERENCE

Agboola. A.A (1975) *Problems of improving soil fertility by use of green manuring in the tropical farming systems.* FAO Soils Bulletin No.27, 147-164

Akinsanmi. O (1975) *Certificate Agriculture Science.* Longman Group Ltd. London.

Alegre J.C and D.K. Cassel (1986) effect of land clearing methods and post clearing management on aggregate stability and organic matter content of a soil in the humid tropic. *Soil Science.* 142(5). 289-295

Alexander. M.J. (1986)*Soil characteristics and factors influencing their development on mine spoil of the Jos plateau.* Jos Plateau Environmental Resource Development. Interim Report.

Allison. F.E (1973)Soil organic matter and its role in crop production. *Development in Soil Science.* No 3, Elsevier Amsterdam.

Alloway, B.J and D.C Ayres (1990) *Chemical Principles of Environmental Pollution.* 1st Edition Blackie Academic and Professional. Glasgow, London Pp 291

Amani. H.K.R. (1992) Agriculture Market Reforms in Tanzania. Evolution Performance and Future Policy Issues. In: *Market Reforms and Parastatal Restructuring in Tanzania.* Economics Department and Economics Research Bureau. Dar es salaam.

Baize. D (1993) *Soil Science Analysis. A guide to current use.* John Wiley and Sons Limited. West Sussex

Barrios, E., R.S.Buresh and J.I. Spent (1996) Nitrogen mineralization in density fraction of soil organic matter from maize legume cropping systems. *Soil Biology and Biochemistry* 28, 1459-1465.

Chatterjee, B.N, B. Maiti and B.K. Mandal (1986) *Cropping System: Theory and Practice*. 2nd Ed. Oxford and IBH Publishing Co. PVT. Ltd. New Delhi.

Chavan, K.N, R.Y Kenjale and A.S. Chavan (1995) Effect of forest tree species on properties of Lateristic soil. *Journal of Indian Society of Soil Science*. 43, 43-46

Cogle,A.L., J.Littlemore and D.H.Heiner (1995). Soil organic matter changes and crop responses to fertilizer under conservation cropping systems in the semi-arid tropical of North Queensland. *Australian Journal of Experimental Agriculture* 35, 233-237.

Costantin,A., D.Cosentino and A.Segat (1996). Influence of tillage systems on biological properties of a Typic Argiudoll soil under continuous maize cultivation in central Argentina. *Soil and Tillage Research* 38, 265-271.

Dallland,A., P.I.Vaje, R.B.Marterns and B.R.Singh (1993). The potential of alley cropping in environment of cultivation systems in the high rainfall areas of Zambia, III. Effect on soil chemical and physical properties. *Agroforestry Systems*. 21, 117-132.

Dao. T.H. (1996) Tillage system and crop residue effect on surface compaction of a Paleoustoll. *Agronomy Journal*, 88, 141-148

Davies. D.B (1982) Soil Management. 4th Edition. Farming press Ltd. Suffolk. PP 287

Dey. S.K (1969) A study of some soils from Assam, central and east African tea areas. *Two and A Bud*. 16(2), 65-69

Dregne, H.E. (1990) Erosion and productivity in Africa. *Journal of Soil and Water Conservation*, 47,8-13

Emerson, W.W (1995). Water retention , organic carbon and soil texture. *Australian Journal of Soil Research* 33, 241-351

EUROCONSULT, (1989) *Agriculture compendium for rural development in the tropics and subtropics*. Elsevier Science Publishers, Amsterdam. Pp 740

Food and Agriculture Organization (FAO) of United Nations (1998) *World Reference Base for Soil Resources* (WRB). World Soil Resources Reports. Rome. Pp 134

Food and Agriculture (FAO) of the United Nations (1990). *Guidelines for Soil Description.* Third edition, Rome. Pp70

Food and Agriculture Organization (FAO) of United Nations, (1978) *Organic material and soil productivity.* FAO Soil Bulletin Number 40. Rome. Pp 107

Franzluebbers.A.J and M.A.Arshad (1996). Soil organic matter pools during early adoption of conservation tillage in Northern Canada. *Soil Science Society of American Journal* 60,1422-1427.

Franzluebbers.A.J, F.M.Hons and D.A.Zuberer (1994) Long term changes in soil carbon and nitrogen pools in wheat management systems. *Soil Science Society of American Journal* 58,1639-1645.

Friedel, J.K. J.C Munch and W.R.Fischer (1996). Soil microbial properties and the assessment of available soil organic matter in a Hyplic Luvisol after several years of different cultivation and crop rotation. *Soil Biology and Biochemistry* 28, 479-488.

Gardner, W.H (1986) Water Content. In: *Methods of Soil Analysis. Part 1, 2nd edition. (Edited by Klute, A).* Agronomy Monograph No 9 SSSA. Wisconsin.

Gee, G.W and J.W Bauder, (1986) Particle Size Analysis. In: *Methods of soil analysis. Part1 2nd edition. (Edited by Klute, A.).* Agronomy Monograph No 9 SSSA. Madison. Wisconsin. pp 383-412

Ghodrati, M.L (1995) Transport of nitrate in the soil as affected by earthworm activities. *Journal of Environmental Quality.* 24(3), 432-438

Grant, R.F, R.C. Izaurralde and D.S. Chnasyk (1995) Soil temperature under different surface management; testing a simulation model. *Agriculture and Forest Meteorology.* 73,89-113

Greenland, D.J (1981) Soil Management and Soil Degradation. *Journal of Soil Science*, 32: 301-322.

Greenland, D.J and P.H Nye (1959) Increase in the carbon and nitrogen contents of tropical soils under natural fallow. *Journal of Soil Science*, 10, 284-299

Gupta, V.V.S.R. M.M.Roper, J.A.Kirkeguard and J.F.August (1994). Changes in microbial biomass and organic matter levels during the first year of modified tillage and stubble management practices on a red earth. *Australia Journal of Soil Research* 32, 1339-1354.

Heenan, D.P. W.J. McGhie, F.M. Thomason, and K.Y. Chan (1995) Decline in soil organic carbon and total nitrogen in relation to tillage, stubble management and rotation. *Australian Journal of Experimental Agriculture*. 35, 877-884

Helalia, A.M. (1993) The relation between soil infiltration and effective porosity in different soils. *Agricultural Water Management*. 24(1), 39-47.

Hesse, P.R. (1984) *A text book of soil chemical analysis*. John Murray Ltd. London. pp 388.

Hillel, D. (1982) *Introduction to Soil Physics*. Academic Press, Inc. London.

Hoffman, C.A. and C.R. Carroll (1995) *Can we sustain the biological basis of agriculture?*. Annual Review of Ecology and Systematics 26, 69-92.

Jaiyeoba, I.A (1996) Amelioration of soil fertility by woody perennial in cropping fields: evaluation of three tree species in the semi-arid zone of Nigeria. *Journal of Arid Environment*. 33, 473-482

Jones, A.M (1994) *Auxin-binding protein*. Annual Review of Plant Physiology and Plant Molecular Biology 45,393-420.

Juma, N.G (1993). Interrelatioships between soil structure/texture, soil biota/soil organic matter and crop production. *Geoderma* 57, 3-30

Juo. A.S.R. K. Frankluebbers. A. Dabiri and B.Ikhile (1995) Changes in soil properties during long-term fallow and continuous cultivation after forest cleaning in Nigeria. *Agriculture, Ecosystems and Environment.* 56, 9-18

Karl. M.M.S. and K.Johannes (1994) *Sustaining Growth. Soil Fertility Management in Tropical Small Holdings.* Weikersheim. Germany. Pp 486

Kasembe, J.N.R. J.M.R.Semoka and J.K.Samki (1983). Organic farming in Tanzania. In: *Proceeding of workshop on Resource Efficient Farming Methods for Tanzania. (Edited by Michael Brusko).* 16-20 May. 1983. Rodale press. Pp 128

Khanna. P.K. R.J. Raison and R.A (1994) Chemical properties of ash derived from Euclyptus litter and its effects on forest soils. *Forestry Ecology and Management.* 66, 107-125

Kileo. E.P. (2000) *Land suitability assessment of the Wami plains in Morogoro, Tanzania with respect to the production of the main food crops and extensive grazing.* MSc dissertation. Sokoine University of Agriculture. Morogoro, Tanzania. Pp 152.

Knott, J.E (1980) *Knott's Handbook for Vegetable Growers.* John Willeys and Sons, New York. Pp 390

Koudokpon.V.J.Brouvers, M.N. Verteeg and A.Budelman (1994) Priority setting in research for sustainable land use: the case of the Adja Plateau Benin. *Agroforestry systems* 26, 101-122.

Lal. R. (1990) *Soil Erosion in the Tropical: Principle and Management.* McGraw Hill Inc. New York. Pp 580.

Lal, R, B.T.Kang, F.R. Moorman, A.S.R. Juo and J.C. Mooman (1975) Soil management problems and possible solutions in Western Nigeria. In: *E. Bornemisza and A. Alvarado (eds). Soil management in Tropical America.* North Caroline State University. Raleigh.

Landon, J.R. (1991) *Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in Tropical and Subtropical*. Longman, Sussex

Le Mare, P.H (1991) Rock phosphate in agriculture. *Experimental Agriculture*. 27, 413-422

Lee, J.J, D.L.Phillips and R.Liu (1993) The effect of trends in tillage practices on erosion and carbon content of soil in the US corn belt. *Water, Air and Soil Pollution* 70, 389-401.

Leffelaar, P.A. (1993) Water movement, oxygen supply and biological processes in the aggregate scale. *Geoderma*, 57, 143-167

Lindsay, W.L and W.A Novell (1978) Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America*. 42, 421-428

Low, A.J (1972) The effect of cultivation on the structure and physical properties of grasslaand and arable soils. *Journal of Soil Science* 23: 363-380

Lyamchai.C, M. Owenya, P. Ndakidemi and N. Massawe (1998) *A Participatory Rural Appraisal in Kwalei Catchment, Lushoto District, Tanzania (edited by S.D Lyimo and R.V. Ndondi)* Selian Agricultural Research Institute, Arusha.

Mabbett, T (1999) Brimstone brightens the brew. In: *African and Food Processing*. Novembe/December isssue. 17-18

Mabula, C.L (1999) *Evaluation of the Application of Rice Milling by-product Mixture and Fertilizer Nitrogen on Yield of Flooded Rice at Simbo, Igunga District,Tanzania.* MSc.Thesis. Sokoine University of Agriculture, Tanzania. Pp 120.

Macharia, D.W, W.Moll and P.A. Kamau (1996). Relation of some chemical properties to soil erodibility of some south weatern Kenyan soils. *African Crop Science Journal* 4, 185-196.

MaClean, E.O (1982) Soil pH and lime requirement. In: *Methods of soil analysis. Part 2. Agronomy Monograph No 9 (Edited by A.L. Page, R.H. Mller and D.R.Keeney).* American Society of Agronomy. Madison. Wisconsin. pp 199-224.

Magoggo, J.P, B.M. Msanya and D.N Kimaro (1996) *Environmental profile for agricultural production and development of conservation strategies in Mahenge village, Mbinga District, Tanzania.* Miombo Woodland Research Project. Natural Resource Study Team. Technical Report 3. Pp 38

Mango, N.A.R. (1999) *Integrated soil management in Siaya district, Kenya.* Managing Africa's Soil No 7. Edinburgh, U.K. pp 34.

Marshner, (1986) *Mineral Nutrition of Higher Plants.* Academic press.London.Pp 674.

Marterns, D.A. J.B.Johanson and W.T.Frakenberger (1992) Production and persistence of soil enzymes with repeated addition of organic residues. *Soil Science* 153, 53-61.

Miller, R.W and R.L.Donahue (1992) *Soils: An Introductio to Soil and Plant Growth.* 6th Edition. Prentice-Hall of India Private Limited, New Delhi.Pp 768

Mkindi, G.I (1990) *Effect of spraying coffee with copper fungicides on the copper status of soils of Moshi district, Tanzania.* MSc dissertation, Sokoine University of Agriculture, Morogoro.

Morgan, R.P.C. (1995) *Soil erosion and conservation.* Longman group. Essex. Pp 198

Motavalli, P.P, C.A.Palm, W.J.Parton, E.T.Elliott and S.D.Frey (1995). Soil pH and organic dynamics in tropical forest soils: Evidence from laboratory and simulation studies. *Soil Biology and Biochemistry* 27, 1589-1599.

Msaky, J.J.T, S. Araki and A. Israel (1996) Nutrient dynamics in traditional farming systems in Mbinga District, Tanzania. In: *Proceedings of the 15th Annual General Meeting of Soil*

Science Society of East Africa. Sportman's Arms Hotel from 19-23/8/1996. Nanyuki. Kenya. 38-43

Munsell Colour Company (19975) *Munsell Soil Colour Charts.* Bartimore Maryland. United States.

Mwalilino. J.K (1997) *Assessment of heavy metals accumulation in soils of vegetable growing areas of Mbeya district, Tanzania.* MSc dissertation. Sokoine University of Agriculture. Morogoro.

Nelson. D.W and L.E. Sommers. (1982) Organic Carbon . In: *Methods of soil analysis. Part 2. Agronomy Monograph No 9 (Edited by A.L. Page. R.H. Mller and D.R.Keeney).* American Society of Agronomy. Madison. Wisconsin.

Nyambo. D.B. T. Matimati, A.L.Komba and R.K.Jana (1980) Influence of plant combination and planting configuration on three cereals (Maize. sorghum and millet) intercropped with two legumes (Soybean and greengram). In: *C.L.Keswai and B.J. Ndunguru Eds). Proceeding of the 2nd symposium on intercropping in semi arid areas held in Morogoro,* Tanzania. PP 56-62.

Oborn,I., G. Jahsson and L.Johnsson (1995). A field study on the influence of soil pH on trace element levels in spring wheat (*Triticum aestinum*),potatoes (*Solanum tuberosum*) and carrots (*Daucus carota*). *Water. Air and Soil Pollution* 85, 835-840.

Okalebo, J.R., K.W. Gathua and P.L. Woomer (1993) *Laboratory methods of soil analysis.* A working manual. KARI. Nairobi, Kenya.

Okigbo, B.D and D.J. Greenland (1976) Intercropping system in tropical Africa. In *R.I. Pappendick et al., (Eds), Multiple Cropping Symposium. American Society of Agronomy.*

Olasantan, F.O. H.C. Ezumah and E.O. Lucas (1996) Effect of intercropping maize on the micro-environment, growth and yield of cassava. *Agriculture, Ecosystem and Environment.* 57,149-158

Olsen, S.R. and L.E. Sommers (1982) Phosphorous. In: *Methods of soil analysis part 2. Agronomy Monograph No 9 (Edited by A.L. Page, R.H. Mller and D.R.Keeney).* American Society of Agronomy. Madson. Wisconsin. PP9 14-925

Othieno, C.O (1992) *Soils: In: Tea cultivation to consumption.* Chapman and Hall, London. Pp 137-172

Pagliai,M. And V.Antisari (1993) Influence of waste organic matter on soil micro and macrostructure. *Bioresource Technology* 43, 205-213.

Palm, C.A, K.E Giller and M.J. Swift (2000) *Soil organic matter: An overview.* The Biology and Fertility of Tropical Soils. TSBF Report 1997/1998, 46-48

Parr, J.F and R.I Papendick (1978) Factors affecting decomposition of crop residues by micro-organisms. In: *Crop Residue Management Systems. American Society of Agronomy Special Publication,*No 31 101-127

Parvathappa, H.C, B.S. Murthy (1994). Effect of different land uses on water retention capacity of Alfisols in Kabbalanala watershed of Karnataka. *Journal of the Indian Society of Soil Science,* 42, 128-130

Peters,D.B.(1986) Determination of Field Capacity. In: *Methods of soil analysis part Edited by C.A. Black.* Agronomy Monograph No 9. American society of Agronomy. Madison. Wisconsin. pp 281.

Renault, P.,J. Sierra and P. Stengel (1994) Oxygen transport and anaerobiosis in aggregated soils. Contribution to the study of denitrification. *Agronomy* 14, 395-409

Lieffering, R.E and C.D.A Mclay (1996) Effect of high PH solutions with large monovalent cation concentratins on cation exchange properties. *Australian Journal of Soil Research.* 34, 229-242

Riffald, R., A. Saviozzi, M.R. Aevi and F.Menchetti (1994a). Chemical characteristics of soil after 40 years of continuous maize cultivation. *Agriculture, Ecosystems and Environment* 49, 239-245.

Russell, (1973) *Soil Condition and Plant Growth.* 10th Edition. Longman, London

Sanchez,P.A (1976) *Properties and management of soils in the tropics.* John Wiley and Sons. New York. Pp 618

Sandanam, S.S, S. Krishnapillai and J. Sabaratnam (19978) Nitrification of ammonium sulphate and urea in acid yellow podzolic tea soils in Sri-Lanka in relation to soil fertility. *Plant and Soils.* 49, 9-22

Scott, N.A, C.V.Cole, E.T.Elliott and S.A.Huffman (1996). Soil textural control on decomposition and soil organic matter dynamics. *Soil Science Society of America Journal* 60, 1102-1109.

Sims J.T and G.V. Johnson (1991) Micronutrient soil test. In: Micronutrient in Agriculture. (Edited by Mortvedt, J.J, Cox, F.R, Shuman, L.M and Welch, R.M). *Society of Soil Science of America.* Madison, Wisconsin. Pp 435-449

Singh, B.R, A.P Uriyo, P.N.S Mnkeni and J.J.T Msacky (1977) Evaluation of indices of nitrogen and phosphorous availability for the soils of Morogoro, Tanzania. In: *proceeding of the conference on classification and management of tropical soils.* Kuala Lumpur, Malaysia. 273-278

Soil Survey Staff (1998) *Keys to Soil Taxonomy.* 8th Edition. United States Department of Agriculture, Natural Resource Conservation Service. Pp 328

Stocking. M.A (1994) *Erosion and soil productivity. A Review*. Consultants Working Paper No.1. FAO. Soil Conservation Management Programmes. Land and Water Development Division. Rome. Pp 102

Stott. D.E. L.F. Elliott. R.I Papendick and C.S Cambell (1986) Low temperature or low water potential effects on the microbial decomposition of wheat residue. *Soil Bioloby and Biochemistry*. 18, 577-582

Tandon. H.I.L (1969) *Methods of analysis of soils, plants and fertilizers*. Fertilizers Development and Consultation Organization, New Delhi. India. Pp 144

Tavant. Y.. H.Tavant and S.Bruckert (1994) Variation in organic carbon as a function of soil properties and elevation in jura (france). *Geoderma*. 61. 133-141.

Tester C.F (1990) Organic amendment effects on physical and chemical properties of a sandy soil. *Soil Science Society of American Journal* 54, 827-831

Thiessen, H and J.W.B.Stewart (1983) Particle size fraction and their use in studies of soil organic matter:II. Cultivation effect on organic matter composition in size fractions. *Soil Science Society of American Journal* 47, 509-514.

Thompson, L.M and F.R. Troeh (1985) *Soil and Soil Fertility*. 4th Edition. Tata MacGran-Hill Publishing Company Ltd, New York. Pp 516

Tindall. H.D (1983) *Vegetable in the tropical*. MacMillan Education Ltd. Hong Kong. Pp 533

United Republic of Tanzania (URT), (1994) *Statistical Abstract 1992*. Bureau of Statistics, President's, Planning Commission . Dar es salaam.

Uriyo, A.P, H.O. Mongi, M.S. Chowdhury, B.R. Singh and J.M.R. Semoka (1979) *Introductory Soil Science*. Tanzania Publishing House. Dar es salaam, Tanzania.

VanDyk, J (1999) *Intergrated Crop Management. Department of Entomology*. Iowa State University. Ames, Iowa

Wilson, C.K (1969) *The mineral nutrition of tea. Potash Review* Subject 27, 4th Suite. Pp 1-17.

Woomer, P.L.,A.Martin,A. Albrecht, D.V.S.Resck and H.W.Scharpenseel (1994) The importance and management of soil organic matter in tropics. In: *The Biological Management of Tropical Soil Fertility (Edited by Wommer, P.L.and Swift, M.J)*. John Wiley and Sons. New York. Pp 47-80.

APPENDICES

Appendix 1: Soil properties under tea monoculture cropping system

PARAMETER	Replicate 1	Replicate 2	Replicate 3	MEAN
pH (water)	4.64	5.09	4.81	4.9
%OC	2.01	2.46	2.12	2.2
CEC Cmol(+)/kg	9.73	13.2	11.33	11.4
Ca Cmol(+)/kg	1.10	2.02	1.71	1.6
Mg Cmol(+)/kg	0.32	0.77	0.61	0.6
K Cmol(+)/kg	0.11	0.16	0.16	0.14
Na Cmol(+)/kg	0.004	0.019	0.028	0.02
%Base saturation	16	23	22	20
%TN	0.10	0.15	0.21	0.15
P mg/kg	6.02	2.41	2.55	3.7
Fe mg kg	400	31	36.21	156
Mn mg/kg	72	45	52	56
Zn mg kg	0.51	0.29	0.78	0.5
Cu mg kg	1.62	1.95	2.10	2
Bulk density g/cm^3	1.16	1.19	1.09	1.2
Sandy %	73	70.	70	71
Silt %	4.5	5.	5	4.8
Clay %	23	25	25	24.3
Textural Class	SCL	SCL	SCL	

Appendix 2: Soil properties under coffee/banana cropping system

PARAMETER	Replicate 1	Replicate 2	Replicate 3	MEAN
pH (water)	5.63	5.96	5.95	5.8
%OC	4.65	4.21	5.07	4.6
CEC Cmol(+)/kg	20.40	23.00	.27.47	23.6
Ca Cmol(+)/kg	8.39	8.67	10.18	9
Mg Cmol(+)/kg	2.37	2.56	2.35	2.4
Kcmol(+)/g	0.53	0.69	0.39	0.5
Na Cmol(+)/kg	0.05	0.09	0.03	0.1
%Base saturation	56	52	47	52
%TN	0.35	0.32	0.32	0.3
P mg kg	6.47	3.94	3.66	4.7
Fe mg kg	31	30	26	29
Mn mg/kg	122	141	114	126
Zn mg kg	0.81	1.44	1.74	1.3
Cu mg kg	3.24	3.15	4.47	3.6
Bulk density g/cm^3	0.95	0.92	0.96	0.9
Sandy %	62	61	60	61
Silt %	4.67	5.17	6.17	5.4
Clay %	34	34	34	34
Textural Class	SCL	SCL	SCL	

Appendix 3: Soil properties under maize/beans cropping system

PARAMETER	Replicate 1	Replicate 2	Replicate 3	MEAN
pH (water)	5.75	5.75	6.28	6
%OC	3.82	3.82	4.211	4
CEC Cmol(+)/kg	24.53	24.53	22.2	24
Ca Cmol(+)/kg	7.06	7.06	11.60	8.6
Mg Cmol(+)/kg	1.95	1.95	2.52	2
K Cmol(+)/g	0.20	0.20	0.28	0.2
Na Cmol(+)/kg	0.03	0.03	0.05	0.04
%BS	38	38	65	47
%TN	0.25	0.25	0.29	0.3
P mg/kg	2.7	2.7	1	2
Fe mg/kg	12	6	7	8
Mn mg/kg	80	135	125	133
Zn mg/kg	0.75	0.53	0.41	0.6
Cu mg/kg	1.1	1.6	1.3	1.3
Bulk density	0.79	0.88	0.82	0.8
Sandy %	58	56	59	58
Silt %	4.67	6.5	5.67	5.6
Clay %	38	38	35	37
Textural Class	SCL	SCL	SCL	

Appendix 4: Some soil physical and chemical properties under four valleys which are used for vegetable production

PARAMETER	Valley 1	Valley 2	Valley 3	valley 4
pH	5.85	5.97	5.30	5.58
%OC	3.76	3.63	4.18	4.31
%OM	6.47	6.25	7.19	7.42
CEC Cmol(+)/kg	19	19	18	23
Ca Cmol(+)/kg	6.27	7.33	3.50	5.98
Mg Cmol(+)/kg	1.93	2.25	1.63	2.04
K Cmol(+)/kg	0.33	0.34	0.35	0.17
Na Cmol(+)/kg	0.09	0.37	0.18	0.21
%Base saturation	46	54	31	37
%TN	0.28	0.28	0.27	0.27
P mg kg	6.72	5.09	4.9	5.4
Fe mg kg	8.64	7.58	10.59	5.73
Mn mg/kg	100	107	97	107
Zn mg kg	1.78	1.69	1.95	1.66
Cu mg/kg	8.05	7.65	7.45	7.42
Bulk density g/cc	0.91	0.84	0.85	0.92
% Sand fraction	71	66	68	68
% Silt fraction	5.33	6.33	8.83	7.00
%Clay fraction	23	27	24	26
Textural class	SCL	SCL	SCL	SCL

Appendix 5: Soil properties from woodlot system on summit land.

Soil properties	Replicate 1	Replicate 2	Replicate 3	MEAN
pH (water)	5.40	4.98	4.96	5
%OC	5.25	4.94	4.86	5
%OM	9.04	8.50	8.36	8.6
CEC Cmol(+) kg	23.00	24	25	24
Ca Cmol(+)/kg	3.53	3.64	7.42	5
Mg Cmol(+)/kg	1.13	1.10	1.12	1
K Cmol(+)/kg	0.15	0.16	0.16	0.15
Na Cmol(+)/kg	0.06	0.09	0.01	0.05
%Base saturation	21	21	35	26
%TN	0.22	0.32	0.34	0.3
P mg/kg	1.69	2.00	1.43	1.7
Fe mg kg	2.42	4.38	3.17	3.3
Mn mg/kg	23.36	35.14	43	33.8
Zn mg kg	1.06	0.16	1.52	0.9
Cu mg/kg	2.44	3.10	2.56	2.7
Bulk density g/cc	1.03	1.04	0.80	1
% Sand	64	64	66	64.7
% Silt	5.00	6.00	4.00	5
% Clay	31	30	30	30
Textural class	SCL	SCL	SCL	

Appendix 6: Soil properties from woodlot systems on sloping land

	Eucalyptus			Grevillea			Wattle		
Paramete	R1	R2	R3	R1	R2	R3	R1	R2	R3
PH	4.82	4.63	4.91	5.63	5.02	4.99	4.47	4.62	4.57
%OC	3.53	6.43	8.08	2.58	3.61	2.74	4.23	5.41	5.25
%OM	6.07	11.06	13.89	4.45	6.20	4.72	7.28	9.31	9.04
CEC Cmol(+)/kg	20.2	16.2	28.2	23.40	20.80	21.40	18.40	15.40	17.20
Ca Cmol(+)/kg	1.24	3.39	2.40	4.34	3.28	3.19	4.27	1.11	2.63
Mg Cmol(+)/kg	0.26	0.12	0.64	1.32	0.86	0.93	1.10	0.47	0.69
K Cmol(+)/kg	0.15	0.09	0.16	0.17	0.17	0.16	0.16	0.16	0.16
Na Cmol(+)/kg	0.01	0.01	0.08	0.05	0.04	0.03	0.08	0.06	0.07
%TN	0.27	0.30	0.46	0.18	0.24	0.20	0.31	0.29	0.29
P mg/kg	2.03	1.76	3.45	3.04	5.49	5.23	3.72	1.95	2.33
Bulk density g/cc	0.71	0.70	0.74	1.17	1.08	1.06	0.86	0.94	0.85
%Clay	36.8	36.2	32.2	21.6	24.6	24.6	37.3	37.2	39.3
%Silt	5	4	5	4	4	4	3.5	5	3.5
% Sand	58.20	59.80	62.80	74.40	71.40	71.40	59.20	57.80	57.20

Appendix 7: Description of soil profilePFK1 on summit area

Profile number : PFK1 Mapping unit: summit
Region : Tanga
District : Lushoto
Location :Kibaoni subvillage 50 m west of Bumbuli road
Elevation 1320 m asl. Parent material: metamorphic rocks. Landform: mountain; steeply dissected. Slope: 2 %; straight
Surface characteristics : Erosion: . Deposition: none.
Natural drainage class : well drained
Described on 22/04/00

Soils are deep, well drained dark brown sandy clay topsoil over dark reddish brown clayey.

Ap: 0 - 20 cm: dark brown (7.5YR3/4) dry, very dark brown (7.5YR2.5/3) moist; slightly stony sandy clay; soft dry, friable moist, sticky and plastic wet; strong fine and very fine subangular blocks; many fine and common medium pores; very few medium irregular fresh quartz fragments; many fine and medium roots; clear wavy boundary to

Bw: 20 - 55 cm: dark reddish brown (2.5YR3/4) moist; clay; friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; few fine and many very fine pores; very fine and few medium roots; clear smooth boundary to

C: 55 cm+ weathering rocks

Soil classification: Umbric-Endoleptic Lixisols (FAO)
Typic Rhodudalfs (USDA)

Analytical data

Horizon	Ap	Bt	C
Depth (cm)	0-20	20 - 55	55+
Clay %	42.8	57.4	
Silt %	3.8	6.8	
Sand %	53.4	35.8	
Textural class	SC	SCL	
Bulk density g/cc	1.1	1.3	
pH (H2O)	5.32	4.99	
Organic carbon %	2.45	1.2	
Total nitrogen %	0.16	0.12	
Avail P Bray-1 mg/kg	4.41	2.326	
CEC Cmol(+)/kg	10.6	16.80	
CEC of clay Cmol(+)/kg	5.05	22.05	
Exch. Ca cmol(+)/kg	1.03	6.01	
Exch. Mg cmol(+)/kg	1.27	1.53	
Exch. K cmol(+)/kg	0.28	0.66	
Exch. Na cmol(+)/kg	0.06	0.14	
TEB cmol(+)/kg	2.64	8.33	
Base saturation %	34.70	60.40	
DTPA extractable Fe mg/kg	36.20	61.30	
DTPA extractable Mn mg/kg	82.00	20	
DTPA extractable Zn mg/kg	0.02	0.62	
DTPA extractable Cu mg/kg	2.3	2.26	

Appendix 8: Description of soil profile PFK2 on sloping land

Profile number : PFK2 Mapping unit: Slope
Region Tanga
District : Lushoto
Location Kwaboma subvillage 15 m Northwest of Bumbuli road
Elevation 1279 m asl. Parent material: metamorphic rocks. Landform: mountain; steeply dissected. Slope: 35 %; straight
Surface characteristics : Erosion: . Deposition: cm.
Natural drainage class : well drained
Described on 22/04/00

Soils are very deep, well drained, very dark brown loamy top soil over dark brown to dusky red clayey

Ap: 0 - 20 cm: dark brown (7.5 Y3/4) dry, very dark brown (7.5 Y2.5/3) moist; clay loam; slightly hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; many fine and common medium pores; frequent small irregular fresh quartz fragments; many fine and few coarse roots; clear wavy boundary to

AB 20 - 75 cm: dark brown (7.5 Y3/3) dry, dark brown (7.5 Y3/2) moist; sandy clay; friable moist, sticky and plastic wet; strong fine and very coarse subangular blocks; many fine and common medium pores; very few small irregular slightly weathered fragments; common fine and coarse roots; clear wavy boundary to

Bs 75 - 105 cm: dark red (10 R3/4) moist; sandy clay; friable moist, sticky and plastic wet; moderate medium subangular blocks and strong fine; many fine and medium pores; very few small irregular slightly weathered quartz fragments; common fine and coarse roots; gradual irregular boundary to

Bt 105 - 135 cm: dark red (10 R3/3) moist; clay; friable moist, sticky and plastic wet; moderate coarse and medium subangular blocks; common fine and few medium pores; common fine and few very coarse roots; clear smooth boundary to

2Ab 135 - 160 cm: dark red (10 R3/3) moist; clay; firm moist, very sticky and very plastic wet; weak coarse and medium subangular blocks; fine and many very fine pores; common fine and few very fine roots; clear smooth boundary to

C: 160 cm + weathering rocks.

Soil classification: Orthietri-Humic Fluvisols (FAO)
Mollic Udifluvents (USDA)

Soil profile analytic data

Horizon	Ap	AB	Bs	Bt	Ab	C
Depth (cm)	0-20	20-75	75-105	105-135	135-160	160+
Clay %	43.8	42.8	42.8	38.8	38.8	
Silt %	2.8	2.8	2.8	3.8	4.8	
Sand %	53.4	54.4	54.4	57.4	56.4	
Textural class	SC	SC	SC	SC	SC	
Bulk density g/cc	1.1	1.1	1.1			
pH (H2O)	5.22	5.37	5.69	5.62	5.35	
Organic carbon %	2.3	1.44	1.757	2.42	3.62	
Total nitrogen %	0.063	0.087	0.22	0.09	0.2	
Avail P Bray-1 mg/kg	0.66	2.835	4.3	2.52	6.96	
CEC Cmol(+)/kg	9.82	9.00	8.21	10.02	11.82	
CEC of clay Cmol(+)/kg	4.36	9.40	4.98	4.30	12.60	
Exch. Ca cmol(+)/kg	4.56	3.955	4.51	8.53	6.49	
Exch. Mg cmol(+)/kg	2.24	1.345	1.93	1.96	2.58	
Exch. K cmol(+)/kg	0.024	0.02	0.028	0.07	0.24	
Exch. Na cmol(+)/kg	0.013	0.01	0.013	0.03	0.06	
TEB cmol(+)/kg	6.84	5.34	6.48	10.59	9.35	
Base saturation %	77.70	66.2	79.70	74.55	79.20	
DTPA extr.e Fe g/kg	32.60	16.2	13.80	22.00	22.80	
DTPA extract Mn mg/kg	1.60	6.40	21.00	33.80	22.48	
DTPA extractable Zn mg/kg	0.14	0.04	0.16	2.4	1.56	
DTPA extractable Cu mg/kg	2.04	1.52	1.08	4.32	3.02	

Appendix 9: Description of soil profile PFK3 on sloping land

Profile number : PFK3   Mapping unit: Footslope
Region : Tanga
District : Lushoto
Location : Ugange subvillage near Milling mashine and petrol station
Elevation : 1269 m asl. Parent material: metamorphic rocks. Landform: mountain; steeply dissected. Slope: 37 %; concave
Surface characteristics : Erosion: severe. Deposition: none.
Natural drainage class : well drained
Described on 22/04/00

Soils are very deep, well drained, very dark brown loamy topsoil over red clayey.

Ap: 0 - 60 cm: very dark brown (7.5 Y2.5/3) moist; clay loam; friable moist, sticky and plastic wet; moderate medium subangular blocks and strong fine; many fine and common medium pores; few small irregular fresh quartz fragments; many fine and common medium roots; clear wavy boundary to

Bt: 60 - 140 cm: red (2.5YR4/6) moist; clay; friable moist, very sticky and very plastic wet; moderate medium and fine subangular blocks; many very fine and common fine pores; frequent medium irregular fresh quartz fragments; common fine and medium roots; clear smooth boundary to

C: 140 cm + Weathering rocks

Soil Classification: Chromi-Pachic Phaeozems (FAO)
Pachic Hapludolls (USDA)

Analytic data

Horizon	Ap	Bt	C
Depth (cm)	0-60	60-140	140+
Clay %	23.8	25.8	
Silt %	7.8	4.8	
Sand %	68.4	69.4	
Textural class	SCL	SCL	
Bulk density g/cc	1.0	1.2	
pH (H2O)	5.55	5.01	
Organic carbon %	3.17	1.27	
Total nitrogen %	0.35	0.24	
Avail P Bray-1 mg/kg	1.7	1.5	
CEC Cmol(+)/kg	8.8	10.2	
CEC of clay Cmol(+)/kg	18.6	28.2	
Exch. Ca cmol(+)/kg	3.18	5.28	
Exch. Mg cmol(+)/kg	2.37	2.71	
Exch. K cmol(+)/kg	0.029	0.13	
Exch. Na cmol(+)/kg	0.196	0.066	
TEB cmol(+)/kg	5.78	8.18	
Base saturation %	80.20	80.03	
DTPA extractable Fe mg/kg	6.40	36.00	
DTPA extractable Mn mg/kg	12.4	77.60	
DTPA extractable Zn mg/kg	0.08	1.44	
DTPA extractable Cu mg/kg	2.46	2.18	

SPES