

**PEDOLOGICAL CHARACTERIZATION, CLASSIFICATION AND
EVALUATION OF THE POTENTIAL FOR MAIZE PRODUCTION OF
SOLOMON MAHLANGU CAMPUS FARM MOROGORO, TANZANIA**

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**A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY IN SOIL SCIENCE AND LAND
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MOROGORO, TANZANIA.**

EXTENDED ABSTRACT

In Tanzania, limited attention has been channeled towards the assessment of the fertility status of the soils in areas perceived as suitable for agricultural activities, mainly crop production. In the absence of reliable soil fertility data and information, agricultural land use, and in particular crop production has resulted in very low yields of most of the crops, with subsequent land degradation. The Solomon Mahlangu Campus (SMC) farm – Sokoine University of Agriculture, which is used mostly for crop production, mainly maize and pastures, as well as teaching and research, has not been critically assessed with regard to its soil fertility status, and hence its agricultural potential. This study was carried out with an overall objective of developing the best management packages for the improved maize crop production of Solomon Mahlangu Campus farm. Specifically the study aimed at i) to characterize and classify the soils of the study area using the criteria of the Soil Taxonomy and World Reference Base for Soil Resources soil legend. ii) to establish and evaluate the suitability of soils of the SMC farm for maize production and; iii) to determine the response of maize to different levels of N, P and FYM iv) to identify the limiting factors in different soil units.

The study was conducted in the 300 ha of the uncultivated portion of the Solomon Mahlangu Campus farm, Sokoine University of Agriculture. Grid survey at detailed level (scale, 1:7,500) was carried out to select observation and sampling points. At the beginning of the survey, an initial reconnaissance survey of the study area was conducted, followed by transect walks; auguring and selection of representative transect sampling points. Four mapping units' were thus delineated and identified in the study area. A total of four representatives profile pits (1.5 m x 1.5 m long x 2 m deep/limiting layer) were excavated, studied, described and sampled. Description of the soils and landforms was

done comprehensively following standard procedures as outlined in the FAO (2006) guidelines for soil description. Surface soil samples were collected from the 0-30 cm for general soil fertility evaluation. All soil samples collected were mixed properly, air – dried, grounded, sieved using a 2 mm sieve, bagged and labeled, for general chemical and physical analysis. The samples were analyzed according to laboratory manual for soil analysis by Moberg (2000) in the Department of Soil and Geological Sciences at SUA Morogoro. The data of the physical and chemical characteristics of soils were summarized using descriptive statistics. The soils were classified to family level according to Keys to Soil Taxonomy (Soil Survey Staff, 2014) and to WRB soil name- Tier 2 according to the World Reference Base for Soil Resources [IUSS Working Group WRB (2015)]. The land suitability evaluation was done using the FAO Guidelines on land evaluation for rain fed agriculture (FAO, 2006). Screen house studies were also conducted at the Department of Soil and Geological Sciences screen house to determine the effects of different levels of N, P and FYM on the growth response, nutrient uptake and dry matter yields of maize. The experiments were 3³ factorial in a completely randomized design (CRD) with three replications. The treatments used consist of three levels of nitrogen (0, 75 and 150 kg N ha⁻¹), three levels of phosphorus (0, 40 and 80 kg P ha⁻¹) and three levels of farmyard manure (0, 5 and 10 t FYM ha⁻¹). Parameters determined included plant height, number of leaves; stem girth, dry matter yields (DMY) and nutrients uptake (N and P). The data collected were analyzed using the analysis of variance (ANOVA) technique and means were separated using the New Duncan's Multiple Range Test (NDMRT) at 5% level of probability with the Genstat software package 14th edition.

The results of this study revealed that: all the soils belong to the soil order Ultisols and Ustalfs at suborder level in the Soil Taxonomy while Alisols in the Reference Soil Group (RSG) - Tier 1 for the World Reference Base for Soil Resources soil legend. At great

group and subgroup levels, P1 was classified as Rhodustults and Typic Rhodustults, P1 and P2 as Haplustults and Typic Haplustults, whereas, P4 was classified as Haplustults and Arenic Haplustults (Soil Taxonomy), which correspond to Haplic RhodicAlisols, HaplicAlisols, Haplic Chromic and HaplicAlisols (World Reference Base) in the Tier 2 for RSG soil name for P1, P2, P3 and P4, respectively. Results obtained also indicated that soils were sandy loam to silt loam in texture with a slightly acidic to mildly alkaline soil reaction ($\text{pH}_{\text{water}} = 5.96 - 7.27$). The mean values for organic carbon (0.29%), total nitrogen (0.04%), available phosphorus (9.0 mg kg^{-1}), cation exchange capacity ($9.84 \text{ cmol.kg}^{-1}$), base saturation (21.2%) and exchangeable bases ($\text{Ca}=0.7$, $\text{Mg}=0.85$, $\text{K}=0.31$ and $\text{Na}=0.21 \text{ cmol.kg}^{-1}$) were low in all the mapping units.. The mean EC value (0.03 ds/m) was low indicating that the soils were naturally non-saline. The evaluation of the soils revealed that all the soils of the four mapping units are currently moderately suitable (S2) for maize production. The major limitations in the study area are low soil fertility status and soil moisture content. The results for the screen house studies show that application of different rates of N, P and FYM had significant influence ($P < 0.05$) on the growth, nutrients uptake and dry matter yields of maize.

To improve soil productivity and sustain production of the test crop in the area under investigation, the following recommendations were made: i) an integrated nutrient management system should be adopted which embraces a holistic approach of integrated use and management of organic and inorganic nutrient sources in a sustainable way. ii) Periodic soil tests are very imperative to properly monitor the soil fertility indices and prevent soil fertility decline and degradation. iii) The low TN & OC contents in the soils needs to be amended through an integrated nutrients management (INM) iv) Thus, for enhanced performance of maize in the study area; application of a combination of nitrogen, phosphorus and farm yard manure fertilizers at reduce rates (75 kg N ha^{-1} , 40 kg P ha^{-1} plus FYM 5 t ha) would be sufficient for maize growth, dry matter yields and

nutrients content (N and P) in the test soil.v) Further studies are needed in similar abandoned farms in other agro-ecological zones for sustainable maize production in Tanzania.

Key words: *Solomon Mahlangu Campus, soil fertility, maize, nitrogen, phosphorus, farm yard manure, soil characterization, soil suitability evaluation, mapping unit, soil profiles, soil physico- chemical properties, treatments*

DECLARATION

I Uzaifa Adamu Karfi do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work done within the period of my registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

This work is dedicated to my beloved parents (Late Alh. Adamu Na'ibi Karfi, May his soul rest in perfect peace, Amen and Hajiya Sa'adatu Bayero for devoting their resources in educating me). I also dedicate this work to my wives, our children and Soil Scientists and to all those who love Soil Science as a profession.

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LIST OF ABBREVIATIONS, SYMBOLS AND ACRONYMS

AAS	Atomic Absorption spectrophotometer
ADP	Adenosine di- phosphate
AE	Agronomic efficiency
AEZ	Agro ecological zone
AI	Agronomic index
Al ³⁺	Aluminium iron
ANOVA	Analysis of variance
ATP	Adenosine tri-phosphate
Av	Average
BD	Bulk density
BLK	Block
BS	Base saturation
C	Carbon
Ca	Calcium
CAN	Calcium ammonium nitrate
CE	Cation exchange
CEC	Cation exchange capacity
CL	Clay loam
cm	Centimeter
cmol	Centimol
Co.	Company
CRD	Completely randomized design
Cu	Copper
CV	Coefficient of variance

df	degree of freedom
DFID	Department for Food and International Development
DM	Dry matter
DMY	Dry matter yield
DNA	Deoxyribonucleic acid
DRG	Drainage
DRWT	Dry Root Weight
dSm ⁻¹	decisimens per meter
DSWT	Dry Shoot Weight
e.g.	for example
ECe	Electrical conductivity
Elev.	Elevation
ESP	Exchangeable sodium percentage
<i>et al.</i>	and others
FAO	Food and Agricultural Organization of the United Nations
FAOSTAT	Food and Agricultural Organization Statistic
FC	Field capacity
Fe-ASS	Flame emission Atomic absorption spectrophotometer
FMA & NR	Federal ministry of agriculture and natural resources
FMA. WR. RD	Federal ministry of agriculture, water resources and rural development
FRWT	Fresh Root Weight
FSWT	Fresh Shoot Weight
FYM	Farm yard manure
g	Gram

g/cc	Gram per cubic centimeter
GDP	Gross domestic product
Geol.	Geological
gkg ⁻¹	Gram per kilogram
Gnt	gently
GPS	Global positioning system
H ⁺ Al ³⁺	Exchangeable acidity
H ⁺	Hydrogen iron
H ₂ O	Water
ha	Hectare
Hyp	Hyperthermic
IFDC	International Fertilizer Development Company
IITA	International Institute of Tropical Agriculture
INM	Integrated Nutrients Management
IPNM	Integrated Plant Nutrients Management
ISFM	Integrated Soil Fertility Management
IUSS	International Union of Soil science
K	Potassium
KCl	Potassium chloride
kg	Kilogram
KUST	Kano University of Science and Technology
L	Litre
LEIA	Low external input agriculture
LISF	Local indicators of soil fertility
LN	Leaves Number
LR	Long rains

LS	Loamy sand
LSD	Least Significant Difference
m	Meter
m.a.s.l	Meter above sea level
MAAT	Monthly average annual temperature
Max.	Maximum
mg	Milligram
Mid.	Medium
Min.	Minimum
mm	Millimeter
Mn	Manganese
mod.	Moderate
MPR	Minjngu Phosphate Rock
ms	Mean of square
MT	Metric tonnes
MWD	Medium to well drained
MZB	Mazimbu
N	Nitrogen
n	Not suitable
n.s.	No significant difference
N1	Conditionally suitable
N2	Permanently not suitable
nd	Not determined
NH ₄ AC	Ammonium acetate
NH ₄ F	Aluminium fluoride

NPK	Nitrogen Phosphorus and Potassium
NSS	National Soil Service
NUE	Nutrients Use Efficiency
OC	Organic carbon
OM	Organic matter
OMF	Organo mineral fertilizer
P	Phosphorus
P=0.05	Five percent probability level
PD	Particle density
PG	Plant Girth
pH	potential hydrogen ion concentration
ppm	Parts per million
PSD	Particle size density
r	Correlation coefficient
Rep	Replication
RNA	Ribonucleic acid
RSG	Reference Soil Group
S	Sand
s. e.	Standard error
S:C	Silt to clay ratio
S1	Highly suitable
S2	Moderately suitable
S3	Marginally suitable
SAS	Statistical Analysis System
SC	Sandy clay
SCL	Sandy clay loam

SMC	Solomon Mahlangu Campus
SMR	Soil moisture regime
SOM	Soil organic matter
spp	Species
ss	sum of square
SSA	Sub-Saharan Africa
SSR	Self Sufficiency Ratio
SSS	Soil Survey Staff
Stdev/s.d.	Standard deviation
STR	Soil temperature regime
SUA	Sokoine University of Agriculture
t	Tonne
T	Treatment
TDDMY	Total Dried Dry Matter Yield
TEB	Total exchangeable bases
TET Funds	Tertiary Education Trust Funds
Text.	Texture
TFDMY	Total Fresh Dry Matter Yield
TISF	Technical indicators of soil fertility
TMV	Tanzanian maize variety
TN	Total nitrogen
Trt.	Treatments
TSP	Triple super phosphate
UK	United Kingdom
Ulg.	Uluguru
UNESCO	United Nations Educational Scientific and Cultural Organization

URT	United republic of Tanzania
USA	United States of America
USDA	United State Department of Agriculture
var.	Variety
vol.	Volume
WAP	Week after planting
WAS	Weeks after sowing
WHC	Water holding capacity
WRB	World Reference Base
wt.	weight
www	World wide web
yr	Year

CHAPTER ONE

1.0 INTRODUCTION

1.1 Agriculture and Land Management in Tanzania

Agriculture is the foundation of the Tanzania's economy, as it accounts for about half of the national income, three quarters of merchandise exports, the main source of food and provides employment to about 80% of the Tanzanians (Pascal, 2013). Despite its importance, the agricultural sector in Tanzania is faced with a multitude of problems which include but not limited to low investment, low soil fertility, and unsustainable agricultural practices leading to land degradation. Among the causes of land degradation include ill-suited land use and inappropriate land and soil management practices, notably poor cropping and farming systems, shortening or elimination of the fallow period, insufficient use of manures and fertilizers, removal of crop residues for fodder, and soil erosion (Pascal, 2013).

Land degradation which is caused by erosion, physical, biological and chemical degradation from depletion of plant nutrients through the processes of uptake by plants and leaching are the major setbacks against sustainable agricultural production. Other setbacks include inadequate use of fertilizers and other soil amendments and inappropriate tillage practices (Pascal, 2013). Information on the soils inherent nutrient contents, quantities of the nutrients added to the soils and the nutrient dynamics in most of the soils under cultivation and their agricultural production potentials is scanty. Lack of soil and land management packages based on their agricultural production potentials and suitability for various agricultural practices has led to inappropriate land use.

Over the years, food production in Tanzania has failed to meet the demand, consequently the country has been importing food and receiving food aid to meet the needs of its populace. For example, in 2007 and 2008 the country imported 48,477 MT and 64,193 MT of maize respectively (FAO 2013). This trend could be attributed to the absence of concrete and long term focused approaches and principles in crop production. In Tanzania, in spite of the consistently low yield for most food crops, national food production has generally exceeded theoretical national requirements (URT, 1997). However with the prevailing levels of productivity, the country food production would be unable to keep up with the predicted population growth. The farming sector, which constitutes the backbone of the economy of the country, is characterized by small scale production, poor returns to land and labor market (URT, 1997). Furthermore, much of the productive potentials are not realized due to inappropriate land use systems and practices leading to low and irregular yields and declining productivity (URT, 1997; Pascal, 2013). This low productivity on the part of small-scale farmers is a major constraint to the growth of the agricultural sector. The fundamental challenge is improvement of productivity and sustainability of food production, which is still dominated by smallholders whose productivity is low

The average food crop productivity in Tanzania is 1.7 tonnes per hectare, whereas good management and optimal fertilizer use should result in yields of up to 3.5-4.0 tonnes per hectare. Furthermore, only 15 per cent of all farmers use fertilizers. In addition, the use of hand tools and the reliance upon traditional rain-fed cropping methods and animal husbandry further hamper productivity. AS a result, Tanzania appears not to be fit currently to take advantage of her agribusiness opportunities and the country is also far from being a major food exporter. Agricultural imports have been increasing, with food imports, including wheat, rice and dairy products, taking the largest share (80 per cent) of

the total merchandise imports. Since the 1999/2000 season, the Food Self Sufficiency Ratio (SSR), which compares the volume of domestic food production against the food requirements of the country's population, had been fluctuating between as low as 88 per cent in 2003/04 and as high as 112 per cent in 2006/07. Furthermore, significant variations in food security between different regions and districts have been experienced.

The United Republic of Tanzania was ranked 152nd out of 187 in the 2011 UN Human Development Index and 54th out of 79 on the 2012 Global Hunger Index (FAO, 2014). In Tanzania, the number of chronically hungry people rose from 28.8% in 1992 to 33% in 2013 (FAO, 2014), suggesting that food supply has not matched with the demand. Moreover, despite 2.6% annual population growth rate between 1988 and 2002 in Morogoro Region, (United Republic of Tanzania - URT, 2013) maize yields declined from 2.1 tons ha⁻¹ in 1994/95 season to 1.0 tons ha⁻¹ in 2007/08 season (URT, 2012). Thus the intensification of sustainable agricultural through soil fertility and water management to increase food productivity per unit area, without degrading the environment, is inevitable to attain food security (Inter Academy Council, 2004; New Partnership for Africa's Development - NEPAD, 2003).

One of the major constraints to crop production in the tropics, Tanzania inclusive, is the inherently low soil fertility attributed to low activity clays, low soil organic matter, nitrogen, phosphorus, exchangeable basic cations and low contents of the soil micro-nutrients (Nottidge *et al.*, 2005; Awodun, 2007). The problem of deficient levels of both the macro and micro -nutrients and the physical, chemical and biological constraints to soil productivity in the tropical regions has necessitated increased search for proper soil fertility management practices, which include the use of organic and/or inorganic

fertilizers and other soil amendments to raise soil fertility levels, and thereby increasing crop yields (Awodun, 2007).

In Tanzania, little attention has been channeled towards the assessment of the fertility status of the soils in areas perceived as suitable for agricultural activities, mainly crop production (Pascal, 2013). Absence of reliable data and information on soil fertility have led to continued agricultural lands use and in particular crop production practices, which have resulted into very low yields of most of the crops and subsequent land degradation

There is a growing concern over the decline in the productive capacity of Tanzania's soils as a result of non-sustainable land use practices (Pascal, 2013). Such practices have led to soil erosion and adverse changes in hydrological, biological, chemical and physical properties of the soils. In the country, continual cropping without concurrent use of manure/inorganic fertilizers has reduced soil fertility, leading to low crop yields (Ndaki, 2001). For example, poor maize yields ranging from 0.5 to 1.5 t ha⁻¹ as opposed to the potential yield ranging from 5 to 6 t ha⁻¹, which can be attainable with adequate nutrient supply, has been recorded (Ikerra and Kalumuma, 1991, Ndaki, 2001).

Whereas nutrient replacement through application of mineral or organic amendments is possible, small scale farmers are constrained by several socio-economic factors, such as high prices, timely availability, and low benefit-cost ratios of the amendments (Palm *et al.*, 1997; 2001). A study to assess the extent of nutrient mining in Tanzania conducted by Smaling and Janseen (1993) reported negative balances of 27, 4 and 18 kg ha⁻¹, for N, P and K, respectively, and this was attributed to nutrients uptake by crops and other losses such as erosion by surface run-off.

In Tanzania, little attention has been channeled towards the assessment of the fertility status of the soils in areas perceived as suitable for agricultural activities, mainly crop production (Pascal, 2013). Absence of reliable data and information on soil fertility have led to continued agricultural lands use and in particular crop production practices, which have resulted into very low yields of most of the crops and subsequent land degradation

The low soil fertility status of many soils in Morogoro area, as reported in previous studies (Msanya *et al.*, 2003), and non-use of the appreciable soil amendments by small scale farmers contribute to the low yields of most annual crops, maize inclusive. The Solomon Mahlangu Campus farm of Sokoine University of Agriculture (SUA), which is used mostly for crop production especially maize and pastures, as well as teaching and research, has not been critically assessed with regard to soil fertility status as well as its agricultural potential. This study assessed the soil fertility status of the farm at Solomon Mahlangu Campus (SMC) in Mazimbu Morogoro Tanzania.

1.2 Soil Fertility and Soil Productivity

Soil fertility is the ability of soils to provide the conditions required for plant growth, as a result of physical, chemical and biological processes that act together to provide nutrients, water, aeration and stability to the plant as well as freedom from any substances that may inhibit growth (Stockdale and Shepherd, 2002). The soil's ability to supply the essential plant nutrients is determined by the physical, chemical and biological properties and behavior of the soils (Brady and Weil, 1984).

Soil fertility is thus, the status of a soil with respect to its ability to supply elements essential for plant growth without a toxic concentration of any element (Stockdale and Shepherd, 2002). The fertility of a soil can therefore best be described as an evaluation of

the status of replenishment system which maintains the soil renewable resource in a sustainable form for long term productivity (Singh, 1999).

Soil productivity, on the other hand, is the capacity of the soil in its normal environment, to produce a specified plant or sequence of plants under a specified system of management (Nandwa, 2003). Soil productivity emphasizes the capacity of the soil to produce crops and is expressed in terms of yield. Soil productivity has declined in many areas of Sub-Saharan Africa (SSA), whereby 494 million hectares of land are been affected by soil degradation and out of these, 25 % is highly degraded with significant losses in their productive capacities (FAO, 2001). Different definitions of the term soil productivity have been provided; for instance, FAO (2001) defines soil productivity as the capacity of the soil to support plant growth and development as influenced by the soil, plant and climatic factors. Soil productivity is thus the interaction of the soil, climatic and plant factors as related or linked to plant growth and development.

Farmers used several indicators to assess the soil fertility hence soil productivity on their farms and these are called local indicators of soil fertility (LISF). These are the visually observable and identifiable soil properties, features and characteristics which are used for the qualitative assessment of the fertility status of soil in a given area (Barrios *et al.*, 2000; Beare *et al.*, 1997; Doran and Safley, 1997). Local indicators of soil fertility include such soil properties and such characteristics as the colour of the soil, the soil texture (feel), soil moisture retention capacity, soil structure, soil compaction, presence of soluble salts, stones, gravel and rocks, presence of ant-hills, soil depth, and depth to the water table, the presence and appearance of various plant species (dominant vegetation), and the presence of specific soil fauna. These local indicators of soil fertility have been used by farmers in

the development of indigenous (local) soil fertility management strategies in their localities in sub Saharan Africa (areas).

On the other hand technical indicators of soil fertility (TISF) include the quantified physical, chemical and biological properties of the soil that influence the growth and development of plants (Barrios *et al.*, 2000). Physical properties of soil such as texture, structure, aeration, colour, temperature, density, slope and soil depth, cannot be modified economically by the farmer. Chemical characteristics that affect soil quality include soil reaction, organic matter content, cation and anion exchange capacities, buffering of soils, mineral colloids, and the supply of essential plant nutrients. Biological properties entails the soil micro organisms (bacteria, yeasts, fungi, algae protozoa, est.) also greatly influenced the soil fertility. Tugel *et al.* (2005) referred to properties that change with land use as dynamic soil properties. The fertility status of the soil is therefore dependent on the physical, chemical and biological properties of the soil that control the dynamics and transformations of the nutrient elements in the soil ecosystem.

1.2.1 Processes and factors affecting soil fertility and productivity

Soil fertility is not a static feature; on the contrary, it changes consistently towards accumulation or depletion which is determined by the interplay between physical, biological and anthropogenic processes (Smaling *et al.*, 1992). The Physical properties of soils such as soil texture and soil depth cannot be modified economically by the farmer, yet they (the properties) determine the suitability of a soil for agricultural production. Chemical characteristics that affect soil quality are soil reaction, soil organic matter content, Cation exchange capacity CEC and the supply of the essential and beneficial plant nutrients (Smaling *et al.*, 1992).

Soil physical properties, to a large extent, determine the soil's water and air supplying capacity to plants, and thereby determining their adaptability to cultivation and the level of biological activity that can be supported by the soil (Sanchez *et al.*, 1982). On the other hand, chemical properties also dictate the fertility status of a given land; hence soil chemical properties are among the most important factors that determine the nutrients supplying power of the soil to the plants and microbes. The chemical processes and reactions that occur in the soil also affect processes leading to soil fertility build up (Smaling *et al.*, 1992). Minerals inherited from the soil parent materials overtime release nutrient elements that undergo various changes and transformations within the soil. However, due to continuous cropping and cultivation and the natural nutrient depletion processes and the natural soil fertility of the farmlands are dramatically declining. The destruction of soil physical properties together with the depletion of plant nutrients have caused the imbalance of the natural soil system resulting into a decrease of produce from the farmlands and favoring the prevalence of pests and diseases (Foth, 1990).

Several factors and processes affect soil fertility; these include soil and climatic factors such as soil pH, SOM, CEC and nutrients interaction, whereas processes that influence the fertility of the soil include weathering, leaching, soil erosion, decomposition of organic matter, acidification-alkalinisation, and nutrient transformations that occur in the soil. Other factors influencing soil fertility include ion exchange capacity, soil moisture, soil temperature, soil reaction, mineralogical composition of the inorganic soil constituents, and soil organic matter (Balagopalm and Jose, 1995).

1.2.2 Soil fertility evaluation and management

Soil fertility evaluation is defined as the process of assessing the nutrient supplying capacity of the soil, and the identification and selection of the quantities of nutrients to be

added to address the deficient levels of the nutrients based on the nutrient requirements of the crops (Nandwa, 2003). The main diagnostic methods in soil fertility evaluation include the determination of the local and technical indicators of soil fertility, identification of the plant nutrient deficiencies symptoms and determination of the crop response to inputs applied to soils (Beare *et al.*, 1997). The soils have varying properties and can be classified into soil categories with different productive potentials and constraints and management (Msanya *et al.*, 2003), hence these properties constitute part of the broader concept of soil and land suitability classification.

Farmers use several indicators to assess the potentials of soil productivity, which include the dominant vegetation as an indirect indication of soil fertility, the presence of specific soil fauna and color as an indicator of organic matter content and soil nutrient – supply capacity (i.e. fertility) (Doran and Safley, 1997). Other indicators of soil fertility include the appearance of crops from planting to maturity, crop yields based on the previous harvest over several seasons and appearance of crop during period of drought (soil's capacity to supply water) (Beare *et al.*, 1997). Soil texture and workability (ease or difficult in cultivation), anti-hills, soil depth and rock outcrops are also taken into consideration as indicator of soil fertility (Beare *et al.*, 1997). All these are referred to as local indicators of soil fertility.

Soil fertility management is defined as the management of the soil processes and properties in a sustainable way, so that the present generation is can be fed and soil conditions improved to support future generations (Nandwa, 2003). The problems of soil fertility management in SSA include: land degradation and soil fertility decline, droughts, land rights and inappropriate cropping and farming technologies, and lack of credit facilities.

1.2.3 Effect of declining soil fertility and soil productivity on crop production

Soil productivity has been on the decline in many areas of SSA (FAO, 2001). The decline in soil fertility, hence soil productivity has been attributed to abandonment of soil fertility restoration practices such as fallowing, inadequate and inappropriate nutrient replenishment practices, and soil and water management strategies and practices. The challenge of overcoming soil productivity decline is compounded by the fact that, the soil fertility status is highly dynamic and complex because of the heterogeneous nature of the soils attributed to the horizontal, vertical, spatial, and temporal variations (Nandwa, 2003).

Continuous cultivation which leads to serious decline in soil productivity has being the current practice in most SSA countries (FAO, 2001). Soil nutrient depletion and degradation have been considered as serious threats to agricultural productivity and have been identified as the major causes of decreased crop yields and per capital food production in sub – Saharan Africa (Henao and Baananke, 2006). In many parts of Sub – Saharan Africa, where poor soil conservation method prevails, long term productivity of soil is projected to decline considerably unless soil management practices are improved (Omotayo and Chukwuka, 2009).

1.2.4 Soil fertility maintenance

Maintenance of soil fertility involves the return of the nutrients removed from it by harvests, runoff, erosion, leaching and other loss pathways (Aune, 1993). Failure to return nutrients removed from the soil culminates into a decline of soil fertility and crop production. Despite this fact, humankind neglects this resource and soils are exposed to increasing degree of chemical, physical, and biological stress (Greenland, 1994; Henao and Baananke, 2006). Therefore, restoration of soil fertility to increase land productivity is mandatory especially in areas such as semi-arid areas where production per hectare is low.

Soil fertility maintenance is a major concern in tropical Africa, especially because of the rapid increase in population growth, which has been the trend in the past few decades (Henaio and Baananke, 2006). In traditional farming systems, farmers use bush fallow, plant residues, household refuse, animal manures and other organic nutrient sources to maintain soil fertility and soil organic matter (Henaio and Baananke, 2006). Although this reliance on biological nutrient sources for soil fertility regeneration is adequate with low cropping intensity, but with more intensive cropping, it becomes unsustainable unless inorganic fertilizers is adopted or given due consideration in crop production (Muloney and Merck, 1993; Henaio and Baananke, 2006).

Maize grain yields vary with the levels of soil fertility and fertilizer use. One of the most limiting nutrients for crop growth and yield is nitrogen. Yin *et al.* (2014) indicated that nitrogen was the main factor for determining maize grain yield followed by water availability in their study in a semi- arid environment of Northeast China. This is because N is naturally low in soils with low soil organic matter and is subject to losses through leaching, immobilization, mobilization and soil erosion (Brady and Weil, 2008). If soil fertility is well managed, rain fed dependent crop production will turn out to be productive, and substantial productivity improvement is likely to be realized (Kalhapure *et al.*, 2013). However, up to 89% of fields under annual crops are reported not to receive any kind of fertilizer in Morogoro region because of high fertilizer costs (URT, 2012).

Soil fertility and plant nutrition are closely related and emphasize the forms and availability of nutrients in soils, their movement to and their uptake by roots, and the utilization of nutrients within plants (Foth and Ellis, 1997). Without maintaining soil fertility, one cannot talk of improving agricultural production in feeding the alarmingly increasing population. Therefore, to get optimum, sustained-long lasting and attain self-

sufficiency in crop production, soil fertility has to be maintained. The loss of soil nutrients, which is related to cultural practices such as cultivation, the removal of vegetative cover (such as straw or stubble) or burning of plant residues as practiced under the traditional system of crop production or the annual burning of vegetation on grazing lands must be stopped (Mesfin, 1998). The complementary use of organic and mineral fertilizers has been proven to be a sound fertility management strategy in many countries of the world (Bayu *et al.*, 2006; Rosemary, 2007; Schlegel, 2000).

Maintenance of fertility status of soils is an important concept in agricultural production in order to obtain stable and sustainable agro ecosystem. Many authors (e.g. Usoroh *et al.*, 1986; Mgbagwu, 1990; Walling Ford *et al.*, 1993; Belay *et al.*, 2001) suggest that in order to overcome some of the deficiencies inherent in the use of only one fertilizer to boost crop yield, adequate and effective use of a mixture of organic and inorganic fertilizers will solve the problems associated with food scarcity in Africa and keep the soil in a much better condition than when only one fertilizer type is used.

Soil fertility management should not be considered as a simple issue but rather as a complex one and which has to be approached or addressed holistically. The holistic approach to soil fertility management embraces integrated soil fertility management (ISFM) which takes into account responses to a whole range of driving factors and consequences namely biological, chemical, physical, social, economic and political aspects of soil fertility decline (Bationo, 2003).

1.2.4.1 Application of organic fertilizers

Organic soil amendments are materials such as green and animal manures, crop residues, cover crop, compost manure and mulch which when added to the soil will provide one or

more of the essential nutrients for plant growth following mineralization during decomposition (Goh *et al.*, 2001). Organic resources play a dominant role in soil management in the tropics through their contribution to SOM formation.

Synchronizing nutrient release from organic inputs with crop nutrient needs have also been reported to increase the nutrients use efficiency (NUE) (Palm *et al.*, 2001). However, large increases in soil productivity through the use of organic resources as sources of plant nutrients are constrained by unavailability of sufficient quantities of the resources coupled with their poor qualities that are low in nutrient contents (Rahman, 2004). It is argued that organic resources of plant nutrients form the foundation for any sustainable increase in soil productivity (Rahman, 2004). Strategies for soil fertility enhancement should thus be built on the existing indigenous technical interventions and by improving the management of nutrient flows within the farming systems. Such strategies of soil fertility improvements range from traditional approaches of organic and inorganic fertilizer application to low external input agriculture (LEIA). In traditional farming systems, farmers use bush fallow, plant residues, household refuse, animal manures and other organic nutrient sources to maintain soil fertility and soil organic matter. Other soil fertility enhancement methods include the use of improved fallow, agroforestry and biomass transfer using nutrients available in the farmer's vicinity and adopting agricultural practices geared at soil fertility improvement.

Tanzania is endowed with a large number of livestock such as cattle, goats, sheep, pigs, donkeys and poultry. According to Kimbi *et al.* (1999), animal manure output in mainland Tanzania is about 14 million tons per year. If the average N content of animal manure is assumed to be 0.7%, the total N from the manure is 94 500 tons. This is about four times the amount of nitrogenous fertilizers used in the country in 1980. Efficient use of animal

manure could therefore alleviate the problem of declining land productivity in most parts of Tanzania. Irrespective of the enormous manure production potential, very little amount of the available animal manure is being utilized for crop production. Kimbi *et al.* (1992) observed that in extensive livestock grazing systems only about 1% of the farmers apply animal manure on land, which implies a serious under utilization of such resources. This underutilization is largely due to lack of scientific basis for advising farmers on aspects such as appropriate application rates, storage techniques, and application methods (Gabriel, 1998).

Due to continual removal of nutrients from the soil by crops, soil erosion, leaching and other processes, soils generally become deficient in one or more nutrients (Tandon, 1994). Farmers' reaction towards declining soil fertility has often been practicing shifting cultivation (where land is not scarce) or supplying additional nutrients by using fertilizers and organic manures such as compost, farmyard manure, green manure and use of leguminous cover crops. Restoring, maintaining, and increasing soil fertility are major agricultural priorities in many parts of developing world where soils are inherently low in plant nutrients and the demand for food and raw materials is increasing rapidly (FAO, 1998).

1.2.4.2 Application of inorganic fertilizers

Fertilizer is defined as any organic or inorganic material which is added to the soil to supply certain elements which are essential to the plants but are lacking or deficient in the soil for the growth of these plants. Kumpawat and Rauthore (1995) define inorganic fertilizer as materials usually synthetic which contain elements which are essential for the plant growth. Fertilizers not only improve crop yields but they also increase the quality of

available useful crop residues for livestock feed or organic inputs to the soil (Bationo *et al.*, 2004).

Judicious application of inorganic fertilizers has been responsible for significant increases in crop yields on commercial farms in Africa, although this is not the case with small holder farms (Murwira, 2003). Small crop yields in small holder farms have been attributed to low rates (less than 60 kg $^{-1}$) of fertilizers applied, lack of technical knowledge on fertilizer use and other socio-economic and structural constraints, such as low producer prices for crops and lack of credit support (Murwira, 2003). Integrated approaches incorporating a number of technical interventions are thus needed to improve soil productivity on small holder farms. An efficient nutrient cycling in a farming system requires the application of balanced combinations of plant nutrients that are locally available or generated on the farm and application of moderate amounts or quantities of externally desired nutrients (i.e. inorganic fertilizers) so as to optimize profitability and sustainability of the farming system. The appropriate use of organic residues, manures and inorganic fertilizers in a sustainable way leads to an increase of soil organic matter thereby leading to an increase of soil fertility levels, which lead to an increase of the availability of nutrients and efficient use of fertilizers through the synergistic effects of the different sources of these soil amendments (Murwira, 2003).

In semi-arid southern Zimbabwe, as low as 8.5 kg N ha⁻¹, in combination with 3 t ha⁻¹, increased maize yield from 1.26 t ha⁻¹ (control) to 2.5 t ha⁻¹ when there was good seasonal rains (Ncube *et al.*, 2007). According to Tittonell *et al.* (2008), fertilizer addition (30 kg P ha⁻¹ + 90 kg N ha⁻¹) under rain fed conditions could increase maize yield yields and hence bridge the yield gap in Western Kenya.

In 2007, Tanzania imported 169,027 metric tons of fertilizer, which increased to 318,060 tons in 2011 - a Compound Annual Growth Rate (CAGR) of 13.5 percent. From 2008 to 2010, there was a sharp increase in total fertilizer use. Notwithstanding this increase, the average fertilizer application rate of 19.3 kg/ha in Tanzania is still low. The average maize yield is 1.5 tons per ha, which is far below the potential of 6-7 tons per ha when good agronomic practices and proper amounts of fertilizer are applied (URT, 2012).

1.2.4.3 Integrated soil fertility management

Integrated Soil Fertility Management (ISFM) may be defined as the application of soil fertility management practices and the knowledge of adopting these to local conditions, which maximize fertilizer efficient use of organic resource and crop productivity. These practices necessarily include appropriate fertilizer and organic input management in combination with the utilization of improved germ plasma (Nandwa, 2003). Integrated plant nutrients management (IPNM) therefore entails a combined use of plant nutrients sources (organic and inorganic) in crop production (Belay *et al.*, 2001). Integrated soil fertility management is therefore the adoption of a systematic conscious participatory and broad knowledge intensive holistic approach to research on soil fertility that embraces the full range of driving factors and consequences such as biological, physical, chemical, social, economic and political aspects of soil fertility degradation (Bationo *et al.*, 2006, Nandwa 2003; Kimani *et al.*, 2003).

Integrated soil fertility management is an approach that emphasize on sustainable and cost-effective management of soil fertility (Sanginga and Woolmer, 2009); and attempts to make the best use of inherent soil nutrient stocks, locally available soil amendment resources and mineral fertilizers, and increase land productivity while maintaining or enhancing soil fertility. ISFM Practices involve i) judicious use of mineral fertilizer and

agro minerals in terms of their form, placement and timing of application; ii) management of crop residues and other locally available organic resources that improve agronomical efficiency, iii) the use of locally adopted gemplasm that is resistant to local stressful conditions, both biotic and abiotic and iv) the use of other field practices determined by local agricultural conditions, particularly pest and descale management, soil erosion, moisture conservation and the enhancement of beneficial soil biota (Nandwa, 2003).

Huge quantity of organic wastes in relation to inorganic fertilizer required for soil amendment makes it imperative for a combination of nutrient sources. According to Uyovbisere and Elemo (2000) integration of organic wastes reduces the quantity required and enhances nutrient releases. Furthermore, the use of organic wastes to improve soil productivity as an alternative to mineral fertilizer will help in the disposal of the wastes whose generation has reached alarming proportions especially in developing countries. Organic wastes are of immense importance as potential materials in the restoration of soil productivity (USDA, 2002).

Previous studies (Uyovbisere and Elemo, (2000) showed superior effect of integrated nutrient supply over the sole use of inorganic source. For instance, there was balanced nutrient supply, improved soil fertility and crop yield under integrated nutrient management (Olayinka and Adebayo, 2003; Adeniyani and Ojeniyi, 2006) with the intensive use of land. Singh and Babasubramanian (1980) and Chand *et al.* (2006) corroborated sustainable soil productivity to integrated nutrient management. Sutanto *et al.* (2003) noted high crop yield under integrated nutrient management on acid soils. Integrated nutrient management is effective in the tropics where soil productivity depletion is rapid as a result of accelerated soil erosion, leaching and non-replaceable crop harvest

system. This situation needs to be reversed such that soil nutrient levels would not continue to decline unabated (Donova *et al.*, 1998).

Based upon research findings across numerous countries and diverse agro ecological zones of sub-Saharan Africa (SSA), there is a consensus that the highest and most sustainable gains in crop productivity per unit nutrient are achieved from a mixtures of inorganic and organic inputs (Vanlauwe *et al.*, 2001). The need to combine essential organic inputs with fertilizers and farmer – available organic resources are viewed as a major entry point. Indeed, combining mineral and organic inputs result in greater benefits due to synergistic interaction effects of inputs than is the case in using either input alone (Sanchez, 1994). Many farmers in SSA to some extent know how to practice judicious management of their soils, to use nutrients available in their vicinity and to put agricultural practices geared towards soil fertility improvements such as improved fallow, agro forestry and biomass transfer.

ISFM is a set of principles and practices to intensify land use in a sustainable way. The principles embedded within the definition of ISFM need to be applied within the existing farming systems. There are two examples illustrating the integration of ISFM principles in existing cropping systems: (i) dual-purpose grain legume–maize rotations with P fertilizer targeted at the legume phase and N fertilizer at the rates below those at recommended targeted at the cereal phase in the moist savannah agro-eco zone (Sanginga *et al.*, 2003); and (ii) micro-dose fertilizer applications in legume–sorghum or legume–millet rotations with the retention of crop residues combined with water-harvesting techniques in the semi-arid agro-eco zone (Bationo *et al.*, 1998; Tabo *et al.*, 2007).

ISFM is a holistic approach that not only requires land managers to invest in external farm inputs, do a better recycling of the available organic resources and foster beneficial and biological processes but also provides additional incentives and strengthen understanding for them (managers) to do so (Uphoof, 2002). ISFM is not characterized by unique field practices but is rather a fresh approach of combining available technology in a manner that preserves soil quality while promoting its productivity (Uphoof, 2002). ISFM also embraces a suite of conditions that foster the adoption such as greater access to farm input supplies, fair commodity markets and conducive regulatory and trade policies (Uphoff, 2002). The overall goal of ISFM is to maximize the interaction that results from the potent combination of fertilizers, organic inputs, improved germplasm and farmer knowledge (Nandwa, 2003). ISFM approaches may follow two parallel paths, one for strictly commercial production that optimizes returns per unit area and another intended for resource poor farmers that makes the best use of limited affordable fertilizers.

1.3 Soil Survey and Land Evaluation

Soil survey is usually carried out with the emphasis of obtaining information demanded in land evaluation. Soil survey involves determining the pattern of the soil cover and dividing this pattern into homogeneous units, and then mapping their distribution and characterizing them (Kaaya *et al.*, 1994). It (soil survey) enables better predictions about specific uses of the land, and allows useful statements to be made with respect to land use potential and behavior towards different management practices (Kaaya *et al.*, 1994).

The FAO (1995) defines land as a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), near-surface

sedimentary layers and associated ground water reserve, the plant and animal populations, the human settlement patterns and physical results of past and present human activities (terracing, water storage of drainage structures, roads, buildings e.t.c).

Land evaluation can be defined as a process of carrying out a preliminary and partial, but very systematic analysis of the variability of the physical, chemical and biological land conditions and its influence on the performance of present land use and determine land use systems, in such a way that the result can be used for optimum land use planning (Fdlar 1982). Land evaluation, therefore serves as a tool for proper, judicious, and more efficient use of land/soil (Mustapha *et al.*, 2001). In land evaluation, the suitability of the soils is matched with crop requirements and a suitability index obtained for the various soil properties like texture, drainage, pH, organic carbon content, base saturation and soil depth (FAO, 1983). The procedures involved in land evaluation are broadly field work, interpretation, and presentation of results.

Land (capacity and suitability) evaluation involves the collection and interpretation of inventories of soil, vegetation, climate and other aspects of land in order to identify and make a comparison of at least, an optional and sustained used as well as management alternatives in a known socio-economic setting (Fdlar 1982). The fertility capability classification system evaluates fertility limitations other than nutrient deficiency (Sanchez *et al.*, 1982).

1.4 Land Suitability and Capability Classification

Land suitability refers to the ability of a portion of land to tolerate the production of crops in a sustainable way (FAO, 1976; 1983). Land suitability analysis involves identification of the main limiting factors on land against agricultural production and enables decision makers to develop soil and crop management packages to increase land productivity

(FAO, 1983). The land suitability classification is one of the principles to the approach and methods employed in land evaluation (FAO, 1976; 1983). The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976).

While the term land capability is used in a number of low classification systems (Baja *et al.*, 2002a), capability is viewed by some as the inherent capacity of land to perform at a given level of general use, and suitability as a classification of land primarily in relation to degradation hazards; while some regard the terms “Suitability” and “Capability” as interchangeable (Baja *et al.*, 2002a). Land capability refers to the potential of land to sustain a number of predefined land uses in a built – in descending sequences of disability, arable crops, pasture, woodland, and recreation/wildlife; if the capability of land decreases, the land becomes suited for fewer major land uses (Baja *et al.*, 2002b). Baja *et al.*, (2002b) reported two general kinds of land suitability evaluation approaches: qualitative and quantitative. By qualitative approach, it is possible to assess land potential in qualitative terms, such as highly suitable, moderately suitable, or not suitable. In the second approach, quantitative assessment of land suitability is given by numeric indicators.

1.5 Effects of Organic and Inorganic Fertilizers on Plant Growth

Application of organic manures plays a direct role in plant growth as a source of all the essential major and minor nutrients in available forms subsequent to mineralization which improves both the physical and biological properties of the soil (Abou El-Magd *et al.*, 2006). To meet crop’s nutrient needs, organic manures are however, required in rather large quantities which call for a strong advocacy for fortifying these manures with inorganic fertilizers. The combined use of organic sources of nutrients such as farmyard

manure not only supply essential nutrients but also offer some positive interaction with chemical fertilizers to increase their efficiency and thereby to improve the soil structure, water retention capacity, microbial activities, soil's buffering capacity, and pH (Elfstrand *et al.*, 2007).

Animal (cattle, sheep and goats, poultry and pig) manures have been shown to contain large amounts of organic matter, high nitrogen, and significant concentration of basic cations such as magnesium, calcium and potassium which are essential nutrients for plant growth and development (Johnson *et al.*, 2006, Ojeniyi *et al.*, 2009). Manure from livestock is an important source of nitrogen for crop production in the small holder sector as it helps farmers to reduce inputs of commercial fertilizers, thereby increasing the profit margins of the farmer (Ayoola and Makinde, 2008). Nutrients contained in organic manure are released more slowly and have residual effect of a long time in soil thus supporting better root development leading to higher crop yields (Sharma and Mitra, 1991; Abou EL-Magd *et al.*, 2005; Davari *et al.*, 2012).

Apart from supplying nutrients, manures suppress diseases by generating ammonia and or nitrous acid in the soil, and thus reducing Al toxicity (Larzarovita, 2001). It was reported that when organic manures are used they usually release 30% N to the subsequent crops (Jamaval, 2006); and according to Shaikh and Patil (2013), this is because the release of plant available form of nitrogen is slow. Gasket *et al.* (2006) and George (2011) also reported that the gradual release of nutrients from organic fertilizers when organic manures are applied to the soil. The efficiency of manure utilization by a crop is determined by the method of application, the time of incorporation and the rate of decomposition in the soil. Characteristically, not all of the nutrients in manure are directly available after its incorporation in the soil. Organic forms of nutrients must first be

mineralized into plant-available forms such as nitrate. The rate of mineralization is variable and depends on soil type, moisture, temperature, and manure composition. When cow dung and urine are mixed, a balanced nutrition is made available to the plants (George, 2011).

The beneficial effects of manure on soil fertility are well documented (Mugwira and Murwirwa, 1997; Gasket *et al.*, 2006; George, 2011). Crop yield responses to manure can be seen for several years after the application of the said manures as these reduce soil acidification and improve the soil buffering capacity and the release of nutrients (Williams *et al.*, 1995). Hoffman *et al.* (2001) found that the combined crop-planting patterns and the application of organic and mineral fertilities in an effective way could maintain fertility in the soils.

Similarly, many studies demonstrated the response of maize to the application of mineral fertilizers (Adetunji, 1994). For example maize has been reported to require high amounts of nutrients particularly nitrogen, phosphorus and potassium which are needed for good growth and high yields of crops (Onasanya *et al.*, 2009; Mengel and Kirkby, 2001). Thus, without an adequate nutrient supply, maize would fail to produce high grain yield (Adediran and Banjoko, 1995). These nutrients could be supplied either from organic or inorganic source or a combination. Busari *et al.* (2004) stress the need for improved management practices through the use of external inputs from organic and inorganic sources on tropical soil.

Among the inorganic fertilizers, nitrogen is a major yield determining factor in maize production (Reddy, 2006). It (nitrogen) is a critical component of protein, which controls the metabolic processes, required for optimum plant growth, and so it must be available in

sufficient quantities throughout the growing season of the plant (Lombin, 1983). Law-Ogbomo and Law-Ogbomo (2009) reported that maize plant height increased with successive increment of NPK fertilizer application rate of up to 60 kg N ha⁻¹. The stem girth increased significantly (P=0.05) with the application of N to maximum values of 2.92 cm while leaf area and a number of leaves increased up to 60 kg N ha⁻¹ with values of 692 cm² and 14.30 respectively. Unfortunately, the capacity of tropical soils to supply N declines rapidly as a result of agricultural activities such as multiple and continuous cropping systems with low fertilizer application (Wondewosen, 2009; Tenaw *et al.*, 2006).

Phosphorus is also an important nutrient which is required by maize for growth, being an essential component of nucleic acids (DNA and RNA), phosphorylated sugar, phospholipids, and protein; and so, Phosphorus plays a vital role in grain production. It forms high-energy phosphate bonds with adenine, guanine and uridine, which act as carriers of energy for many biological reactions in plant (Khan *et al.*, 2008). It (Phosphorus) is important for seed and fruit formation and hastens crop maturation. Phosphorus hastens the ripening of fruits and can counteract the effects of excess N applied to the soil. Adequate P supply is critical in the early stages of growth of plant, as it is needed for growth and development of the root (Ahn, 1993; Adediran and Banjoko, 1995; Mollier and Pellerin, 1999).

An increase in maize plant height with the application of nitrogen and phosphorus at recommended rates has been reported by Grazia *et al.* (2003), Ayub *et al.* (1997), and Cheema (2000). This observation is also in agreement with the findings of Babatola (2006) who reported that increasing levels of fertilizer (N and P) application led to an increase in the growth and yields of crops. Maize varieties are known to vary in P uptake, utilization efficiencies and adaptability to different soil types (Machado *et al.*, 1999).

According to Lode (2004), as the percentage of clay particles and colloids contained in the soil increases, so is the content of plant nutrients bound by these particles and colloids. This is due to the very high specific surface area of colloids and their net negative charges which give soil its great ability to hold more nutrients.

Despite the effectiveness of organic manure in crop production, its availability remains an important issue due to its bulky nature, while on the other hand inorganic fertilizer which releases nutrients immediately when applied to the soil is no longer within the reach of resource poor farmers due to its high costs (Rahman, 2004). The continuous use of inorganic fertilizers has been associated with an increase in soil acidification, nutrient imbalances and soil degradation (Ayoola and Makinde, 2008). This shortcoming of inorganic fertilizer use has motivated agronomists to explore an ecological approach for soil amendments (Ayoola and Makinde, 2008). However, while inorganic fertilizers increase the crop yield; its frequent use causes deterioration of the soil structure and contamination of ground water (Sagardoy, 1993). Therefore, the productivity can be improved by proper combination of manure with mineral fertilizers at reduced levels (Bello and Hatom, 2008) because of some positive interaction with chemical fertilizers to increase their efficiency and thereby to improve soil structure.

There is evidence of positive interaction between the combinations of organic manures and urea as N source (Bocchi and Tano, 1994; Khaliq *et al.*, 2004). Khaliq *et al.*, (2004) reported that the combined use of poultry manure and urea gave the best performance for sweet corn amongst all treatments due to adequate supply of nitrogen which speed up photo assimilation process. This process, in turn, boosts up growth. Manure application has also been reported to increase the N and exchangeable cations levels in the soil (Boateng *et al.*, 2006). This is because N has the ability of improving soil physical

condition which determines the health of microbial population that decomposes the organic nutrients.

Organic inputs are needed to maintain the physical and chemical fertility of the soil while inorganic inputs are needed to supply quick and sufficient amount of readily available nutrients to crops (Vanlauwe *et al.*, 2001). Complementary application of organic and inorganic fertilizers helps in sustaining soil quality and crop yield potentials (Makinde *et al.*, 2010). A combination of organic and synthetic amendments has been reported to improve crop yield and soil fertility status (Palm *et al.*, 1997; Vanlauwe *et al.*, 2012). Inorganic fertilizers supply the needed nutrients, and thus enhance plant luxuriant growth, development, and yield (Stefano *et al.*, 2004). Integrated use of chemical fertilizers and organic material may be a good approach for sustainable production of crops. Integrated use of organic matter and chemical fertilizers is beneficial in improving crop yield, soil pH, organic carbon and available N, P and K in sandy loam soil (Rautaray *et al.*, 2003).

Organic sources ameliorate the micronutrient deficiencies. Humic acid present in organic matter was found to increase the permeability of cell membrane, which resulted in increased uptake of water and nutrient elements (Cheng, 1997). Organic matters not only increase the water holding capacity of the soil but also the portion of water available for plant growth and improve physical properties of the soil (Sial *et al.*, 2007).

1.6 Major Limitations to Increased Maize Production in Tanzania

Maize is grown widely in many countries of the world, Tanzania inclusive. According to Rowhani *et al.* (2011), annual production of maize in Tanzania has hardly gone beyond 3.0 million tonnes for the past ten years with average yields of 1.4 t ha^{-1} which is far below the global potentials of 4.9 t ha^{-1} . The adverse and erratic weather conditions, low soil

fertility and the use of ungraded seeds are usually reported to be the major factors contributing to the low levels of maize production (Morris *et al.*, 1999; Kisetu *et al.*, 2014). Low maize production in most African countries has also been attributed to low soil fertility due to continuous cropping with little or no external inputs (Owusu-Gyimah *et al.* (2013).

Studies by Smaling *et al.* (1997) and Lynan *et al.* (1998) estimated nutrient depletion at farm, on national and continental scales for SSA, to be 22 kg N, 2.5 kg P and 15 kg K ha⁻¹ yr⁻¹, respectively. Symptomatic of the problem is that, per capital food production has continued to decline over the two decades in SSA. Agricultural production (in terms of use of land and soil resources) in SSA is threatened by both endogenous and exogenous factors such as climate, deforestation, soils properties, nutrients depletion and negative nutrient balance, pest and diseases, population pressure, farming practices, cleaning and tillage techniques and grazing (Quansah *et al.*, 1997).

Agriculture is closely linked to the management of environmental resources. Tanzania, as is the case with most Sub-Saharan countries, is believed to face an increasing pressure on environmental resources, in spite of being a nation with rich resource endowments relative to population size. The problems gaining most attention are deforestation, soil erosion, and soil nutrient mining processes, because all of these are believed to be strongly interlinked with agricultural production. Deforestation is believed to happen because of expanding agricultural frontiers and fuel wood extraction (Mayawalla, 1996). Reliable figures on deforestation, however, are scarce and unreliable. An increasing number of studies identify soil-mining as the most significant environmental problem in southern Africa with soil nitrogen as the limiting soil nutrient (Stoorvogel and Smaling, 1990). Tanzania, and some other sub-Saharan countries, are believed to move along the path of declining

agricultural productivity, due to losses of soil nutrients, and that these are not being fully replaced by external sources such as chemical fertilizers (URT, 1997). Such a development may constitute a hindrance for future increase of agricultural production, which can lead to food insecurity in these countries.

Smallholder farmers in Tanzania are confronted by a set of difficulty conditions that threaten their ability to feed themselves and their families (URT, 1997). Over the past two decades, Tanzania has experienced a series of periodic drought that required food relief from international agencies (URT, 1997). The problem is even more severe in semi-arid areas where soils with low organic matter, moisture, N, P, and mineral nutrients are common (URT, 1997). Sustainable agriculture in these areas therefore requires frequent addition of soil nutrients by combining the use of inorganic fertilizers and organic materials (Bekunda *et al.*, 1997). Sakala *et al.*, (2003), Chingonikaya (1999) and Mgangamundo (2000) found that growing maize after legume residues resulted in increased maize yields vis-à-vis continuous cropping due residual/carry over effects of the legume residues on the soil.

Maize production in Tanzania is hampered by a wide range of constraints which include inadequate use of inputs such as fertilizers, improved maize seeds, and inadequate access to information and extension services and erratic and inadequate rainfall (Rates, 2003). Increased productivity is crucial for alleviating poverty and enhancing the livelihoods of smallholder maize farmers who make up the majority of the rural poor in Tanzania (Rates, 2003).

In Tanzania, as human population is growing, more land is being brought under cultivation, including marginal lands that are particularly vulnerable to degradation by

such processes as erosion, depletion of organic matter and nutrients, pollution, water logging and salinization (Owino *et al.*, 2006). In effect, degraded lands are cultivated without full recovery of the soil from previous degradation; this invariably results in low yields, poverty and malnutrition. The trend is a cause for concerns as a result of its perceived threat to the earth's environment and food security. Human activities through deforestation, logging, farming, urbanization, and construction and population explosions are some of the factors contributing to climate change (Offiong and Ita, 2012).

Drought is another major threat to maize production in many parts of Tanzania (URT, 1997). Maize production can be a risky and unreliable business because of erratic rainfall and high susceptibility of maize to drought. The performance of local drought-tolerant cultivars is low. Maize losses can go as high as 50 percent due to drought related stress. Erratic rainfall makes maize farmers in Tanzania vulnerable to low yields which translate to food insecurity (WEMA, 2010).

The agricultural sector, which is predominantly crop based is typically rain fed. The sector is dominated by smallholder farmers cultivating an average farm size of between 0.9 ha and 3.0 ha (WEMA, 2010). Of the 44 M ha arable land country wide only 23% is cultivated. About 70% of Tanzania's cropped area is cultivated by hand hoe, 20% by ox plough, and 10% by tractor (URT, 2009; TNBC, 2009).

Furthermore the agriculture sector is risky because of its dependency on highly variable weather. Future climate change is anticipated to exacerbate production risks in agriculture by shifting the already volatile long – term weather conditions (Tumbo *et al.*, 2010). The global climate change judging from the decrease in the rainfall and number of rainy days indicates an increase in temperature and irregular relative humidity over three decades. On

the basis of agricultural potential, it is estimated that more than 50% of the land in Tanzania is semi – arid or arid (URT, 1997). The semi aridity is caused by low amounts of rainfall, high evapotranspiration rates and erratic temporal and spatial rainfall distribution (URT, 1997). The main problems of semi-arid areas are inadequate soil moisture for plant growth and low availability and imbalances of nutrients (URT, 2012). In semi arid areas, inadequate soil moisture for plant growth aggravates the problem of soil fertility.

1.7 Justification to Undertake the Study

Despite the importance of maize as the main staple crop, the average yields in farmers' fields are relatively low averaging 1.2 metric tonnes per hectare as opposed to the estimated potential yields of 4 to 5 metric tonnes per hectare (FAO, 1998), which could be used as human food or as a component of animal feeds. The low soil fertility status of many soils in Morogoro, as reported by Msanya *et al.* (2003), and non-use of fertilizers by small scale farmers contribute to the low yields of most annual crops, maize inclusive. In Morogoro, there has been a substantial number of studies on the collection of basic information on soil' in the form of soil surveys and soil fertility studies (Msanya *et al.* (1991); Msanya and Mogoggo (1993) and Kilasara *et al.* (1994), which have centered on a few selected areas. Moreover, the cited studies have by-passed the SMC farm area, which has a different parent material from the other soils studied; but it well established that different soil types have specific properties that affect directly their functions in relation to supporting crop growth and performance. Moreover, there is no land suitability assessment that has been done to indicate the suitability of the SMC soils for production of maize; hence, the need to assess the suitability of the soils occurring in the SMC farm for the various crops commonly grown in Morogoro.

The pedological information provided by the previous studies is very much useful mostly to the soil scientists, but may not be of immediate interest to the farmers; what farmers need the most is an interpretation of these findings. This involves identifying the most limiting land qualities or characteristics and provides a good basis for advising farmers on appropriate management practices for optimum production in a particular agro-ecological zone (FAO, 1976; Dent and Young, 1981).

This study therefore addressed the soil fertility status of the SMC farm through, a comprehensive and critical evaluation of the fertility status and productivity of the soils of the SMC farm, classification of soils in the farm, establishment of soil and land suitability maps and maximization of maize yields in the farm through the use of fertilizers. The study also provides information that will enable land users of the farm to make proper use of the farm and adopt appropriate alternative management practices.

1.8 Objectives of the Study

1.8.1 Overall objective

In view of the above highlighted knowledge gaps, the overall objective of this study, was to develop the best management packages for improved maize production in the SMC Farm.

1.8.2 Specific objectives

The specific objectives were:

- i. To characterize and classify the soils of the study area [using the criteria of the Soil Taxonomy and World Reference Base for Soil Resources soil legend.
- ii. To establish and evaluate the suitability classes of soils of SMC farm for maize production.
- iii. To determine response of maize to different levels of N, P and FYM
- iv. To identify limiting factors in different soil units.

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CHAPTER TWO

2.0 PHYSICO-CHEMICAL PROPERTIES AND CLASSIFICATION OF SOILS OF SOLOMON MAHLANGU CAMPUS FARM, MOROGORO, TANZANIA

2.1 Abstract

A study was undertaken with a view of establishing morphological, pedological and physic-chemical properties and classifying the soils of part of the Solomon Mahlangu Campus farm, Sokoine University of Agriculture Morogoro Tanzania, for improved agricultural productivity of the farm. Four soil profiles were excavated to represent the identified mapping units of the study area, examined and described. Samples were collected from the four pedons according to the natural pedogenic horizons identified, analyzed for both physical and chemical properties and characterized. Soil profiles were described as per FAO (2006) and Soil Survey Staff (2010) soil profile description guidelines. The study revealed that soil colour varied from brown (7.5YR 4/2) through dark brown (7.5YR 4/4) to reddish brown (2.5YR 4/6). Soil structure varied from being weak to moderate sub angular blocky with dominant sand texture. The soil textural class was predominantly sandy loam/sandy clay loam/sand clay. The bulk density and soil moisture values were generally low and ranged between 1.4 and 1.78 cm⁻³ and 1.42 and 12.51%, respectively. Based on the Soil Taxonomy (Soil Survey Staff, 2014) and the World Reference Base for Soil Resources [IUSS Working Group WRB (2015)] soil classification systems, all the soils belong to the soil order Ultisols and Ustalfs at suborder level in the Soil Taxonomy, while Alisols in the Reference Soil Group (RSG) - Tier 1 for the World Reference Base for Soil Resources soil legend. At great group and subgroup levels P1 was classified as Rhodustults and Typic Rhodustults, P1 and P2 as Haplustults and Typic Haplustults, whereas, P4 was classified as Haplustults and Arenic Haplustults (Soil Taxonomy), which correspond to Haplic RhodicAlisols, HaplicAlisols, Haplic

Chromic and HaplicAlisols (World Reference Base) in the Tier 2 for RSG soil name for the P1, P2, P3 and P4, respectively. To increase the productive capacity of this farm, recommended management strategies such as crop rotation, planting cover crops, reducing overgrazing and burning and adoption of integrated nutrient management system which embraces a holistic approach of integrated use and management of organic and inorganic plant nutrient sources in a sustainable way are suggested to improved soil condition and crop production.

Key words: *Soil physico-chemical properties; Pedons; Horizons; Soil characterization; Soil classification; Solomon Mahlangu Campus*

2.2 Introduction

Most of the soils in Africa, Tanzania inclusive are characterized by inherent or induced deficiencies of the major plant nutrient elements, namely N and P and in some cases, low or excess K and micronutrients (Murwira, 2003). Other soil fertility constraints include low nutrient retention capacities, strong acidity, alkalinity and low organic matter contents (Murwira, 2003). Some of the aforementioned constraints lead to land degradation which has been caused by ill-suited land use and inappropriate management practices, notably poor crop rotation, shortening or elimination of the fallow, insufficient use of manures/fertilizers, and removal of crop residues for fodder, inappropriate tillage practices, just to mention but a few. The low agricultural productivity in Tanzania, and hence the very high rate and risks of food insecurity is related to the low quality of the soil resources base.

In Morogoro, there have been a substantial number of studies on the basic information on soils in the form of soil surveys and soil fertility studies for sound land use planning

(Msanya *et al.*, 1991; Msanya and Magoggo, 1993; Kilasara *et al.*, 1994). These studies have centered on a few selected areas and have not been specific to Solomon Mahlangu Campus (SMC) and some adjacent lands. Hence there is inadequate information on SMC farm soils and especially inherent nutrient contents. The parent materials of the soils in question are different from the soils found at SMC farm, which have been derived from pyroxene granulites' containing plagioclase and quartz-rich veins (Moberg *et al.*, 1982).

The nature of parent material is said to profoundly influence development and characteristics of soils (Brady and Weil, 2005). In small regions of uniform climate, the nature of parent material is probably more important than any other single factor in determining the characteristics and productivity of a soil (Olaitan and Lombin, 1984). The type of soil formed under a particular set of environmental conditions is a function of parent material and time. The ability of any soil to supply the required quantity of plant nutrients is mostly affected by the soil genetic composition (parent material), the degree to which the parent material has been altered by the forces of weathering, and the management of the soil by man. It is no gainsay, therefore, that the soil productive potentials and its resiliencies to amendment and management for sustainable agricultural production depend largely on the soil parent material (Ajiboye, 2010).

The appropriate and profitable use of the SMC farm, calls for the study of the properties, classification and characterization of the soils. This study provides information that will enable land users to make proper use of the farm and adopt the appropriate alternative management practices for improved and sustainable productivity. Specifically, the study's objective was to examine and characterize the soils morphological, pedological and physico-chemical properties.

2.3 Materials and Methods

2.3.1 Study location

The study was conducted at Solomon Mahlangu campus farm in Mazimbu village Morogoro District, situated about 200 km west of Dar es-salaam, the major business town of Tanzania. The farm has a total area of 1 030 ha out of which 300 ha were chosen for the study. The area is located between latitudes $6^{\circ}47''S$ and $37^{\circ}3''E$ with an elevation ranging from 500 to 600 m above sea level in Mazimbu village. The study site experiences bimodal rainfall distribution with the long rains having a peak in April-May while the short rains reaches its peak in October-November (Fig. 2.1 and 2.2). The area receives annual rainfall ranging from 600 to 1200 mm. The mean monthly temperature varies from $21.4^{\circ}C$ to $24.3^{\circ}C$ in June and July, respectively, to $26.4^{\circ}C$ in November to February. On the high plateau of the Uluguru Mountains frosts are known to occur during the long rains and the temperature is always cool (Mwango, 2000). The rainfall data (Fig. 2.1 and 2.2) indicate that there is a variation in the total yearly rainfall as in some years moisture may be limiting to crop production; for instance, the average rainfall between 2012 and 2014 is <500 mm which is low for most of the crops. The sketch map of the study area is shown in Appendix 2.1.

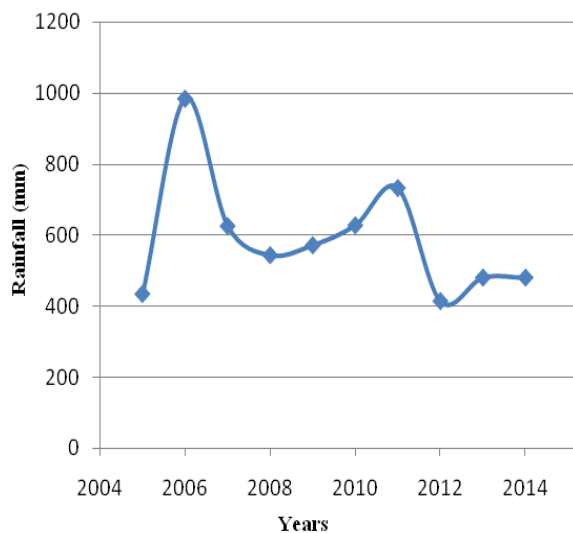


Figure 2.1: Yearly total rainfall of the study area for the last 12 years

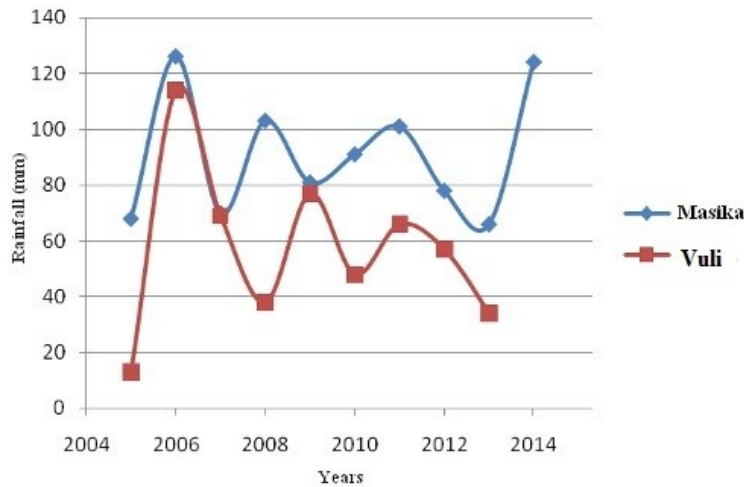


Figure 2.2: Mean annual rainfall (Masika and Vuli) of SMC for the past 12 years

2.3.2 Site survey

The study area was surveyed using the grid method. Auger point investigations were carried out at 100 m intervals along traverses cut at 100 m apart on the baseline. An initial reconnaissance survey of the study area was done to identify the external features (local indicators of soil fertility), followed by transect walks; auguring and selection of representative transect sampling points. Soil from the auger points were grouped into mapping units based on similarities of the morphological properties. Four mapping units were thus delineated and identified from the selected area. The coordinates and elevation of the study area were taken with the aid of a portable global positioning system (GPS) receiver (MODEL GARMIN 12 L).

Four profile pits (1.5 m x 1.5 m long x 2 m/limited layer deep) were sited, excavated, studied, described and sampled (Fig. 2.3 to 2.6). Geo-referencing of all profiles was done with the aid of the portable global positioning system (GPS) receiver (MODEL GARMIN 12 L). The profiles were coded as profile I to IV (Fig. 2.7). Soil profiles were described as per FAO (2006) soil profile description guideline.



Figure 2.3: Picture for profile I



Figure 2.4: Picture for profile II



Figure 2.5: Picture for profile III



Figure 2. 6: Picture for profile IV

All profiles were sampled according to the identified natural horizons from bottom to the top and carefully labeled for laboratory studies. Soil colour was determined by Munsell soil colour charts (Munsell Colour Co., 1992). A total of 21 composite soil samples were collected from natural horizons of the four profiles representing four mapping units and four core samples were taken by using cores sampler and geological harmer for the determination of bulk density and moisture characteristics. The collected samples were bagged and labeled to reveal profile horizon number, depth and horizon designation. The collected soil samples were air-dried, gently crushed and sieved to pass through a 2 mm sieve to obtain the fine earth fraction (< 2 mm) for laboratory investigation. The soil samples were taken to the laboratory for analyses.

2.3.4 Analysis of soil physico-chemical properties

Particle size distribution was determined by the hydrometer method as modified by Udo *et al.* (2009). Bulk and particle densities were determined by the methods of Blake and Hartge (1986) as described by Longanathan (1984). Soil pH was determined in 1:1 soil: water and 1:2 soils: 1.0M KCl suspensions respectively, using a glass electrode pH meter (Longanathan, 1984). Organic carbon was determined by the Walkley and Black (1934) wet oxidation method as modified by Udo *et al.* (2009). Exchangeable basic cations (Mg, Ca, K and Na) were extracted by IM NH_4AC buffered at pH 7. Total nitrogen was determined by Kjeldahl- digestion- distillation method of Bremner and Mulvaney (1982) while extractable phosphorus was determined by the Bray and Kurtz No.1 for acid soils and Olsen method for alkaline soils (Udo *et al.*, 2009). Available micronutrients (Cu, Zn, Fe and Mn) were extracted by DTPA and then determined quantitatively by Atomic Absorption Spectrophotometer (AAS) (Senjobi, 2007). Soil moisture retention characteristics were determined using sand kaolin box for low suction values and pressure membrane apparatus for higher suction values (NSS, 1990).

2.3.5 Data summary and description

All data obtained were summarized and presented using tables and graphs.

2.3.6 Soil classification

Using field and laboratory data, the soils were classified to family level according to Keys to Soil Taxonomy (Soil Survey Staff, 2014) and to WRB soil name- Tier 2 according to the World Reference Base for Soil Resources [IUSS Working Group WRB (2015)] soil classification system.

2.3.7 Soil map production and data analysis

Using both field and laboratory data a spatial distribution of soils was established and presented in Fig. 2.8. The data on physical and chemical soil properties were summarized using descriptive statistics such as minimum, maximum, means and standard deviation. These were subjected to simple linear correlation analysis using GenStat Discovery Edition 14 software between measured characters to assess the relationships between parameters.

2.4 Results and Discussion

2.4.1 Morphology and genesis of the soils

Table 2.1 gives the distinctive characteristic features of the study site soils (Profiles I to IV). The soils were described and distinguished on the basis of parent materials, geological formation, slope, drainage class, vegetations, and land use, morphological and physical characteristics. Soil profiles morphological properties representing the area are presented with description of each unit (Appendices 2.1 – 2.4).

2.4.2 Description of the soil mapping units

Fig. 2.3 presents topographic information of the soil mapping units using a representative soil profiles (1-4) in the whole study area. Profile 1 which represent mapping unit 1 is situated at an average altitude of 500 meter a.s.l, with a slope gradient range of 2 - 3% (gently sloping).

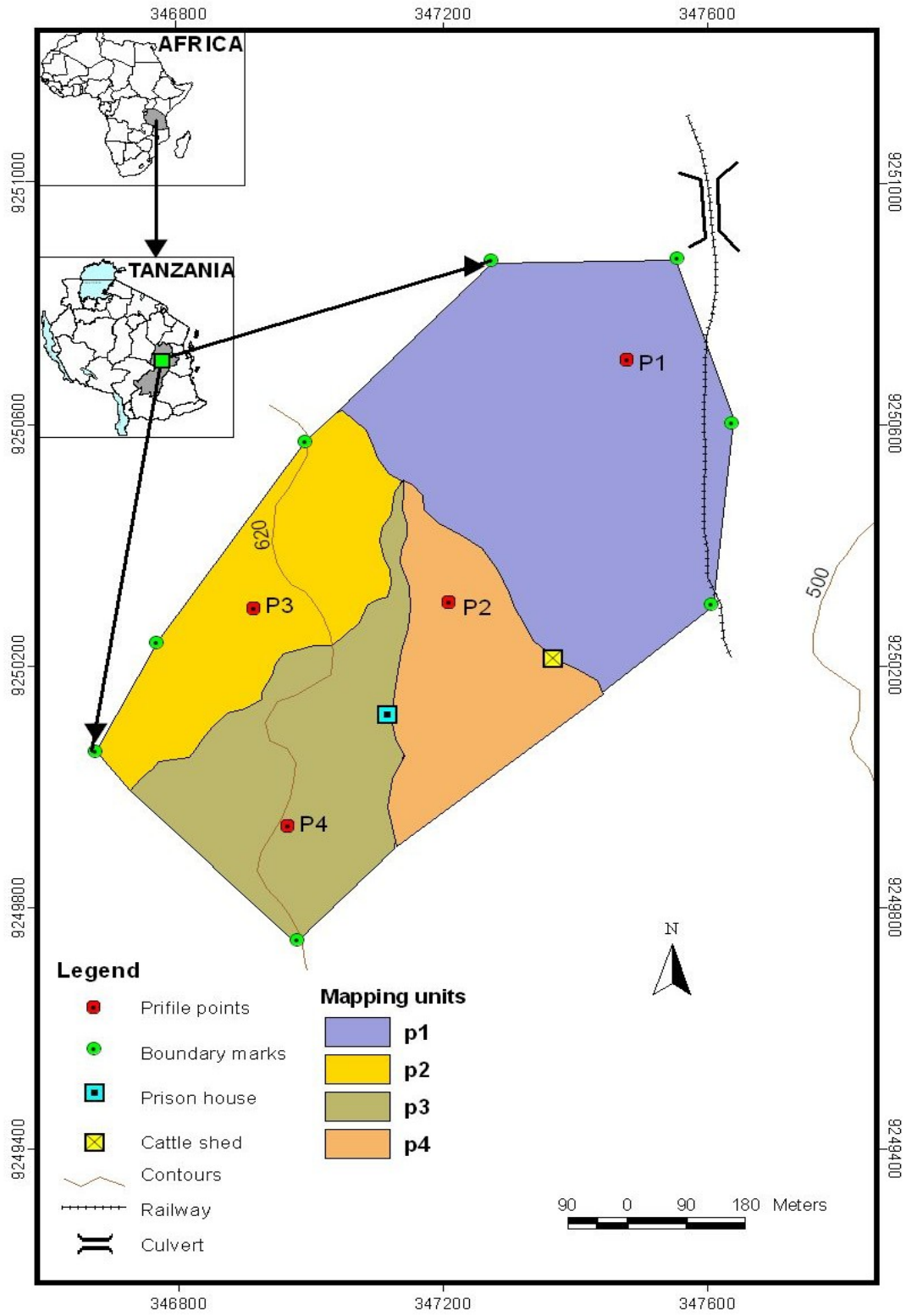


Figure 2.7: Sketch map of the study area showing the mapping units and pedons locations

Table 2.1: Site characteristics of the Solomon Mahlangu Campus farm soils

Pedon No.	Soil Unit	Elev. M.a.s.l	Coordinates	Landforms	Parent material	Land use/Vegetation	STR	SMR	DRG	Slope (%)
1	SMC-1	500	34748'S 9250758'E	Colluvial Plains	Sedimentary rocks	Maize, natural grasses, Acacia, Eucalyptus spp.	Hyp	Ustic	Well	3 gnt.
2	SMC-2	509	347216'S 9250347'E	Colluvial Plains	Sedimentary rocks	Maize, livestock	Hyp	Ustic	Well	2 gnt.
3	SMC-3	522	346928'S 925000335'E	Colluvial Plains	Colluvium derived from mafic metamorphic rocks	Grazing, natural grasses & shrubs	Hyp	Ustic	Moderate ly Well	2 str.
4	SMC-4	522	346928'S 9249972'E	Colluvial Plains	Sedimentary rocks	shrubs	Hyp	Ustic	Well	4 gnt., mid

SMC= Solomon Mahlangu Campus SMR= Soil moisture regime STR= Soil temperature regime Colmv.=colluvium

DRG= Drainage Sedm=sedimentary hyp= hyperthermic gnt= gently str= straight m=mid Elev. =elevation m.a.s.l=meters above sea level

The parent material of all the profiles is colluvium derived from mafic metamorphic rocks (hornblende pyroxene granulites) of the Uluguru Mountains with many macro relief and geological formation of sedimentary rocks through weathering of rocks (Moberg, *et al.*, 1982). All the four profiles have surface soils of the moderately to well drained. The natural vegetation includes natural grasses, *Acacia spp*, *Eucalyptus spp* and shrubs with a land use systems that embraces maize and sunflower production. There were no sealing deposition and runoff problems with very slight sheet erosion. Hyperthermic soil temperature and ustic soil moisture regimes in all the soils pedons a condition of limited water with a mean annual soil temperature equal or greater than 22 °C.

The profiles 2, 3 and 4 that represented mapping units 2, 3 and 4 respectively are situated at an average altitude of 509, 522 and 521 m.a.s.l., with approximately 200 cm modified ground water level. The variations in slope forms have had significant influences on characteristics and distribution of soils such as texture mineral content and drainage conditions.

Table 2.2 provides a summary of morphological properties of all the four pedons studied at SMC Farm Soils. The soil pedons have structures that varied from weak-sub-angular-blocky peds (W-sbk) in the surface horizons to crumbly-sub-angular blocky peds (cr-sbk) in the subsurface soil with abrupt, clear and smooth to diffuse and smooth horizon boundaries from surface to subsurface horizons, respectively. The weak sub angular blocky peds of very friable to loose consistence were probably due to the low clay content.

Table 2.2: Some Morphological/Physical Characteristics of SMC Profile soils

Pedon	Horizon	Sampling depth (cm)	Horizon boundary	Munsell – soil colour notation		Texture	Consistence	Structure	Curtains	Pores	Roots	Other features		
				moist	dry								dry	m & w
	Ap	0 – 27	A & S	7.5YR4/4	7.5YR3/2	S	Sh	vfr,ns & np	W, sbk	—	a, f-m	vf-m	—	
	Bt1	27 – 35	C & S	5YR4/4	5YR4/6	SL	H	fr, ss & sp	W - msbk	f,cc	m, f-m	mf&vf	v.f. fer	
1	Bt2	35 – 77	D & S	2.5YR4/6	2.5YR3/4	SCL	Sh	fr, ss & sp	m-Csbk	f,cc	m, f-m	mf&vf	Mites	
	Bt3	77 - 120	D & S	2.5YR4/6	2.5YR4/4	SCL	Sh	fr, ss & sp	m - csbk	f-m cc	m, f-m	fvf-vf	Nest	
	Bt4	120 –167 ⁺	—	2.5YR4/8	2.5YR4/6	SCL	H	fr, ss & sp	cr - csbk	f- m, cc	m,f	v.vf& v.f	—	
	AP	0 – 46	CS	7YR4/2	7YR3/2	S	Sh	vfr,ns & np	W, sbk	—	mf	fvf & fim	—	
2	Bt1	46-120	CS	7.5YR5/4	7.5YR4/4	SL	H	fr, ss & sp	w-m sbk	f-cc	mf	vfm&ff	Few cracks	
	Bt2	120 -162 ⁺⁺	DS	7.5YR6/4	7.5YR5/4	SL	H	fr, ss & sp	cr-sbk	—	a,f	vff&m	—	
	AP	0 -19	DS	7.5YR4/3	7.5YR4/4	S	Sh	vfr,ns & np	W,sbk	vff-cc	a,f	vfm-f	—	
3	Bt1	19 - 40	CS	7.5YR4/3	7.5YR4/2	SL	Sh	fr, ss & sp	w-m sbk	f, cl	af-m	vff-m	—	
	Bt2	40 - 100	DS	5YR4/4	5YR4/3	SL	H	fr, ss & sp	cr, sbk	f-m,	af-vf	vff	—	
	Bt3	100 -175 ⁺⁺	DS	5YR4/3	5YR4/3	C	Vh	rh, ss & sp	m-crsbk	f, cc	f-m	—	—	
	Ap	0 -38	CS	7.5YR4/3	7.5YR4/2	S	S	vfr,ns & np	W, f-msbk	df-cc		vff	—	
4	Bt1	38-79	CS	7.5YR6/4	7.5YR5/7	SL	Sh	vfr,ns & np	W, fsbk	ff-cc		vff	—	
	Bt2	79-138	CS	7.5YR6/4	7.5YR5/3	SCL	H	sfr, ns & np	M-crsbk	mf-cc		mf	—	
	Bt3	138-161 ⁺⁺	DS	7.5YR7/4	7.5YR6/4	SCL	H	vfr,ns & np	f-m sbk	m-cc		cf	—	

1) a = Abrupt, c=clear d = diffuse S=smooth

2) S = Sand; SL = Sandy loam; C = Clay; CL = Clay loam Sc = Sandy clay L = loam L = loam S = Silt

3) S = Soft, h = hard, sh = slightly hard vh = very hard; sfr = slightly friable fr = friable; vfr = very friable; ns = non sticky;

SS = slightly sticky, np = non plastic, Sp = slightly plastic.

4) W, sbk = weak sub angular blocky; W-m, sbk = weak to moderate sub angular blocky; m-c, sbk = moderate to crumbly sub angular blocky,

cr - crumb, cr,sbk = crumbly sub angular blocky; m-crsbk = moderate to crumbly sub angular blocky.

F-msbk = fine to moderate sub angular blocky

5) f,cc = fine clay cutans; f-m,cc = fine to medium clay cutans; vff, cc = very few fine clay cutans m,cc = medium clay cutans

6) a,f - m = abundant fine to medium; m,f - m = many fine to medium; mf = many fine, af = abundant fine, af - vf = abundant fine to very fine,

Vff = very few fine; cf = common fine.

7) vf - m = very fine to medium; mf-vf = many fine to very fine; fvf&vf = few very fine & very fine; vvf&vf = extremely fine and very fine. Vfm - f = very few medium to fine

8) v.f = very few.

The pedons have different matrix colour that ranged from light brown (7.5YR 4/2) to dark brown (7.5YR 4/4) then to reddish brown (2.5 YR 4/6) in the surface and subsurface horizons. The variation in colour and the presence of mottles are most likely due to the high degree of hydration and redox reactions, occasioned by the proximity of fluctuating underground water table (70-100 cm) within the zone. The parent materials of the soils are derived from pyroxene granulites containing plagioclase and quartz-rich veins (Moberg *et al.*, 1982) implying that the rocks are metasediments covered mostly by red and reddish brown soils of low nutrient contents.

The soil texture showed that the materials were largely sandy and sandy loam in the surface horizons to sandy clay and clay loam in the sub-horizons. This explains why the consistence of the materials was friable to lose when moist due to weak cohesion and adhesion forces act on the soil materials.

2.4.3 Soils physical and chemical characteristics

Tables 2.3, 2.4 and 2.8 show the physical and chemical properties of soils at Solomon Mahlangu campus farm. The clay content of the soils from all profiles ranged from 8.12 to 38.12 %. Generally, the clay content was higher in the subsurface horizons and increased regularly down the profile (Table 2.3). These increases in clay content with depth could be probably due to illuviation process in the sub surface horizons. Similar results were obtained by Adamu (2013) and Singh (1999) in their studies of soils in Kano and Kebbi States, Nigeria.

In the current study, the sand content ranged from 24 to 90.24%. The highest value of sand was recorded in the surface horizon of profile 1, while the least sand value was recorded in the subsurface (last) horizon of profile 3. The observed high sand content in the surface

soil could probably be due to high precipitation of clay in the surface down to the profile leaving much of the sand in the surface soil; d also, the sand might have been transported from high elevated area to lowland. Unlike clay content, the sand values were generally the highest at the surface horizon of all the profiles and decreased with an increase in the depth down the profile with the lowest value occurring in the deepest horizons of all the profiles. The differences between the sand contents of the surface (first) and the last horizon were greater than 20%. The percentage silt content was similar in all the profiles (1.64%) except for profile 4 and surface horizon of profile 2. The values of silt were the lowest compared to those of sand and clay fractions.

The soil textural class was predominantly sandy clay loam/loamy sand/sand clay. The general characteristics of the soils were of high sand and low silt contents. Most of the profiles had greater than 60% sand, 20% clay and less than 5% silt (Table 2.3). The sandy nature of these soils could be attributed to the nature of parent materials. Sand fraction appeared to be the dominant size (70.12-90.24%) in the surface horizons in all profiles, while silt and clay contents were low and medium. This is in line with the findings in a study by Okanny *et al.* (1999) and Ayolagha and Onuegbu (2002) who reported that the levee crest and levee slopes are dominantly sandy, while the flood plains and back swamps are dominantly clay in textures in their study of soils of Rivers State Nigeria. Similar findings were also reported by Lekwa (1992) in the soils of Kano Nigeria.

In the current study, the bulk density (BD) values were high and ranged from 1.4 to 1.78 cm^{-3} with values increasing with soil depth gradually from surface to subsurface horizons. The high BD indicates that, the high sand content and soils were non-compacted; and, its increase with soil depth could be attributed to a decrease in organic matter content from surface to subsurface horizons. Soil moisture content generally varied from 1.42 to 5.77% in the surface horizon and from 3.38 to 12.51% in the subsurface horizons of all the profiles.

Soil pH ranged from strongly acidic (pH in H₂O = 5.1; pH in KCl = 4.3) to slightly alkaline (pH in H₂O = 6.9; pH in KCl = 5.5). The soil pH decreased with soil depth in Profiles 2 and 3, while it increased with an increase in depth in profile 4. The decrease of soil pH with depth could probably be due to variation of soil moisture content and drainage condition as pH is normally higher in the well- drained soils in the dry season, when there are limited root and microbial activity in the soil as CO₂ content in the soil is much lower in the dry season than is the case in the wet season. The soil pH in KCl was lower than the pH in H₂O with almost 1 unit which indicates an increase in the activity of H⁺ in the soil that was caused by the K⁺. The pH of these soils currently could not pose any serious problem to crop production, as most crops will thrive well in soils with pH between 5.5 and 6.5 (Ajiboye, 2012).

The content of organic carbon of the soils was low to moderate. The surface horizons have higher percentage organic carbon and organic matter than the subsurface horizons. The surface horizons had organic carbon contents that ranged from 0.29% to 0.51%, while the subsurface had a value of 0.02% and organic carbon of 0.27%. The organic matter ranged from 0.23 to 0.84% for the surface horizons and from 0.03 to 0.54% for the subsurface horizons (Table 2.4). The low levels of organic matter as related to the organic carbon properties might partly be attributed to the rapid organic matter mineralization and frequent burning of the area commonly carried out during the dry season. The burning destroys valuable organic materials that add organic matter to the soil and this indicates impossibility of having optimum maize yields in the area as maize is a high feeder which requires adequate nutrients for good performance and optimum yields.

The cation exchange capacity (CEC) for the surface soils ranged from 9.0 to 11.40 cmol (+) kg⁻¹ for the surface horizons and from 15.0 to 17.80 cmol (+) kg⁻¹ for the subsurface horizons. The CEC increased with an increase in depth in all the profiles except in horizon 3 of profile 4 (Table 2.4). The low values of CEC as per the rating scale in Table 2.7 may

be attributed to low clay and organic matter contents of these soils; something which invariably leads to low nutrients retention capacity of these soils.

Table 2.3: Some Physical Properties of Soils of the Study Area

Horizons	Depth	% Particle Size Distribution			Texture	BD (g/cc)	Soil Moist (%)
		Sand	Silt	Clay			
Profile- MZB 1							
AP	0-27	90.24	1.64	8.12	Sand	–	–
Bt1	27-35	74.24	1.64	24.12	Sandy loam	1.56	2.68
Bt2	35-77	70.24	1.64	28.12	Sandy clay loam	1.52	6.06
Bt3	77-120	70.24	1.64	28.12	Sandy clay loam	1.55	4.06
Bt4	120-160	268.24	1.64	30.12	Sandy clay loam	–	–
Means		74.64	1.64	23.72		1.54	4.27
SD		8.99	0.01	8.99		0.02	1.70
Profile- MZB 2							
Ap	0-46	84.24	3.64	12.12	Sand	1.64	5.77
Bt1	46-120	74.24	1.64	24.12	Sandy loam	1.66	7.17
Bt2	120-162	60.24	1.64	38.12	Sandy clay	1.64	7.28
Means		2.90	2.31	24.79		1.66	6.74
SD		9.84	0.94	10.62		0.02	0.69
Profile- MZB 3							
Ap	0-19	86.24	1.64	12.12	Sand	1.54	2.99
Bt1	19-40	72.12	1.64	26.12	Sandy loam	-	-
Bt2	40-100	54.24	1.64	44.12	Sandy clay	1.54	9.45
Bt3	100-175	44.24	1.64	54.12	Clay	1.51	12.51
Means		64.21	1.64	34.12		1.52	8.32
SD		18.67	0.01	18.69		0.02	4.86
Profile- MZB 4							
Ap	0-38	86.24	5.64	8.12	Sand	1.47	1.42
Bt1	38-79	82.24	1.64	16.12	Sandy loam	1.50	3.38
Bt2	79-138	62.24	3.64	34.12	Sandy clay loam	1.78	6.4
Bt3	138-161	70.64	1.64	28.12	Sandy clay loam	-	-
Means		75.34	3.14	21.12		1.58	3.73
SD		10.96	1.91	11.70		0.17	2.51

The available or extractable phosphorus ranged from 4.97 mg kg⁻¹ to 11.52 mg kg⁻¹ for the surface horizons and from 2.6 to 5.6 mg kg⁻¹ for the sub surface horizons. This is probably due to a decrease in soil pH from surface to sub surface horizons, hence the low soil pH which normally favours P immobilization (Brady and Weil, 2008). The production of maize will therefore be low as P is among the important nutrients element for maize production.

The exchangeable bases (Ca²⁺, Mg²⁺, K⁺ and Na⁺) were also low. The exchange sites of the soils were dominated by exchangeable calcium and magnesium. The values of exchangeable calcium (Ca²⁺) of the surface horizon ranged from 0.37 to 3.16 cmol kg⁻¹ and from 0.37- 5.03 cmol kg⁻¹ for the subsurface horizons. The exchangeable magnesium content varied from 0.38 to 2.13 cmol kg⁻¹ for the surface horizons and from 2.20 to 3.50 cmol Kg⁻¹ for the subsurface horizons (Table 2.4). The content of Mg²⁺ increased with an increase in the depth of the soils, the highest content been observed in the last horizons in all the profiles. This is attributed to an increase in clay content from surface to sub surface horizons.

The exchangeable K and Na status of the soils are medium in most of the horizons. The value of exchangeable K ranged from 0.13 to 0.52 cmolkg⁻¹ and from 0.10 cmolkg⁻¹ to 5.00 cmolkg⁻¹ for the surface and subsurface horizons respectively, while the exchangeable sodium varied from 0.12 cmolkg⁻¹ to 0.60 cmolkg⁻¹ for the surface horizon and from 0.30cmolkg⁻¹ to 1.10cmolkg⁻¹ for the subsurface horizons. The exchangeable bases occur in the order Mg > Ca > K > Na as also reported by many other workers in alluvial soils (Esu, 1991). The low content for these exchangeable bases especially Ca and Mg might be due to low content of CEC of the soils.

Table 2.4: Some Chemical Properties of the Solomon Mahlangu Campus Farm Soils

Horizon	Depth (cm)	pH				Avail. P mg/kg	Exchangeable bases and CEC (cmol (+))/kg TEB					B S %	
		H ₂ O	KCl	OC(%)	TN		Ca	Mg	K	Na	CEC		
Pedon 1- SMC-1													
Ap	0-27	7.23	5.84	0.29	0.04	11.54	1.30	0.58	0.28	0.21	9.0	2.37	26.35
Bt1	27-35	6.29	5.54	0.33	0.04	2.75	3.16	2.13	0.21	0.22	11.8	5.73	48.54
Bt2	35-77	6.81	5.05	0.29	0.04	2.84	1.77	2.20	0.10	0.24	13.2	4.31	32.63
Bt3	77-120	6.99	5.99	0.12	0.01	6.15	2.23	2.58	0.10	0.30	15.4	5.21	33.85
Bt4	120-162	7.14	6.54	0.02	0.02	2.65	5.03	2.62	0.10	0.35	15.4	8.21	52.66
Pedon 2- SMC-2													
Ap	0-46	6.76	5.85	0.49	0.04	6.73	1.30	1.03	0.25	0.24	9.20	2.58	28.03
Bt1	46-120	6.34	4.68	0.27	0.04	3.38	0.37	1.75	0.30	0.40	11.20	2.82	25.21
Bt2	120-162	6.22	4.50	0.27	0.04	4.61	0.37	2.91	0.39	1.10	15.0	4.78	31.84
Pedon 3-SMCF-3													
Ap	0-19	7.12	5.53	0.51	0.04	9.30	0.37	0.74	0.36	0.18	11.20	1.65	14.76
Bt1	19-40	6.92	5.42	0.39	0.04	2.05	0.84	1.72	0.52	0.28	13.80	3.35	24.31
Bt2	40-100	6.84	5.49	0.31	0.04	2.02	1.30	2.65	1.25	0.77	16.80	5.97	35.56
Bt3	100-175	5.06	4.27	0.16	0.05	3.75	1.77	3.16	0.55	0.98	17.80	10.91	61.31
Pedon 4-SMCF-4													
Ap	0-38	7.25	5.32	0.14	0.03	4.97	0.37	0.38	0.14	0.12	11.40	1.02	12.96
Bt1	38-79	6.78	4.58	0.29	0.04	2.17	0.37	1.23	0.13	0.60	13.20	2.33	17.66
Bt2	79-138	6.95	5.20	0.27	0.04	1.30	0.84	3.27	0.17	0.34	10.80	4.62	42.80
Bt3	138-161	6.25	5.15	0.04	0.03	5.62	2.70	3.50	0.30	0.64	16.60	7.13	42.98

TEB= Total exchangeable bases BS= Base saturat

Tables 2.5, 2.6 and 2.7 indicate that the critical limit/rating of interpreting soil fertility level. These tables were used as a guide in rating some of the physical and chemical properties of the soils as low or medium soil fertility class.

Table 2.5: Rating for Soil Fertility Classes

PARAMETER	LOW	MEDIUM	HIGH
Total N gkg ⁻¹	<1.5	1.5 – 2.0	>2.0
Bray 1P mg kg ⁻¹	<8	8 – 20	>20
Exch K cmol kg ⁻¹	<0.20	0.20 – 0.40	>0.40
Exch Ca cmol kg ⁻¹	<5.0	5.0 – 10.0	>10.0
Exch Mg cmol kg ⁻¹	<1.5	1.5 – 3.0	>3.0
Exch Na cmol kg ⁻¹	<0.3	0.3 – 0.7	>0.7
Org. matter gkg ⁻¹	<20	20 – 30	>30

Sources: FMA & NR (1990).

Table 2.6: Critical Limits for Interpreting Levels of Analytical Parameters

Parameter	Rating			Unit
	Low	Medium	High	
Ca	<2	2 – 5	>5	cmol (+) kg ⁻¹
Mg	<0.3	0.30-1.0	>1.0	cmol (+) kg ⁻¹
K	<0.15	0.15-0.30	>0.30	cmol (+) kg ⁻¹
Na	<0.1	0.1-0.30	>0.30	cmol (+) kg ⁻¹
ECE	<5	5.0-1.0	>10.0	cmol (+) kg ⁻¹
CEC (Soil)	<6	6-12	>12	cmol (+) kg ⁻¹
CEC (Clay)	<15	15-25	>25	cmol (+) kg ⁻¹
Exch. Acidity	<2	2-5	>5	cmol (+) kg ⁻¹
Base saturation	<50	50-80	>80	percent
Org. C	<10	10-15	>15	gkg ⁻¹
Total N	<0.1	0.1-0.2	>0.2	gkg ⁻¹
Avail. P	<10	10-20	>20	mgkg ⁻¹

Source: Esu (1991); Enwezor *et al.* (1981).

The low N suggests that it is associated with organic matter contents of the soils as weathering of soil and minerals decomposition replaces annual deflation of soils nutrients (Adamu, 2013; Havlin *et al.*, 2005).

Table 2.7: Rating of the status of copper (Cu) Zinc (Zn) manganese (Mn) iron (Fe) exchangeable acidity (H^+ Al^{3+}) and (CEC) in the savannah zone adopted by Tisdale *et-al.* (1995)

Parameters	RATING		
	<u>Low</u>	<u>Medium</u>	<u>High</u>
Copper (Cu) (ppm)	0—2.5	2.6—4.5	>4.5
Zinc (Zn) (ppm)	1.0	—	>1.0
Manganese (Mn)(ppm)	1.0	1.0	>1.0
Iron (Fe) (ppm)	0.25	2.6-4.5	>4.5
Exchangeable acidity	2	2-5	>5(mo (+)kg ⁻¹)
CEC (soil)	6	6-12	>12(mo (+)kg ⁻¹)

The percentage base saturation (BS) content of the soils (12.96 - 61.31 %) was rated low to high (Wood, 1981). In almost all the profiles the BS% increased with an increase of the content of exchangeable bases and CEC which probably might be due to an increase in the clay content from surface to sub surface horizons.

However, the available micronutrients, notably Cu, Zn, Fe and Mn ranged from being medium to high in all the profiles (Table 2.8). The Cu and Zn content were medium and Fe and Mn were generally high. While Cu value varied from 0.16 mg kg⁻¹ to 0.76 mg kg⁻¹ and Zn content ranged from 0.08 mg kg⁻¹ to 0.61 mg kg⁻¹ in all the profiles, the exchangeable Fe and Mn varied from 4.97 mg g⁻¹ to 64.14 mg kg⁻¹ and 2.90 mg kg⁻¹ to

31.50 mg kg⁻¹ in the surface and subsurface horizons of all the profiles. The medium to high values of these micronutrients may be due to long period of fallows as land has not been under cultivation for many years and also the soil genetic composition (parent materials), which is said to profoundly influence development and characteristics of soils (Brady and Weil, 2005).

The results of the investigated physico-chemical soil parameters indicate that in some areas there were deficiencies of major nutrients element and therefore requires additions of manures and fertilizers from external sources for optimum crops production including maize crop production in the area.

Table 2.8: Profile Distribution of Micro-nutrients

Horizons	Depth (cm)	Cu	Zn mgkg ⁻¹	Fe	Mn
Pedon 1 SMCF SUA					
AP	0-27	0.40	0.31	11.26	29.0
Bt1	27-35	0.40	0.61	20.68	31.5
Bt2	35-77	0.61	0.11	17.02	27.75
Bt3	77-120	0.73	0.11	12.30	24.0
Bt4	120-162++	0.64	0.08	7.07	20.25
Pedon 2 SMCF, SUA					
Ap	0-46	0.40	0.28	25.39	18.28
Bt1	46-120	0.40	0.08	43.19	13.28
Bt2	120-162	0.76	0.11	64.14	12.75
Pedon 3 SMCF, SUA					
Ap	0-19	0.46	0.23	18.06	15.28
Bt1	19-40	0.46	0.10	19.11	14.65
Bt2	40-100	0.55	0.12	15.45	8.40
Bt3	100-175	0.61	0.13	23.30	3.90
Pedon 4 SMCF, SUA					
Ap	0-38	0.16	0.19	17.54	7.53
Bt1	38-79	0.25	0.08	32.20	3.65
Bt2	79-138	0.64	0.14	27.49	4.40
Bt3	138-161	0.37	0.08	4.97	2.90

2.4.4 Soil classification

Summary of diagnostic horizons and features of the studied soils (USDA Soil Taxonomy) was presented Table 2.9. The soils of the study area were classified to family level according to Keys to Soil Taxonomy (Soil Survey Staff, 2014) and to WRB soil name-Tier 2 according to the World Reference Base for Soil Resources [IUSS Working Group WRB (2015)]. Soil classification systems as presented in Tables 2.10 and 2.11. The P1, P2, P3 and P4 all have Ochricepiedon, Argillic horizons and hence classified at order level as Ultisols. The ustic moisture regime qualified all pedons as Ustalfs at suborder level. In the World Reference Base for Soil Resources soil legend, these soils were grouped as Alisols in the (RSG) - Tier 1 because of an Argic horizon. At great group and subgroup levels, P1 was classified as Rhodustults and Typic Rhodustults, P1 and P2 as Haplustults and Typic Haplustults, whereas P4 was classified as Haplustults and Arenic Haplustults (Table 2.10). This correlated with the Haplic RhodicAlisols, HaplicAlisols, Haplic Chromic and HaplicAlisols (Table 2.11) in the Tier 2 for WRB soil name for P1, P2, P3 and P4, respectively.

Table 2.9: Summary of diagnostic horizons and features of the studied soils (USDA Soil Taxonomy)

Pedon No.	Diagnostic epipedon and subsurface horizon	Soil depth class	Particle size class	Soil Reaction class	Other diagnostic features
SMC-P1	Ochricepiedon, Argillic horizon	Very deep	Loamy	Slightly acid to neutral	Ustic*SMR, Isohyperthermic#STR, presence of clay skins, appreciable clay gradient between eluvial and illuvial horizons
SMC-P2	Ochricepiedon, Argillic horizon	Very deep	Loamy	Slightly acid to neutral	Ustic SMR, Isohyperthermic STR, presence of clay skins, appreciable clay gradient between eluvial and illuvial horizons
SMC-P3	Ochricepiedon, Argillic horizon	Very deep	Loamy over clayey	Slightly acid to neutral	Ustic SMR, Isohyperthermic STR, presence of clay skins, appreciable clay gradient between eluvial and illuvial horizons
SMC-P4	Ochricepiedon, Argillic horizon	Very deep	Loamy	Neutral to mildly alkaline	Ustic SMR, Isohyperthermic STR, presence of clay skins, appreciable clay gradient between eluvial and illuvial horizons

*SMR = Soil moisture regime

#STR = Soil temperature regime

**Table 2.10: Classification of the studied soils according to Keys to Soil Taxonomy
(Soil Survey Staff, 2014)**

PedonNo.	Order	Suborder	Great group	Subgroup	Family
SMC-P1	Ultisols	Ustults	Rhodustults	Typic Rhodustults	<i>Very deep, loamy, slightly acid to neutral, ustic, isohyperthermic, TypicRhodustults</i>
SMC-P2	Ultisols	Ustults	Haplustults	Typic Haplustults	<i>Very deep, loamy, slightly acid to neutral, ustic, isohyperthermic, TypicHaplustults</i>
SMC-P3	Ultisols	Ustults	Haplustults	Typic Haplustults	<i>Very deep, loamy over clayey, slightly acid to neutral, ustic, isohyperthermic, TypicHaplustults</i>
SMC-P4	Ultisols	Ustults	Haplustults	Arenic Haplustults	<i>Very deep, loamy, neutral to mildly alkaline, ustic, isohyperthermic, ArenicHaplustults</i>

Table 2.11: Diagnostic horizons and other features of the studied soil profiles and their classification according to the World Reference Base for Soil Resources [IUSS Working Group WRB (2015)]

Pedon No.	Diagnostic horizons and other features	Reference Soil Group (RSG) - Tier 1	Principal Qualifiers	Supplementary Qualifiers	WRB soil name- Tier 2
SMC-P1	Argichorizon	Alisols	Rhodic, Haplic	Loamic,Cutanic	<i>HaplicRhodicAlisols (Loamic, Cutanic)</i>
SMC-P2	Argic horizon	Alisols	Haplic	Arenic, Cutanic	<i>HaplicAlisols (Arenic, Cutanic)</i>
SMC-P3	Argic horizon	Alisols	Chromic, Haplic	Haplic Chromic	<i>Haplic Chromic Alisols (Clayic, Cutanic)</i>
SMC-P4	Argic horizon	Alisols	Haplic	Arenic, Cutanic	<i>HaplicAlisols (Arenic, Cutanic)</i>

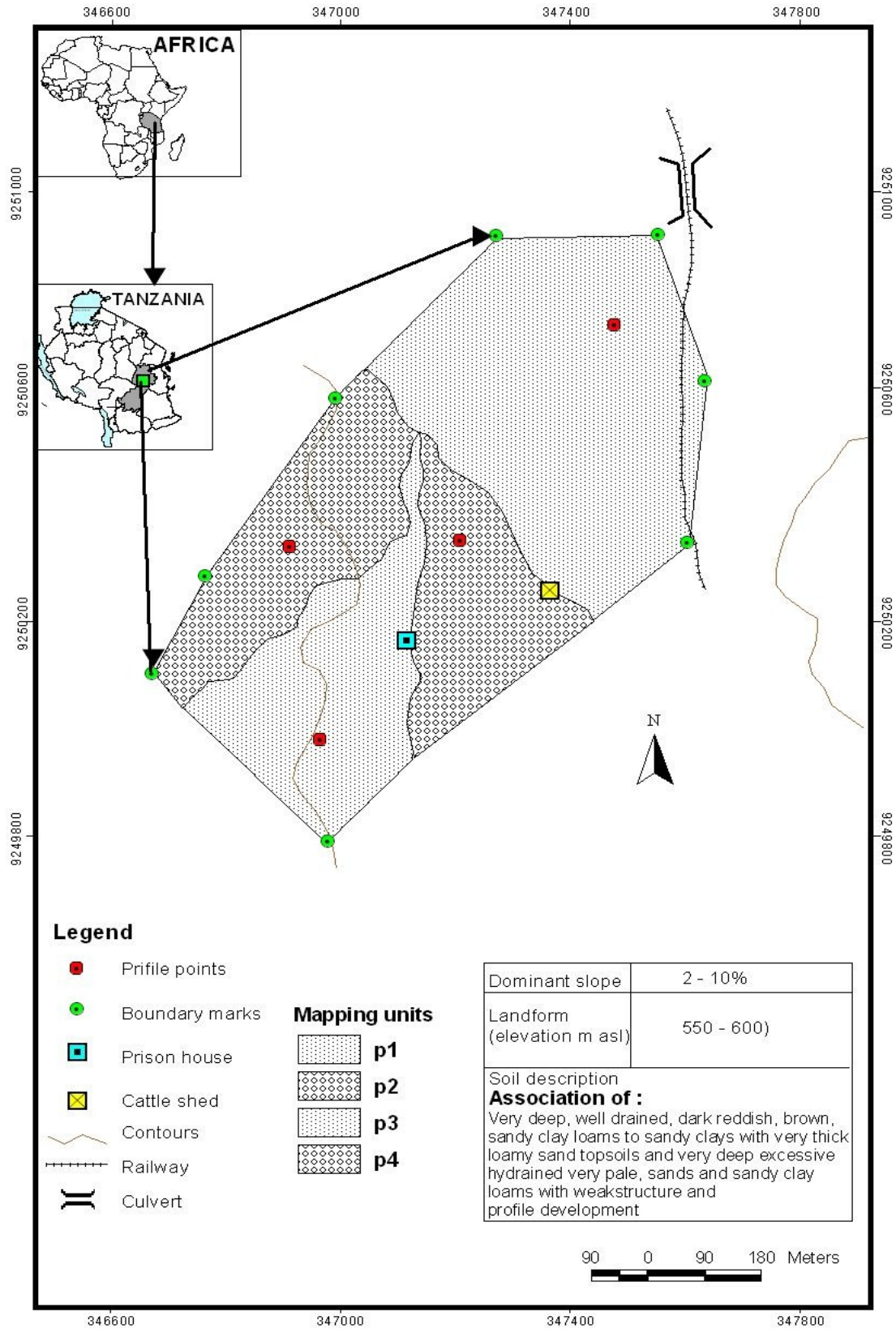


Figure 2.8: Sketch map of the study area showing soil's spatial distribution

2.4.5 Soil management strategy

Major problems with the soil morphological and physical properties investigated include weak structure and inadequate moisture retention capacity. Based on these limitations therefore, it is suggested that the recommended soils management practices and approaches of reducing nutrients losses caused by overgrazing, burning, erosion, surface run off and leaching, crop residues management and complementary use of organic and inorganic manures should be determined on the farm to improved soil productivity.

2.5 Conclusions and Recommendations

The soils were described and distinguished on the basis of parent materials and forms, macro relief, Geological formation, slope, drainage class, vegetation, land use, and morphological and physical characteristics. Soil colour varied from brown (7.5YR 4/2) through dark brown (7.5YR 4/4) to reddish brown (2.5YR 4/6). Soil structure varied from being weak to moderate sub angular blocky with dominant sand texture. The results of this study have indicated that, the predominant soil textural classes of the study area were sand, sandy clay loam, sandy clay, and loamy sand. The general characteristics of the soils were high sand and low silt contents. Most of the profiles had greater than 60 % sand, 20 % clay and less than five percent (5 %) silt.

Furthermore this study reveals that:

- i. All the soils belong to the soil order Ultisols and Ustalfs at suborder level in the Soil Taxonomy, while Alisols in the Reference Soil Group (RSG) - Tier 1 for the World Reference Base for Soil Resources soil legend.
- ii. At great group and subgroup levels P1 was classified as Rhodustults and Typic Rhodustults, P1 and P2 as Haplustults and Typic Haplustults, whereas, P4 was classified as Haplustults and Arenic Haplustults (Soil

Taxonomy), which correspond to Haplic RhodicAlisols, HaplicAlisols, Haplic Chromic and HaplicAlisols (World Reference Base) in the Tier 2 for RSG soil name for P1, P2, P3 and P4, respectively.

- iii. Chemically the soils were slightly acidic to mildly alkaline in reaction and had low contents of organic carbon and total nitrogen.
- iv. Available micronutrient (Fe and Mn) status in these soils was however found to be adequate in the soils; but the soils were deficient in the major nutrients such as N, P and exchangeable bases (Ca^{2+} , Mg^{2+} , K^+ and Na^+).

Recommendations

To improve soil productivity and sustain production of crops in the area (SMC farm) under investigation the following recommendations/measures are suggested:

- i. Maintaining high level of organic matter in the soil to improve physical condition of soil such as soil structure and CEC content to make soil to support good plant growth.
- i. An integrated nutrient management system which embraces a holistic approach of integrated use and management of organic and inorganic nutrient sources in a sustainable way should be adopted.
- ii. Periodic soil tests of site are very imperative to properly monitor the soil fertility indices and prevent decline and degradation of soil fertility.
- iii. The low TN and OC contents in the soils need to be amended through N-fertilizer management and the application of integrated nutrients management (INM)
- iv. A more detail soil survey of the site is advocated to put the land into best uses, makes predictions about the behavior of soils and evaluates/predicts the effects of land use on the environment of the study area.

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CHAPTER THREE

3.0 EVALUATION OF THE FERTILITY STATUS AND SUITABILITY FOR MAIZE PRODUCTION IN SOLOMON MAHLANGU CAMPUS MOROGORO TANZANIA

3.1 Abstract

The low fertility status of most of the soils in Morogoro area and non-use of fertilizers by small scale farmers contributes to the low yields of most annual crops, including maize. This study was carried out in 2014/15 cropping season at the Solomon Mahlangu Campus (SMC) farm, part of Sokoine University of Agriculture (SUA) Morogoro, Tanzania, to evaluate the current fertility status and suitability classes of the soils for maize production. A grid survey of the whole study area covering 300 ha was conducted and four mapping units were delineated. Composite soil samples were collected from each block (mapping unit) at the depth of 0 – 30 cm and analyzed for different physico-chemical properties using standard laboratory procedures as advocated by Moberg (2000). Correlation analysis was also conducted to establish the relationships between measured soil parameters. The suitability of the soils for maize production was assessed following conventional approach and matching methods. The results obtained indicated that, soils from all blocks were sandy loam to silt loam in texture with a slightly acidic to mildly alkaline reaction ($\text{pH}_{\text{water}} = 5.9 - 7.2$). As per the critical nutrients limit for maize production, the mean values for organic carbon (0.29 %), total nitrogen (0.04 %), available phosphorus (9.0 mg kg^{-1}), cation exchange capacity ($9.84 \text{ cmol.kg}^{-1}$), base saturation (21.2%), and exchangeable bases ($\text{Ca}=0.7, \text{Mg}=0.85, \text{K}=0.31$ and $\text{Na}=0.21 \text{ cmol.kg}^{-1}$) were low in all the mapping units.. The levels of available Cu, Zn, Fe and Mn were medium to high. The mean EC value (0.03 ds/m) was below the critical limit indicating that the soils were naturally non-saline. There was a significant ($P < 0.05$) positive correlation between the clay% and the

soil's CEC, Zn, Cu, K, Mg, Na and EC and a significant relationship between the OC and pH in H₂O and KCl. Equally, TEB and BS were significantly ($P < 0.001$) and positively correlated ($r = 0.9993$). The evaluation of the soils revealed that, all the soils of the four mapping units are moderately suitable (S2) for maize production. In conclusion, the soils of the study area were low in major macronutrients. This suggests low soil fertility that may require some extenuating measures to improve the soil fertility status.

Key words: *Soil suitability evaluation, soil mapping unit, maize, soil fertility and Solomon Mahlangu Campus farm.*

3.2 Introduction

The most prominent constraint to food production in most parts of the world is low soil fertility (Bationo and Mokwunye, 1991; Henao and Baananke, 2006). Thus, proper soil fertility management remains a key factor for increased food production. The rate of nutrient depletion of African soils has been reported to be on the increase (Julio and Carlos, 1999) due to inappropriate soils management practices. In Tanzania, the low productivity on the part of small-scale farmers is a major constraint to the agricultural sector; and is a fundamental challenge to improve the productivity and sustainability of farm production. The low soil fertility status of many soils in Morogoro area, as reported in previous studies (Msanya *et al.*, 2003), and non-use of fertilizers by small scale farmers contributes to the low yields of most annual crops, including maize.

Singh (1999) describes soil fertility management as an evaluation of the status of replenishment system which maintains the soil renewable resource in a sustainable form for long term productivity. Soil productivity on the other hand, is the capacity of the soil in its normal environment, to produce a specified plant or sequence of plants under a

specified system of management; soil productivity emphasizes the capacity of the soil to produce crops and is expressed in terms of yield.

The availability of one nutrient may be affected by the amount of other nutrient elements in the soil. It has been reported (see Tisdale *et al.*, 1995) that the greater the proportion of clay mineral high in K, the greater will be the potential K availability in soils. It is possible to induce or aggravate magnesium deficiency by the liberal use of potash. Application of phosphorus fertilizers at high rates has been found to reduce zinc availability in soils because of antagonistic effect, especially when the levels of zinc are only marginally sufficient (Barow, 1987; Foth, 1990). However, some of the antagonistic effects may be used effectively in reducing toxicities of certain micronutrients. For example, adding iron and phosphate fertilizers may reduce copper toxicity in citrus groves caused by residual copper from fungicidal sprays (Brady and Weil 1996).

Making effective decisions regarding agricultural land suitability is vital to achieve optimum land productivity and to ensure environmental sustainability. According to FAO (2006), the term “land suitability evaluation” could be interpreted as the process of assessing the land performance when the land is used for a specified purpose like for example crop production. Many workers have used crop yield to confirm the suitability of soils for crop production. Attempts have been made to predict the yield of crops through studies on land evaluation at different management levels (Fasina and Ogunkule, 1995). There is therefore the need to classify and estimate the potential of land for one use or several alternatives uses in order to develop agriculture efficiently and enhance precision farming (Osei, 1993).

A land utilization type (LUT) is a kind of land use defined in more detail, according to a set of technical descriptors in a given physical, economic and social setting. Land utilization types are specified by a set of land use requirement (LUR), which are the condition of land necessary for the successful and sustainable practice of a given land utilization type.

Maize (*Zea mays L.*) is an important cereal crop which ranks third after wheat and rice in the world (David and Adams, 1985). It is grown widely in many countries of the world, and it is the major and most preferred staple food and cash crop in Tanzania (Rates, 2003). The popularity of maize is evidenced by the fact that it is grown in all the agro-ecological zones of Tanzania. Over two million hectares of land are planted per year with maize and with the average yield of between 1.4 tons per hectare. Maize accounts for 31% of the total food production and constitutes more than 75% of the cereals consumed in the country. More so, about 85% of Tanzania's population depends on maize as an income generating commodity (Sassi, 2004). The annual per capita consumption of maize in Tanzania is over 115 kg and the national consumption is projected to be three to four million tonnes per year.

However, there is no land suitability assessment that has been carried out in details to indicate the suitability of the SMC soils for maize production which could be used for human consumption and as a component of feeds for livestock in the SMC University farm. Similarly, each soil type has specific properties and behaviours which affect directly its functions in relation to supporting crop growth performance and hence the need to assess the suitability of the soils for the crops that are commonly grown in the farm. Specifically the study was undertaken with a view to establish and evaluate the fertility status and suitability of the soils of SMC farm for maize production.

3.3 Materials and Methods

3.3.1 The location of the study area

The study was conducted at the SMC farm, one of the Sokoine University of Agriculture campuses, Morogoro, Tanzania. It is located between latitude 6°47'S and 37°37'E in Mazimbu about 200 km west of Dar es-Salaam, Tanzania. The study area covered 300 ha of uncultivated site of the farm with an elevation ranging from 500 to 600 m above sea level in agro ecological zone 2 (AEZ 2) of Tanzania. The area receives an annual rainfall ranging from 600 to 1200 mm. The long rains (Masika) usually fall in February to June, followed by a dry season between July and September while the short rains (Vuli) last for 4 months (October – January). However, on average small amount of precipitation usually prevails throughout the year (Mwango, 2000). The mean monthly temperature is about 24.0°C.

3.3.2 Field survey and soil sampling

The area (300 ha) was surveyed using the grid method and auger point investigations were carried out at 100 m intervals along traverses cut on the baseline. Four soil mapping units were identified based on soil colour, texture, depth and subsurface characteristics (Chapter 2). Surface soil sample for general soil fertility evaluation was done by collecting twenty soil samples from each mapping unit at the depth of 0-30 cm in a zig-zag pattern based on the random sampling plan (FAO, 2006) using a Dutch auger. The collected samples were air-dried, ground and sieved using a 2 mm sieve for laboratory analysis.

3.3.3 Laboratory analysis of soil physical and chemical properties

Particle size distribution was determined by the hydrometer method as modified by Udo *et al.* (2009). Walkley and Black (1934) wet digestion method was used to determine soil organic carbon content and percent soil organic matter was obtained by multiplying

percent soil OC by a factor of 1.724 following an assumptions that on average OM is composed of 58% carbon. The total N was determined using Kjeldahl digestion, distillation and titration method as described by Black (1965). The available soil P was determined by Bray 1 method according to the standard procedure of soil, plant and water analysis advocated by Udo *et al.* (2009) extraction method. Cation exchange capacity (CEC) and exchangeable bases (Ca, Mg, K and Na) were determined after extracting the soil samples by ammonium acetate (1M NH₄ OAc) at pH 7.0. Exchangeable Ca and Mg in the extracts were analyzed using atomic absorption spectrophotometer, while Na and K by flame photometer (Chapman, 1965). Cation exchange capacity was thereafter estimated titrimetrically by distillation of ammonium from KCl filtrates (Chapman, 1965). The percentage base saturation (PBS) was calculated by dividing the sum of charge equivalents of base-forming cations (Ca, Mg, Na and K) by CEC of the soil and multiplying by 100. The soil pH was measured in water and potassium chloride (1M KCl) suspensions in 1:2.5 (soil: liquid ratio) potentiometrically using a glass pH meter. The electrical conductivity (EC) of soils was determined from soil water ratio of 1:2.5 soaked for one hour by electrical conductivity method as described by Udo (2009). The plant available micronutrients (Fe, Cu, Zn and Mn) were extracted by DTPA and all these micronutrients were quantified by atomic absorption spectrophotometer.

3.3.4 Land evaluation

The agricultural potentials of the soils were developed by matching the characteristics of the soils with the requirements of the maize crop. The land suitability evaluation was done using the principles of FAO Framework for land evaluation (FAO, 1976) and FAO Guidelines on land evaluation for rain fed agriculture (FAO, 2006). Using the climatic data, information obtained from the field and laboratory, together with the ecological requirements of the selected crop (maize) and the relevant land qualities were used in

rating the soil by matching crop requirements with land qualities of each mapping unit. The land suitability class for each mapping unit was obtained by subjective combination of the individual ratings.

Land qualities used in this evaluation include annual rainfall, temperature regime, slope, drainage, soil texture, and soil depth and nutrients availability. The suitability of the soils was assessed for maize crop in the study area following the principles of the FAO Framework (FAO, 1976). The ratings of the land qualities and characteristics for maize requirement adopted by Sys (1985) were used for the purpose of maize suitability evaluation in this study.

3.4 Results and Discussion

Most important local indicators of soil fertility with their technical equivalents are presented in Table 3.1. The local indicators of soil fertility identified include soil colour, soil texture, soil moisture retention capacity, soil structure, gravel and rock, soil depth, plant species, and vegetations cover. Based on these soil properties, the soils were classified as either good or poor soils. Good soils are assumed to have the desired combination of the soils physical, chemical, and biological attributes or aspects of soil fertility and productivity while bad soils are those soils with many limitations with respect to crop production due to imbalances in the levels and interaction of the soils physical, chemical and biological attributes or aspects of soil fertility and productivity.

Table 3.1: Local indicators used for soil fertility evaluation

Local indicators	Technical equivalent
Good soil	
1. Black color	Rather high organic matter content
2. Cracks during dry season	High clay content
3. Good crop performance	Adequate supply of growth factors
4. Presence/vigorous growth of certain plants	Large supply of plant nutrients
5. Presence of plants in a dry environment	High water holding capacity (WHC)
6. Low frequency of watering	High infiltration rate and WHC
7. Abundance of earth worms	High biological activity, high organic matter content and neutral pH
Poor soil	
1. Yellow and red colors	Low soil fertility/low organic matter content
2. Compacted soils	Presence of cementing materials (Al, Fe ₂ O ₃ heavy clays) and low biological activity
3. Stunted growth	Physical, chemical and biological limitation
4. Presence of bracken ferns	Low pH
5. Salt visible on surface	High pH, high osmotic pressure
6. Presence of rocks and stones	Shallow soils

Source: Mrema *et al.* (2003).

3.4.1 Physical and chemical properties of the surface soils

The physical and chemical properties of the surface soils of the study area are presented in Table 3.2. The particle size distribution of soil properties shows that sand separates ranged from 80.64 to 86.24% with a mean of 84.24% and clay separates ranged from 10.12 to 16.12% with a mean of 12.52% while silt separates ranged from 1.64 to 3.64% with mean of 3.24%. Sand appeared to be the dominant size separates in all blocks. Sand separates accounted for over 80% while clay accounted for less than 20% and silt had less than 5% in all the four mapping units of the study area.

Table 3.2: Analytical Data for surface soil

Parameters	HORIZONS					Means	STDEV	Range
	BLK1A	BLK1B	BLK2	BLK3	BLK4			
Depth (cm)	0-30	0-30	0-30	0-30	0-30	-	-	-
Clay %	12.12	14.12	16.12	10.12	10.12	12.52	2.61	10.12-16.12
Silt %	3.64	1.64	3.64	3.64	3.64	3.24	0.89	1.64-3.64
Sand %	84.24	84.24	80.24	86.24	86.24	84.24	2.45	80.24-86.24
Text.	S	LS	LS	LS	LS	-	-	-
S:C	0.3	0.12	0.23	0.36	0.36	0.274	0.10	0.12-0.36
pH _{H2O}	7.08	7.27	7.12	5.96	6.72	6.83	0.53	5.96-7.27
pH _{KCl}	5.68	5.64	6.1	5.16	5.5	5.616	0.34	5.50-6.10
Org. C %	0.21	0.47	0.1	0.33	0.33	0.288	0.14	0.1-0.47
Total N %	0.04	0.04	0.06	0.04	0.04	0.044	0.01	0.04-0.06
C:N	5.11	11.14	1.74	7.89	7.89	6.754	3.52	1.74-11.14
Avail P mg kg ⁻¹	6.68	8	13.32	10.86	6.16	9.004	3.02	6.16-13.32
CEC cmol(+).kg ⁻¹	10.2	10	11	10.4	7.6	9.84	1.31	7.6-11
Ex.Ca cmol(+).kg ⁻¹	0.37	0.84	1.77	0.37	0.37	0.744	0.61	0.37-1.77
Ex. Mg cmol(+).kg ⁻¹	0.8	0.79	1.27	0.52	0.85	0.846	0.27	0.52-1.27
Ex.K cmol. (+)kg ⁻¹	0.33	0.38	0.36	0.24	0.22	0.306	0.07	0.24-0.38
Ex. Na cmol(+).kg ⁻¹	0.2	0.21	0.19	0.22	0.21	0.206	0.01	0.20-0.22
TEB cmol. (+)kg ⁻¹	11.7	2.21	3.58	1.34	1.65	4.096	4.34	1.34-11.7
BS (%)	16.68	22.12	32.59	12.92	21.75	21.212	7.41	16.68-32.59
Ex. Cu mg ⁻¹	0.28	0.46	0.61	0.25	0.25	0.37	0.16	0.25-0.61
Ex. Zn mg ⁻¹	0.19	0.26	0.32	0.12	0.16	0.21	0.08	0.12-0.32
Ex. Fe mg ⁻¹	21.2	21.2	28.53	33.77	19.63	24.866	6.06	21.2-33.77
Ex. Mn mg ⁻¹	31.5	31.5	41.5	21.5	29	31	7.16	21.5-41.5
EC dSm ⁻¹	0.02	0.03	0.04	0.02	0.02	0.026	0.01	0.02-0.04

Textural classes varied from loamy sand to silt loam. Silt separates significantly correlated with silt to clay ratio ($r = 0.846$, $p = 0.05$). The values of silt and clay were generally low indicating that the soils are highly weathered (Obi and Ogunkule, 2009). Both silt + clay and silt/clay ratio were similar and these may reflect similarity in parent materials of the soils from the different mapping units. Moreover, the soil separates were similar in distribution between the four mapping units. Iqbal *et al.* (2005) and Obi and Ogunkule (2009) reported similarities of means and medium values of particle size distribution in their study of alluvial soils which implies an increase in sand content leads to a decrease in the contents of some chemical properties of soil such as CEC, OC and some micro nutrients.

Chemical properties of soils presented in Table 3.2 show that the inherent fertility status of the soils which was observed vis-à-vis the rating scale given in Tables 3.3 and 3.4 was low. Soil reaction as indicated in Table 3.2 shows that the pH in water (range = 5.9 - 7.2; mean = 6.83) and pH in KCl (range = 5.16 - 5.68; mean = 5.61). These results indicate slightly acid to mildly alkaline reaction (Esu, 1991). In all mapping units, pH values in water suspension were higher than corresponding values in IM KCl solution, indicating that soils in their natural state were negatively charged (Villapando and Greatz, 2001). Organic carbon generally ranged from 0.1 to 0.47% with a mean of 0.29%, indicating low (Esu, 1991) in all soils. Organic carbon which is an indicator of organic matter was uniformly distributed and rated low in all mapping units of the study area. The low level organic carbon (below 1%) could be attributed to high rates of organic matter decomposition and burning of organic residues. This indicates non possibility of obtaining potential crop yield in the area. Electrical conductivity of the saturation extract was low (Esu, 1991) in all pedons, indicating that soils were naturally non-saline. As per the critical limit for rating of land use requirements for maize production (Table 3.11), the land quality characteristics are not very suitable for the production of maize.

Total nitrogen was generally low (Esu 1991). The available phosphorus and exchangeable bases were also low with calcium and magnesium being the most dominant in all the pedons. The low levels of organic carbon, nitrogen, and exchangeable bases could probably be attributed to rapid decomposition and mineralization of organic matter and annual burning of the sparse vegetation commonly carried out by farmers and cattle rearers' especially the Maasai nomads. Organic carbon and nitrogen decreased the profile depth indicating that stable rate of the soil profiles development have implications for the stabilization of soil aggregate and environment (Adebayo *et al.*, 2009). Organic matter was reported to be the main agent for binding particles and stabilizing soil aggregates in soils of both humid and sub-humid tropics; organic matter is also the sole source of N in the soil

(Adebayo *et al.*, 2009). These nutrient levels (N less than 60 kg⁻¹ and P less than 20 kg⁻¹) are not supportive for optimum maize production; hence there is a need of supplement application of both organic soil amendments and inorganic fertilizers.

3.4.2 Relationships between the soil physical and chemical properties of surface soil

Correlation analysis was carried out between soils physical and chemical properties of surface soils as presented in Table 3.5. There was significant ($P < 0.05$) negative correlation between the percentage of sand (% sand) and soils content of P, CEC, Clay, Cu, Fe, Mn²⁺, OC, Zn²⁺ and pH in both H₂O and in KCl. Correlation coefficient (r) values for these relationships varied from -0.96 to -0.12 indicating a decrease in the values of these soil chemical properties with an increase of sand content. The clay content of these surface soils was significantly and positively correlated with the pH in KCl, Zn²⁺, TEB, Mn, K⁺, EC, Cu and BS. Thus the higher the clay content, the more the content of these chemical properties.

Table 3.3: Critical Limits for Interpreting Levels of Analytical Parameters

Parameter	Rating			Unit
	Low	Medium	High	
Ca	<2	2 – 5	>5	cmol (+) kg ⁻¹
Mg	<0.3	0.30-1.0	>1.0	cmol (+) kg ⁻¹
K	<0.15	0.15-0.30	>0.30	cmol (+) kg ⁻¹
Na	<0.1	0.1-0.30	>0.30	cmol (+) kg ⁻¹
ECE	<5	5.0-1.0	>10.0	cmol (+) kg ⁻¹
CEC (Soil)	<6	6-12	>12	cmol (+) kg ⁻¹
CEC (clay)	<15	15-25	>25	cmol (+) kg ⁻¹
Exch. Acidity	<2	2-5	>5	cmol (+) kg ⁻¹
Base saturation	<50	50-80	>80	percent
Org. C	<10	10-15	>15	gkg ⁻¹
Total N	<0.1	0.1-0.2	>0.2	gkg ⁻¹
Avail. P	<10	10-20	>20	mgkg ⁻¹

Source: Esu (1991) and Enwezor *et al.* (1981).

Table 3.4: Copper (Cu), Zinc (Zn), manganese (Mn), iron (Fe), exchangeable acidity (H⁺ and Al³⁺) and (CEC) Ratings in the savannah zone (adopted from Tisdale *et al.* 1995)

Parameters	RATING		
	Low	Medium	High
Copper (Cu)(ppm)	0—2.5	2.6—4.5	>4.5
Zinc (Zn)(ppm)	1.0	-	>1.0
Manganese (Mn)(ppm)	1.0	1.0	>1.0
Iron (Fe)(ppm)	0.25	2.6-4.5	>4.5
Exchangeable acidity	2	2-5	>5 cmo(+) kg^{-1}
CEC (soil)	6	6-12	>12 cmo(+) kg^{-1}

Sources: - Tisdale *et al.* (1995).

Table 3.5: Pearson correlation of some Surface composites Soil parameters

Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	1/8	19	20	21	22	23
P	1																						
BS_%	0.4663	1																					
CEC	0.7226	0.1513	1																				
C_N	-0.5476	-0.5203	-0.4135	1																			
Ca	0.7575	0.9063*	0.534	-0.5796	1																		
Clay_%	0.5466	0.8126*	0.6103	-0.4306	0.9118*	1																	
Cu	0.6575	0.874*	0.5518	-0.4133	0.9697**	0.9697**	1																
EC_dS_m	0.7053	0.8922*	0.5304	-0.4473	0.9861**	0.9432**	0.9948***	1															
Fe	0.8106*	-0.1205	0.6015	-0.2838	0.2319	0	0.1133	0.169	1														
K	0.2368	0.4962	0.6233	-0.1541	0.6152	0.8827*	0.7624	0.6934	-0.1919	1													
Mg	0.4172	0.9604**	0.1853	-0.6991	0.8602*	0.7855	0.8019*	0.8159*	-0.1558	0.4891	1												
Mn	0.3664	0.9201*	0.31	-0.6376	0.8571*	0.8839*	0.8504*	0.8394*	-0.2263	0.6862	0.9672**	1											
Na	-0.323	-0.7841	-0.3557	0.7971*	-0.7399	-0.7736	-0.6982	-0.6864	0.1894	-0.6067	-0.9146	-0.9495	1										
OC_%	-0.5186	-0.485	-0.3999	0.9989***	-0.5413	-0.3966	-0.373	-0.4063	-0.2747	-0.1317	-0.6733	-0.6125	0.7845	1									
OM_%	-0.5186	-0.485	-0.3999	0.9989***	-0.5413	-0.3966	-0.373	-0.4062	-0.2747	-0.1317	-0.6733	-0.6125	0.7845	1***	1								
S_C_ratio	-0.1567	-0.4824	-0.3997	-0.2058	-0.5495	-0.7876	-0.7367	-0.675	0.2476	-0.8942	-0.356	-0.5269	0.3238	-0.238	-0.238	1							
Sand_%	-0.6496	-0.84	-0.6248	0.7125	-0.9393	-0.9393	-0.9177	-0.9129	-0.1234	-0.7304	-0.8802	-0.9267	0.8951*	0.6847	0.6847	0.5296	1						
Silt_%	0.1855	-0.0688	-0.0684	-0.6958	-0.0857	-0.343	-0.3141	-0.25	0.338	-0.5734	0.1205	-0.039	-0.1961	-0.7188	-0.7188	0.846*	0	1					
TEB	0.6609	0.9439**	0.4689	-0.6126	0.9879***	0.9264*	0.9621**	0.972**	0.0976	0.6449	0.9224*	0.9261*	-0.8228	-0.5769	-0.5769	-0.5541	-0.9601	-0.0715	1				
TN_%	0.798*	0.8578*	0.4962	-0.7952	0.9432**	0.7717	0.8377*	0.875*	0.338	0.4067	0.8761*	0.8199*	-0.7845	-0.7656	-0.7656	-0.252	-0.9129	0.25	0.9362**	1			
Zn	0.4673	0.8765*	0.4751	-0.4029	0.9089*	0.9869***	0.9669**	0.9429**	-0.1162	0.8489*	0.8401*	0.9216**	-0.7907	-0.3678	-0.3678	-0.7872	-0.9201	-0.3576	0.9381**	0.7641	1		
pH_H2O	-0.1682	0.6226	0.093	-0.1415	0.477	0.7282	0.6056	0.5414	-0.6763	0.8091*	0.6484	0.7875	-0.7079	-0.1261	-0.1261	-0.7398	-0.6047	-0.4671	0.582	0.3079	0.7856	1	
pH_KCl	0.3414	0.8904*	0.3343	-0.6435	0.8343*	0.884*	0.8338*	0.8173*	-0.2432	0.7126	0.951**	0.9975***	-0.9618	-0.6204	-0.6204	-0.5316	-0.9266	-0.0395	0.9076*	0.7976*	0.9164*	0.8067*	
	P	BS_%	CEC	C_N	Ca	Clay	Cu	EC_dS_m	Fe	K	Mg	Mn	Na	OC_%	OM_%	S/C	Sand%	Silt%	TEB	TN_%	Zn	pHH2O	pHKCl

*Significant at P=0.05 level, ** Significant at P=0.01 level, *** Significant at P=0.001 level, TN= Total nitrogen (N),TEB= Total exchangeable bases, S:C= Silt to clay ration, C:N= Carbon to nitrogen ration

3.4.3 Relationships between soil physical and chemical properties of the soil profiles

Correlation analysis between the soil's physical and chemical properties was carried out separately for the representative profiles in the study area (Tables 3.6 – 3.9). The particle size distribution of the soils shows that sand separates ranged from 60.64 to 90.24 %. Soil reaction as indicated shows that the pH in water (range = 6.22 - 7.23 ;) and pH in KCl (range = 4.50 - 6.54). pH values in water suspension were higher than the corresponding values in 1 M KCl Solution, indicating that the soils in their natural state were negatively charged (Villapando and Greatz, 2001). Organic Carbon generally ranges from 0.02 to 0.49 % indicating low level of organic carbon in the soils. The organic carbon which is an indicator of organic matter (Sole Source of N) was uniformly distributed and rated low in all the profiles of the study area. The low level of organic carbon (below 1 %) could be attributed to high range of organic matter decomposition and burning of organic residues and these indicate impossibility of obtaining potential crop yield in the area. Electrical conductivity of the saturation extract was low in all the pedons, indicating that the soils were naturally non-saline (Ogban *et al.*, 2012).

There was a significant ($p < 0.05$) positive relationship between the percentage of clay (% clay), CEC and EC with K, Mg and Na (Table 3.5.), while there was a significant negative correlation with C: N and pH_{H_2O} with sand, Zn and Mn (Table 5.3). The TEB showed a significant ($P = 0.05$) positive relationship with CEC and Ca, implying that the measures of improving the status of basic cation would invariably increase the content of the bases in the absorption complex and Base saturation percentage. CEC was significantly ($P = 0.05$) and positively related with Mg, Na, Ca and TEB and with clay, Fe and exchangeable bases (Table 3.7).

The correlation between Na and Ca as well as EC with K and Na was significant ($P = 0.05$) (Tables 3.6 and 3.7). Mn content on the other hand had a significant positive relationship with OC, OM and Zn with r values of 0.9963, 0.9963 and 0.9708 respectively

(Table 3.7). There was a significant ($P = 0.05$) negative correlation between TN and pH in H_2O , P and Ca as well as % clay with C: N and pH in H_2O . There was also a significant ($P = 0.05$) negative relationship between TEB with P as well as pH in H_2O with K and between Zn and EC content in Tables 3.8 and 3.9 respectively. A significant ($P = 0.05$) positive relationship was found between base saturation percentage with exchangeable bases, clay, Cu and TEB (Table 3.8), but negatively correlated with sand, silt, Fe, Mn and pH in H_2O (Table 3.6), implying that a decrease in CEC and exchangeable cations result in low levels of soil fertility.

The CEC was significantly ($P = 0.01$) and positively correlated with Ca, Mg, C: N in profile 3. There was a negative correlation between % clay with S: C, % Sand, Zn and Mn (Table 3.9). The % clay was significant ($P < 0.05$) negatively correlated with available P in Tables 9 and 10, meaning that the higher the clay content, the lower the available P. This may be an indicator of a possibility of P fixation” by the clay particle size separates. The observed positive relationship between available P and percentage sand may be a result of humus coatings on the sand surface which had probably adsorbed a greater proportion of the available P (Ajiboye, 2010).

The significant positive relationship existed between the exchangeable cations, TEB, clay and CEC and also between OC, TN, OM with pH in H_2O and in KCl in both horizons (Tables 3.6 – 3.9). The significant positive relationship which was found between the exchangeable cations implies that a synergistic relationship exists between the exchangeable cations whereby the availability of one cation enhances the availability of the other (Abu, 2012).

Table 3.6: Pearson correlation of some soil parameters for profile 1

Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
BS_%	-0.7431	1																					
CEC	-0.645	0.4815	1																				
C_N	0.3966	-0.7291	-0.4984	1																			
Ca	-0.6261	0.9406**	0.5873	-0.9075	1																		
Clay_%	-0.8848	0.5892	0.9165*	-0.4052	0.5805	1																	
Cu	-0.3408	0.0582	0.8976*	-0.2822	0.2386	0.7297	1																
EC_dS_m	-0.546	0.9314*	0.3862	-0.9031	0.9723	0.4105*	0.0225	1															
Fe	-0.3056	-0.0284	-0.3026	0.6607	-0.3604	0.0364	-0.4218	-0.3269	1														
K	0.6936*	-0.3196	-0.9339	0.378	-0.413	-0.9262	-0.9045	-0.222	0.1864	1													
Mg	-0.8415	0.6262	0.9394**	-0.4128	0.6182	0.9854**	0.7324*	0.4387	0.0049	-0.8901	1												
Mn	0.2088	-0.3233	-0.7722	0.7614*	-0.6037	-0.5192	-0.7825	-0.4743	0.834*	0.6752	-0.5416	1											
Na	-0.4488	0.567	0.8812*	-0.8079	0.7734*	0.7006*	0.7658*	0.6323	-0.6636	-0.748	0.7369*	-0.9511	1										
OC_%	0.205	-0.4149	-0.7818	0.7677*	-0.6713	-0.5144	-0.738	-0.5387	0.8086*	0.6157	-0.5699	0.9777**	-0.9664	1									
OM_%	0.205	-0.4149	-0.7818	0.7677*	-0.6713	-0.5144	-0.738	-0.5387	0.8086*	0.6157	-0.5699	0.9777**	-0.9664	1	1								
S_C_ratio	0.9157*	-0.6106	-0.8582	0.3113	-0.5461	-0.9862	-0.6373	-0.3845	-0.1874	0.8624*	-0.9773	0.3828	-0.5985	0.3959	0.3959	1							
Sand_%	0.8848*	-0.5892	-0.9165	0.4052	-0.5805	-1	-0.7297	-0.4105	-0.0364	0.9262*	-0.9854	0.5192	-0.7006	0.5144	0.5144	0.9862	1						
Silt_%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1					
TEB	-0.7621	0.9156*	0.7768*	-0.8119	0.9566**	0.7855*	0.4466	0.8689*	-0.2635	-0.628	0.8203*	-0.6419	0.8377*	-0.7034	-0.7034	-0.7576	-0.7855	0	1				
TN_%	-0.0107	-0.0414	-0.755	0.375	-0.2887	-0.4333	-0.8633	-0.1021	0.6997*	0.6119	-0.5037	0.8607*	-0.8	0.8814*	0.8814*	0.3267	0.4333	0	-0.4031	1			
Zn	0.8716*	-0.6046	-0.9327	0.4722	-0.621	-0.9965	-0.7495	-0.4533	0.0414	0.9374**	-0.9811	0.5823	-0.7514	0.573	0.573	0.9704**	0.9965***	0	-0.8133	0.4703	1		
pH_H2O	0.5713	-0.3966	0.046	-0.3201	-0.0658	-0.288	0.3361	-0.0796	-0.9002	-0.0372	-0.2915	-0.6172	0.3506	-0.5376	-0.5376	0.4397	0.288	0	-0.154	-0.5688	0.2207	1	
pH_KCl	0.1124	0.4398	0.3761	-0.753	0.6641	0.0779	0.2709	0.6309	-0.8221	-0.0959	0.1814	-0.7428	0.7263*	-0.8334	-0.8334	0.0111	-0.0779	0	0.5569	-0.6465*	-0.14	0.5284	
	P	BS_%	CEC	C_N	Ca	Clay_%	Cu	EC_dS_m	Fe	K	Mg	Mn	Na	OC_%	OM_%	S_C_ratio	Sand_%	Silt_%	TEB	TN_%	Zn	pH_H2O	pH_KCl

*Significant at P=0.05 level, ** Significant at P=0.01 level, *** Significant at P=0.001 level , TN= Total nitrogen (N),TEB= Total exchangeable bases, S:C= Silt to clay ration, C:N= Carbon to nitrogen ration

Table 3.7: Pearson correlation of some Soil Parameters for Profile 2

Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
P	1																						
BS_%	0.6826	1																					
CEC	-0.4679	0.3266	1																				
C_N	0.9275	0.36	-0.7643	1																			
Ca	0.9275	0.36	-0.7643	1	1																		
Clay_%	-0.5809	0.1984	0.9912*	-0.843	-0.843	1																	
Cu	-0.1401	0.628	0.9406	-0.5	-0.5	0.8874	1																
EC_dS_m	0.1018	0.7965	0.8316	-0.2774	-0.2774	0.7506	0.9707*	1															
Fe	-0.5789	0.2008	0.9915*	-0.8417	-0.8417	1***	0.8885	0.7522	1														
K	-0.5165	0.2733	0.9984*	-0.7991	-0.7991	0.997*	0.9202	0.7993	0.9972*	1													
Mg	-0.5034	0.2879	0.9992*	-0.7899	-0.7899	0.9958*	0.926	0.8083	0.996*	0.9999**	1												
Mn	0.8919	0.2783	-0.8169	0.9963*	0.9963*	-0.8862	-0.5727	-0.359	-0.8851	-0.8479	-0.8397	1											
Na	-0.3061	0.4868	0.9846*	-0.6397	-0.6397	0.9527*	0.9855*	0.9159	0.9535*	0.9733*	0.9767*	-0.7035	1										
OC_%	0.9275	0.36	-0.7643	1	1	-0.843	-0.5	-0.2774	-0.8417	-0.7991	-0.7899	0.9963*	-0.6397	1									
OM_%	0.9275	0.36	-0.7643	1	1	-0.843	-0.5	-0.2774	-0.8417	-0.7991	-0.7899	0.9963*	-0.6397	1	1								
S_C_ratio	0.8911	0.2765	-0.818	0.9961*	0.9961*	-0.8871	-0.5743	-0.3608	-0.8859	-0.8489	-0.8408	1**	-0.7049	0.9961*	0.9961*	1							
Sand_%	0.5382	-0.2487	-0.9967	0.8142	0.8142	-0.9987	-0.9099	-0.7837	-0.9988	-0.9997	-0.9992	0.8611	-0.9671	0.8142	0.8142	0.8621	1						
Silt_%	0.9275	0.36	-0.7643	1	1	-0.843	-0.5	-0.2774	-0.8417	-0.7991	-0.7899	0.9963*	-0.6397	1	1	0.9961*	0.8142	1					
TEB	-0.1382	0.6295	0.94	-0.4983	-0.4983	0.8864	1***	0.9712*	0.8876	0.9194	0.9253	-0.5711	0.9852*	-0.4983	-0.4983	-0.5726	-0.9091	-0.4983	1				
TN_%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1			
Zn	0.9744*	0.5007	-0.6547	0.9878*	0.9878*	-0.7491	-0.3592	-0.1245	-0.7475	-0.6958	-0.6849	0.9708*	-0.5124	0.9878*	0.9878*	0.9703*	0.7139	0.9878*	-0.3574	0	1		
pH_H2O	0.8321	0.1626	-0.8795	0.9791*	0.9791*	-0.9348	-0.6658	-0.4671	-0.934	-0.9047	-0.8981	0.993*	-0.7827	0.9791*	0.9791*	0.9932*	0.9153	0.9791*	-0.6643	0	0.9355	1	
pH_KCl	0.8751	0.2436	-0.8371	0.9926*	0.9926*	-0.9022	-0.6018	-0.3923	-0.9012	-0.8664	-0.8587	0.9994*	-0.7286	0.9926*	0.9926*	0.9994*	0.8788	0.9926*	-0.6002	0	0.9615*	0.9966*	
	P	BS_%	CEC	C_N	Ca	Clay_%	Cu	EC	Fe	K	Mg	Mn	Na	OC_%	OM_%	S_C_ratio	Sand_%	Silt_%	TEB	TN_%	Zn	pH_H2O	pH_KCl

*Significant at P=0.05 level, ** Significant at P=0.01 level, *** Significant at P=0.001 level , TN= Total nitrogen (N), TEB= Total exchangeable bases, S:C= Silt to clay ration, C:N= Carbon to nitrogen ration

Table 3.8: Pearson correlation of some soil parameters for Profiles 3

Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
P	1																						
BS_%	-0.4477	1																					
CEC	-0.7095	0.9078*	1																				
C_N	0.671	-0.9441	-0.9951	1																			
Ca	-0.6254	0.9691*	0.9826**	-0.9962	1																		
Clay_%	-0.6517	0.9427*	0.9954**	-0.9992	0.9946**	1																	
Cu	-0.3728	0.9568*	0.9177*	-0.9365	0.9487*	0.9465*	1																
EC_dS_m	-0.4113	0.9722*	0.8161*	-0.8691	0.9079	0.86*	0.8659*	1															
Fe	0.0242	0.654	0.3086	-0.4003	0.476	0.3831	0.4581	0.8008*	1														
K	-0.2146	0.9635*	0.7644	-0.8221	0.8678*	0.8218*	0.9047*	0.9697*	0.7921	1													
Mg	-0.7044	0.928*	0.9978**	-0.9988	0.9912**	0.9973**	0.9205*	0.8504*	0.3683	0.7946	1												
Mn	0.4105	-0.9663	-0.9321	0.9509*	-0.9625	-0.9592	-0.9989	-0.8806	-0.4696	-0.9079	-0.9363	1											
Na	-0.4993	0.9412*	0.9646*	-0.9707	0.9707*	0.9792*	0.9878**	0.8367*	0.3664	0.8485*	0.9621*	-0.9909	1										
OC_%	0.5837	-0.9873	-0.9521	0.9776*	-0.9918	-0.9732	-0.9373	-0.9537	-0.5839	-0.9119	-0.969	0.9524*	-0.9458	1									
OM_%	0.5837	-0.9873	-0.9521	0.9776*	-0.9918	-0.9732	-0.9373	-0.9537	-0.5839	-0.9119	-0.969	0.9524*	-0.9458	1									
S_C_ratio	0.8854*	-0.8018	-0.9528	0.9387*	-0.9157	-0.9289	-0.7597	-0.7398	-0.247	-0.6181	-0.9534	0.7865	-0.8394	0.8858*	1								
Sand_%	0.6517	-0.9427	-0.9954	0.9992***	-0.9946	-1	-0.9465	-0.86	-0.3831	-0.8218	-0.9973	0.9592*	-0.9792	0.9732*	0.8858*	1							
Silt_%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9732*	0.9289*	1						
TEB	-0.4427	0.9993***	0.9146*	-0.9486	0.9718*	0.9486*	0.967*	0.963*	0.6306	0.9598*	0.9325*	-0.9753	0.9522*	-0.9861	0	0	0	1					
TN_%	-0.2055	-0.523	-0.1363	0.2336	-0.3162	-0.2184	-0.3333	-0.6836	-0.9816	-0.7023	-0.1972	0.3392	-0.222	0.4326	-0.9861	-0.802	-0.9486	0	1				
Zn	0.9842**	-0.4337	-0.6496	0.6235	-0.588	-0.5981	-0.3099	-0.4391	-0.0885	-0.2238	-0.6552	0.352	-0.4275	0.5667	0.4326	0.0584	0.2184	0	-0.4993	1			
pH_H2O	0.222	-0.949	-0.7306	0.794	-0.8442	-0.7897	-0.86	-0.9796	-0.8474	-0.9942	-0.7667	0.8666*	-0.8019	0.8992*	0.5667	0.8498*	0.5981	0	-0.4222	-0.0845	1		
pH_KCl	0.1638	-0.913	-0.6613	0.7322	-0.789	-0.7259	-0.8047	-0.9653	-0.8963	-0.9804	-0.7026	0.8115*	-0.7366	0.8555*	0.8992*	0.6048	0.7897	0	-0.9414	0.7603*	0.2498	1	
P		BS %	CEC	C N	Ca	Clay %	Cu	EC	Fe	K	Mg	Mn	Na	OC %	0.8555*	0.5397	0.7259	0	-0.9025	0.8227	0.2075	0.9948*	1

*Significant at P=0.05 level, ** Significant at P=0.01 level, *** Significant at P=0.001 level , TN= Total nitrogen (N),TEB= Total exchangeable bases, S:C= Silt to clay ration, C:N= Carbon to nitrogen ration

Table 3.9: Pearson correlation of some soil parameters for Profile-4

Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
P	1																						
BS %	-0.1365	1																					
CEC	0.5988	0.3646	1																				
C_N	-0.9171	-0.2699	-0.7306	1																			
Ca	0.5536	0.7152	0.8484*	-0.8266	1																		
Cl_%	-0.3552	0.9735*	0.1791	-0.0465	0.5384	1																	
Cu	-0.5637	0.8467*	-0.1728	0.2078	0.2417	0.9381*	1																
Ec_m	-0.266	0.984**	0.1933	-0.1373	0.5882	0.993**	0.9265*	1															
Fe	-0.8976	-0.3073	-0.681	0.9959**	-0.8245	-0.0897	0.1469	-0.1856	1														
K	0.5934	0.7012	0.8147*	-0.8594	0.9959**	0.5197	0.2353	0.579	-0.8629	1													
Mg	-0.1018	0.9981***	0.4201	-0.3029	0.7486	0.9617*	0.8153*	0.9716*	-0.3356	0.7319	1												
Mn	0.1873	-0.6987	-0.6637	0.1012	-0.6073	-0.6701	-0.4351	-0.6159	0.0711	-0.5364	-0.73	1											
Na	-0.032	0.469	0.7766	-0.1602	0.5664	0.4108	0.1354	0.3527	-0.1056	0.4895	0.5138	-0.9508	1										
OC%	-0.9505	-0.1712	-0.6623	0.9926**	-0.7529	0.051	0.2812	-0.0456	0.9901**	-0.7935	-0.2017	-0.0184	-0.0539	1									
OM_%	-0.9505	-0.1712	-0.6623	0.9926**	-0.7529	0.051	0.2812	-0.0456	0.9901**	-0.7935	-0.2017	-0.0184	-0.0539	1	1								
S_C_ratio	0.3971	-0.7503	-0.4697	-0.0823	-0.4814	-0.7714	-0.6046	-0.7079	-0.0979	-0.4116	-0.7684	0.9707*	-0.8634	-0.2029	-0.2029	1							
Sand_%	0.3573	-0.9527	-0.065	0.0356	-0.4831	-0.9876	-0.9663	-0.9916	0.0907	-0.4772	-0.9328	0.5454	-0.2633	-0.0493	-0.0493	0.6652	1						
Silt_%	0.1155	-0.4706	-0.721	0.0796	-0.5119	-0.4313	-0.1753	-0.3656	0.0265	-0.4319	-0.5124	0.9584*	-0.9965	-0.0284	-0.0284	0.8885*	0.2845	1					
TEB	0.1848	0.9259*	0.6823	-0.5529	0.9185*	0.8217*	0.5831	0.8444*	-0.5659	0.9006*	0.9456*	-0.7668	0.6298	-0.4534	-0.4534	-0.7253	-0.768	-0.6045	1				
TN_%	-0.9776	0.1411	-0.4428	0.8929*	-0.4851	0.3453	0.4983	0.2425	0.8906*	-0.5411	0.1179	-0.3374	0.2203	0.9407*	0.9407*	-0.5177	-0.3145	-0.3015	-0.1291	1			
Zn	0.0412	-0.4025	-0.7619	0.1245	-0.5145	-0.3488	-0.0783	-0.2858	0.065	-0.4351	-0.4485	0.9292*	-0.9971	0.0222	0.0222	0.8383*	0.1977	0.9949**	-0.5693	-0.2357	1		
pH_H2O	-0.4075	-0.3884	0.0808	0.5503	-0.3943	-0.3086	-0.3414	-0.4147	0.6226	-0.4712	-0.3637	-0.3361	0.505	0.576	0.576	-0.3166	0.4221	-0.542	-0.3385	0.5621	-0.5654	1	
pH_KCl	0.724	0.5763	0.8114*	-0.936	0.9701*	0.3745	0.0915	0.4467	-0.9371	0.9844*	0.6087	-0.4033	0.3909	-0.8881	-0.8881	-0.2545	-0.3417	-0.3235	0.8105*	-0.6801	-0.3411	-0.5154	
24	P	BS_%	CEC	C_N	Ca	Clay_%	Cu	EC	Fe	K	Mg	Mn	Na	OC_%	OM_%	S_C_ratio	Sand_%	Silt_%	TEB	TN_%	Zn	pH_H2O	pH_KCl

*Significant at P=0.05 level, ** Significant at P=0.01 level, *** Significant at P=0.001 level, TN= Total nitrogen (N),TEB= Total exchangeable bases, S:C= Silt to clay ration, C:N= Carbon to nitrogen ratio

3.4.4 Land suitability for maize

The suitability of the soils was assessed for maize following the procedures of matching principle. Table 3.10 represents the detailed soil characteristics of all mapping units and Table 3.11 represent the land and soil rating requirements for rain fed maize. The matching of the soil characteristics of the mapping units (Table 3.10) with the land requirements of maize (Table 3.11) produced various suitability of maize cultivation as given in Table 3.12. The agricultural potentials of these soils are judged by matching the land qualities with the requirements of the maize crop, in this suitability rating emphasis was paid on the limitations of the soils and their negative effects on the crop and environment. The various limitations of the four soil units (unit I - IV) identified in the farm are low soil fertility and moisture content. These limitations are considered alongside the requirements of the maize crop in the area. The suitability of the soils for maize production as shown in Table 3.12 revealed that all the soils in all land mapping units are currently moderately suitable (S2).

Table 3. 10: Soil Characteristics of site for the suitability classification

Parameters	Profile I			Profile II			Profile III			Profile IV			
	Means	Range	SD	Means	Range	SD	Means	Range	SD	Means	Range	SD	
Clay (%)	23.73	8.12-30	8.92	24.79	12.12-38.12	10.62	24.79	12.12-38.12	18.69	24.79	12.12-38.12	11.70	
Silt (%)	1.64	1.64-1.6	0.00	2.31	1.64-3.64	0.94	2.31	1.64-3.64	0.00	2.31	1.64-3.64	1.91	
Sand (%)	74.64	68.24-90.24	28.99	72.91	60.24-84.24	9.84	72.91	60.24-84.24	18.69	72.91	60.24-84.2	10.96	
PH (H2O)	6.89	6.2-9	7.23	0.37	6.45	6.2-6.78	0.23	6.45	6.2-6.78	0.96	6.45	6.22-6.78	1.00
PH (KCl2)	5.79	5.05-6.5	0.55	5.01	4.50-5.86	0.60	5.01	4.50-5.86	0.61	5.01	4.50-5.86	1.40	
Org. C (%)	0.22	0.02-0.34	0.13	0.34	0.27-0.49	0.10	0.34	0.27-0.49	0.15	0.34	0.27-0.49	0.12	
Total N (%)	0.03	0.01-0.04	0.01	0.04	0.04-0.04	0.00	0.04	0.04-0.04	0.01	0.04	0.04-0.04	0.01	
Org. M (%)	0.36	0.03-0.57	0.23	0.60	0.47-0.84	0.17	0.60	0.47-0.84	0.24	0.59	0.47-0.84	0.20	
Av. P (mg/kg)	5.18	2.65-11.52	3.87	4.89	3.33-6.73	1.38	4.89	3.33-6.73	3.44	4.89	3.33-6.73	2.21	
CEC (cmol+/kg)	12.96	9.00-15.40	2.69	11.80	9.20-15.00	2.41	11.80	9.20-15.00	3.00	11.80	9.20-15.00	2.61	
Ex. Ca	2.70	1.30-5.03	1.47	0.68	0.37-1.30	0.44	0.68	0.37-1.30	0.60	0.68	0.37-1.30	1.11	
Ex. Mg	2.02	0.58-2.62	0.84	1.90	1.03-2.91	0.77	1.90	1.03-2.91	1.07	1.90	1.03-2.91	1.53	
Ex. K	0.16	0.09-0.28	0.08	0.31	0.25-0.39	0.06	0.32	0.25-0.39	2.18	0.31	0.25-0.39	0.08	
Ex. Na	0.26	0.21-0.35	0.06	0.58	0.24-1.10	0.37	0.58	0.24-1.10	0.38	0.58	0.24-1.10	0.24	
BS (%)	38.80	26.35-52.61	11.23	29.27	25.21-31.84	2.72	29.27	26.21-31.84	20.10	29.27	25.21-31.84	17.4	
Ex. Cu	0.56	0.40-0.73	0.15	0.52	0.40-0.76	0.17	0.52	0.40-0.76	0.07	0.76	0.40-0.76	0.21	
Ex. Zn	0.15	0.08-0.31	0.22	0.16	0.08-0.26	0.09	0.16	0.08-0.28	0.06	0.16	0.08-0.28	0.05	
Ex. Fe	13.66	7.07-20.68	5.28	44.24	25.39-64.14	15.84	44.77	12.75-18.24	3.27	44.24	25.39-64.14	12.05	
Ex. Mn	26.50	20.25-31.50	4.42	14.77	12.75-18.27	2.49	14.77	12.75-18.27	5.42	14.77	12.75-18.27	2.03	
Ec	0.03	0.02-0.04	0.01	0.03	0.01-0.05	0.02	0.03	0.01-0.05	0.03	0.03	0.01-0.05	0.01	

Table 3.11: Rating of Land use requirements for maize

Land quality and characteristics		100-95 S1	94-85 S2	84-40 S3	39-20 N1	19-0 N2
1.	Climate (C) : Annual rainfall (mm)	850-1250	850-750 1250-1600	750-600 1600-1800	600-500 > 1800	
	Length of dry season (days)	150-220	130-150	110-130	90 – 110	
	Mean annual max. temp (⁰ C)	22-26	22-18 26-32	18-16 > 32	36-30	
	Relative humidity (%)	50-80	80-42	> 80		
2.	Topography (t) Slope (%)	0-2 0-4	2-4 4-8	4-8 8-16	8-16 16-30	> 30
3.	Wetness (w) Flooding	F0	N0	F1	Aeric	Poor
	Drainage	Good	Moderate	Poor	Poor	Drainable
4.	Soil physical Characteristics (S) Texture / Structure	CL-L	SL, LS	LCS	CS, S	S
	Coarse fragments (%) 0 – 10cm	< 3	3 -15	15 - 35	35 - 55	
5.	Fertility (f) : CEC (cmolkg ⁻¹ clay)	> 24	16 - 24	< 16 (-)	16 (+)	
	Base Saturation (%)	> 50	35 – 50	20 -35	< 20	
	PH	> 5.5 – 7.0	5.5 – 7.0	5.0 – 8.0	5.0 – 8.0	
	OC (%) 0 – 15cm	> 2	> 2	0.8 – 1.2	< 0.8	
	AV. P (mg kg ⁻¹)	> 22	> 22	7 -13	3.7	< 3
	Total N (%)	> 0.15	> 0.15	0.08 – 0.10	0.04 – 0.08	<0.08
	Ext. K (cmolkg ⁻¹⁺)	> 0.5	> 0.5	0.2 – 0.3	0.1 – 0.2	< 0.1

KEY : F0 = No flooding, F1 = Seasonal flooding, CL = clay loam; SL = Sandy loam,
LS = Loamy Sand, SCL = Sandy Clay Loam, S = Sand

Source: Modified from Sys (1985)

Table 3.12: Maize suitability class of the mapping units in Solomon Mahlangu

Land Quality and characteristics	Mapping Units			
	1	2	3	4
Land quality				
Annual rainfall (mm)	S2	S2	S2	S2
Mean annual max temperature	S1	S1	S1	S1
Slope (%)	S1	S1	S1	S1
Drainage	S2	S2	S2	S2
Land characteristics				
Soil texture	S2	S2	S2	S2
Soil depth	S1	S1	S2	S1
Soil pH (1:1 water)	S3	S3	S3	S3
CEC Cmol (+) kg ⁻¹	S3	S3	S2	S2
Org. C (%)	NI	N1	NI	NI
Base saturation	S1	S3	S1	S2
AV. P (mgkg ⁻¹)	S3	NI	S3	NI
Total N (%)	NI	NI	NI	NI
Limiting characteristics	f, m	f, m	f, m	f, m

Land suitability class symbols: S1 = highly suitable; S2 = moderately suitable S3 = marginally suitable; N1 = currently not suitable. Land suitability subclass symbols; f = Soil fertility limitation, m = moisture availability limitation

3.5 Conclusions and Recommendations

The results of this study established and evaluate the suitability classes of the soils of SMC farm for maize cultivation. The suitability assessment result showed that there was no highly suitable (S1) land for maize cultivation in the area. The area was moderately suitable (S2), marginally suitable (S3) and currently non-suitable (N1) for maize production. Even though some land qualities such as mean annual rainfall and temperature are adequate for maize, but most of the land/soil characteristics such as levels of organic carbon and CEC are low.

The study indicates that:

- Physically the predominant textures of these soils were sandy, sandy clay loam, sandy clay and loamy sand. None of the four mapping units fell under highly suitable (S1) class, for maize production.

- The major limitations in the surveyed area are low fertility status and moisture content. Some of the soil fertility indicators have moderate, low or very low values in all units
- There was a significant ($P < 0.05$) positive correlation between the clay% and the soil's content of CEC, Zn, Cu, K, Mg, Na and EC, there was also a significant relationship between the OC and pH in H₂O and KCL and Equally, TEB and BS were significantly ($P < 0.001$) and positively correlated ($r = 0.9993$).
- For improved soils physical and chemical properties and hence productive capacity of the study soil, an integrated nutrient management system should be adopted to raise the soil fertility level for optimum production.

3.6 References

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CHAPTER FOUR

4.0 RESPONSE OF MAIZE TO DIFFERENT RATES OF NITROGEN, PHOSPHORUS AND FARMYARD MANURE APPLICATION, IN MOROGORO, TANZANIA.

4.1 Abstract

Pot experiments were carried out in the screen house Department of Soil and Geological Sciences College of Agriculture Sokoine University of Agriculture Morogoro, Tanzania in 2014 and 2015 to determine the effects of different levels of nitrogen, phosphorus and farmyard manure on the growth response, nutrient uptake and dry matter yields of maize. The experiment was conducted in completely randomized designed (CRD) with three replications. The treatments consisted of three levels of nitrogen (0, 75 and 150 kg N ha⁻¹), three levels of phosphorus (0, 40 and 80 kg P ha⁻¹) and three levels of farm yard manure (0, 5 and 10 t FYM ha⁻¹). Plant growth parameters which were determined included plant height, number of leaves, stem girth, nutrients uptake and dry matter yields of maize at the age of week's interval. The results obtained showed that maximum plant height (66.75 and 115.4 cm), number of leaves (8.50 and 9.00) and stem girth (4.90 and 5.85 cm) were achieved with the application of 150 kg N ha⁻¹ + 80 kg P ha⁻¹ + 10 t FYM ha⁻¹. The results also showed that, the combined rates of nitrogen, phosphorus and farmyard manure significantly increased dry matter yield and N and P uptake of maize when compared with most of the treatments and with the control. Root and shoot biomass ranged from 0.54 and 1.47 cm to 2.32 and 10.89 cm in 2014 and from 3.43 and 11.52 cm to 9.28 and 24.34 cm in 2015 respectively. The differences in the two years might be due to differences of the soils used. The nutrient uptake ranged from 1.04 and 0.089% to 2.94 and 0.37% for N and P in 2014 and from 0.367 and 0.037% to 2.55 and 0.31% for N and P respectively in 2015. The effects of treatments combination on parameters which were determined

were significant ($P \leq 0.05$) in both experiments. The combined application of nitrogen, phosphorus and farmyard manure at moderate rates (75 kg N ha^{-1} , 40 kg P ha^{-1} plus FYM 5 t ha^{-1}) would be cost effective and sufficient for maize growth, dry matter yield and nutrient content (N and P). It is recommended that field experiments have to be conducted so as to confirm the results of this study.

Keyword: *fertilizers, maize, plant height, leaves, green house nitrogen, phosphorus, farmyard manure, dry mater yield.*

4.2 Introduction

Maize is one of the highly consumed cereal crops ranked the first in terms of production and third in terms of consumption among the ten staples that feed the world (Allianz, 2010; FAOSTAT, 2011) and therefore the crop dominates agriculture in many regions of the world. Maize was introduced in Africa in 1500s and has since become one of the Africa's dominant food crops and an important staple food for more than 1.2 billion people in Sub – Saharan Africa and Latin America (IITA, 2012). The declining soil fertility is widely perceived and regarded as a major limitation to increasing yields and a threat to sustainability of the maize cropping systems (Nkhuzenje *et al.*, 2002). In Tanzania, it is estimated that the annual per capita consumption of maize is over 115 kg and the national consumption is projected to be three to four million tonnes per year (Rates, 2003). The popularity of maize is evidenced by the fact that, it is grown in all the agro-ecological zones in the country (Rates, 2003).

In Tanzania, continual cropping without concurrent use of organic/inorganic soil amendments has reduced soil fertility, leading to low crop yields. A study to assess the

extent of nutrient mining conducted by Smaling and Janseen (1993) reported negative balances of 27, 4 and 18 kg ha⁻¹, for N, P and K respectively; and this was attributed to nutrients uptake by crops, and other losses like erosion and run-off. Consequently, low yields ranging from 0.5 to 1.5 t ha⁻¹ have been recorded, compared to potential yield of 5 t ha⁻¹ attainable with adequate nutrient supply (Ikerra and Kalumuma, 1991; Ndaki, 2001). Nutrient replacement through the application of mineral or organic amendments is possible, but small scale farmers are constrained by a multitude of socio-economic factors such as high cost and scarcity of the amendments. The use of inorganic fertilizers by small scale farmers is limited by their high prices, and which are frequently not available in time and low benefit cost ratios (Palm *et al.*, 1997; 2001) of the amendments, inadequate use of inputs such as fertilizer, lack of improved maize seed, inadequate access to information and extension services, erratic rainfall and high susceptibility of maize to drought (Palm *et al.*, 2001).

Over three million hectares of land are under maize cultivation (Rates, 2003) in Tanzania with average yields of between 1.2 and 1.5 tonnes per hectare. The crop accounts for 31 percent of the total food production and constitutes more than 75 percent of the cereals consumption in the country (Rates, 2003). However with continuous cultivation, most of the essential plant nutrients which were previously adequate have declined to deficient levels, hence the need to apply them in the form of fertilizers or other soil amendments. The three nutrients N, P and K are often the most limiting in many soils, in the order N>P>K (Smaling and Janseen 1993).

Many studies have reported positive effect of both organic and inorganic fertilizers as well as their combinations, in supporting higher growth of maize (Bhataacharyya *et al.*, 2008; Mando *et al.*, 2005; Donovan and Casey 1998; Achieng *et al.*, 2010). The

use of inorganic fertilizers has not been that helpful as it is associated with increased soil acidity and nutrient imbalance in savanna soil (Lombin, 1987). On the other hand, organic manure has low nutrients content thus could hardly supply the quantity needed by crops (Titiloye, 1982). However application of organic manure offers the best advantage because apart from enhancing the availability of the plant nutrients it improves the soil physical, chemical and biological properties (Tiwani *et al.*, 2002; Celik *et al.*, 2004).

Based upon research findings across numerous countries and diverse agro ecological zones of sub – Saharan Africa (SSA), a consensus has been reached that the highest and the most sustainable gains in crop productivity per unit nutrient are achieved from mixtures of inorganic fertilizers and organic inputs (Vanlauwe *et al.*, 2001). The need to combine organic inputs with inorganic fertilizers and farmer – available organic resources are viewed as a major entry point (Sanchez, 1994). Indeed combining mineral and organic inputs result in greater benefits than using either of the inputs alone (Sanchez, 1994). Organic and organomineral fertilizers were found to significantly increase yields of maize and vegetables such as pepper, tomato, okra, melon and amaranths (Akanni and Ojeniyi, 2008; Makinde, 2007). The basic concept underlying the integrated nutrient management system (INMS), nevertheless, remains the maintenance and possible improvement of soil fertility for sustainable crop productivity on long term-basis and also the reduction of inorganic (fertilizer) input costs in crop production (Roy and Ange, 1991).

Maize requires adequate supply of nutrients particularly nitrogen, phosphorus and potassium for good growth and high yields. Nitrogen and phosphorus are essential for good vegetative growth and grain development in maize production (Kang, 1981; Oad,

2004). The estimate of the needed fertilizer usually vary depending upon the climate, crop requirement, soil conditions, fertilizer type, soil organic matter content, tillage methods and light intensity (Kang, 1981). Nitrogen is a vital plant nutrient and a major yield determining factor required for maize production (Adediran and Banjoko, 1995; Shanti *et al.*, 1997). As Tisdale *et al.* (1993) revealed, nitrogen is an important plant nutrient and is the most frequently deficient of all major nutrients required by plant. The low nitrogen supplying power of soils calls for large additions of nitrogen fertilizers to soils to meet the nitrogen needs of high yielding non legume crops (Foth, 1990). Since nitrogen in the soil is normally transient after breakdown of organic matter, adequate supply of nitrogen is essential during the growing season of plant so that growth and yields are not limited by N. N fertilizers were the first to be used and are still predominant (FAO, 1995).

Phosphorus availability is equally critical during the early stages of plant growth because the movement of P to the plant roots promote early root formation and growth (Sharpley *et al.*, 1994). Phosphorus is known as the master key to agriculture because lack of available P in soils limits the growth of both cultivated and uncultivated plants (Foth and Ellis, 1997).

The maize must have adequate quantity of nitrogen and phosphorus for profitable good crop growth and development (Wondewosen, 2009; Tenaw *et al.*, 2006). Regular application of organic manure not only supply all the various macro and micro-nutrients, although in small quantities, but also improves soil physical and biological properties (Moyin Jesu, 2002; Olayinka, 2009). Generally, adequate soil nitrogen, potassium and phosphorous are essential nutrients which can be supplied by organic or inorganic fertilizer sources (Moritsuka *et al.*, 2001).

Nitrogen and phosphorus have wider influence on both natural and agricultural ecosystems than any other essential nutrient elements. In most natural ecosystems, such as forests and grasslands, P uptake by plants is constrained by both the low total quantity of the element in the soil and by very low solubility of the scarce quantity that is present (Brady and Weil, 2002). In line with the above therefore, this study was aimed at investigating the growth response, nutrient uptake (N and P) and biomass production (DMY) of maize grown with different levels of organic and inorganic fertilizers at the Sokoine University of Agriculture Solomon Mahalangu Campus Farm Morogoro, Tanzania.

4.3 Materials and Methods

4.3.1 Description of the study area

The soils used in the screen house study were composite surface samples (0–30 cm) that were collected at Solomon Mahlangu Campus farm. The study was conducted in the screen house of the Department of Soil and Geological Sciences at College of Agriculture Sokoine University of Agriculture, Morogoro district of Tanzania. The study area lies between Latitude 5°58'N; 10°0'S and longitude 35°25'; 35°30'E). It experiences bimodal rainfall which ranges from 600 to 1200 mm and mean annual temperatures of about 24°C monthly. The long rains (LR) starts from February to June, and the short rains from October to December.

4.3.2 Collection and preparation of soil and farmyard manure samples

Bulked surface soil samples (400 kg) were collected from identified mapping units of SMC farm, Sokoine University of Agriculture Morogoro at the depth of 0-30 cm for the two pot experiments in 2014 and 2015, respectively while FYM samples were collected from the dairy house of the farm. The soil samples were bulked and

thoroughly mixed so as to obtain a composite sample. The soil samples were air-dried, ground and sieved to pass through 6 mm diameter sieve for the screen house experiments and 2 mm diameter screen for sub samples used for laboratory analysis.

4.3.3 Laboratory analysis of soil and farmyard manure

The soil sub samples for year 2014 and 2015 were analyzed for particle size distribution using the hydrometer method (Bouyoucos 1962), Soil pH (H₂O) in a 1:2.5 soil/solution ratio electrometrically. The total N was determined by the macro Kjeldhal method (Bremner and Mulvaney, 1982) and organic carbon (OC) was determined by the dichromate wet oxidation method as outlined by Nelson and Sommers (1982). Ammonium acetate (NSS, 1990) was used for the determination of CEC and exchangeable bases (Ca, Mg, K and Na). Organic matter content was obtained by multiplying organic carbon values by a factor of 1.724 as recorded by Eno *et al.* (2009). Extractable micronutrients (Cu, Zn, Fe and Mn) were extracted by DTPA and determined quantitatively by Atomic Absorption Spectrophotometer (AAS) (Senjobi, 2007). The analytical methods advocated as Moberg (2000) was used for these analyses. The total analysis of composite FYM sample was conducted using procedures described by Okalebo *et al.* (1993).

4.3.4 Experimental design and treatments

The experiment was 3³ factorial fitted into a completely randomized design (CRD) with three replications. The treatments consisted of three rates of nitrogen (0, 75 and 150 kg N ha⁻¹), three rates of phosphorus (0, 40 and 80 kg P ha⁻¹) and three rates of farmyard manure (0, 5 and 10 t ha⁻¹), thus the experiments consisted of 27 treatments (T) combination (Appendix 4.1).

4.3.5 Screen house pot experiments

Before sowing, eighty one 4 kg soil sample portions of 6 mm composite soil sample were weighed into 5 L capacity plastic pot and thoroughly mixed with N, P and FYM treatments accordingly. Water was then added to each pot to 70% of the soil's water holding capacity. After 10 days of equilibration at field capacity (FC) moisture status, four maize seeds, Tanzanian maize variety (TMV-1) were planted per pot and later the seedlings were thinned to two maize plants per pot two weeks after sowing (WAS).

4.3.6 Planting and agronomic practices

After 10 days, four maize (*Zea mays*) seeds of var. Tanzanian maize variety (TMV-1) were sown per pot and later the seedlings were thinned to two plants per pot at two weeks after sowing (WAS). Fertilizer application of P and N was done at planting followed by a split dosage of N at 2 WAS. Weeding was carried out regularly by hand picking. The pots were maintained close to field capacity throughout the experiment. Maize growth in weeks stages are shown in Plates 4.1-4.6.

4.3.7 Data collection

The growth parameters measured included plant height, number of leaves, stem girth and dry matter yield. The plant heights were measured by using meter scale, while leaves number by counting and stem girth by using rope and 30 cm meter scale. The maize growth parameters were measured every week. The dry matter yields (above and below ground biomass) were determined by weighing the harvested plants using weighing scale.

4.3.8 Harvesting, processing and plant tissue analysis

The maize plant was grown in the screen house for 28 days (4 weeks) after which the whole maize plants above the soil level that is two plants in each pot were harvested.

The shoot and the root were carefully harvested by cutting the shoot just above the soil level and the roots were gently uprooted from the soil. The experiment was repeated and all protocols were the same.



Plate 4.1: Response of maize to treatments at 1 WAS



Plate 4.2: Response of maize to treatments at 10 DAS



Plate 4.3: Response of maize to treatments at 2 WAS



Plate 4.4: Response of maize to treatments at 3 WAS



Plate 4.5: Response of maize to treatments at 25 DAS



Plate 4.6: Response of maize to treatments at 4 WAS

The harvested plant materials (shoots and roots) were later oven-dried in the oven at 65^o C to constant weight for 2 days for the dry matter determination after which they were grounded using micro – hammer stainless steel for N and P content analysis. The total N was determined using micro-Kjeldahl digestion and distillation procedures, while P was analyzed based on the procedures described by Okalebo (1993).

4.3.9 Statistical analyses of data

The data which were collected on growth parameters (plant height, leaves number and stem girth), DM yield and plant uptakes (N and P) were subjected to analysis of variance (ANOVA) technique and treatment means were compared using the New Duncan's multiple range test (NDMRT) at 5% level of probability ($P = 0.05$) with the Genstat 14th edition software package.

4.4 Results and Discussion

4.4.1 Soil physico – chemical properties

Some of the physical and chemical properties of the composite soil sample from SMC -farm, which was used for the screen house pot experiments, are presented in Table 4.1. The pH of the soil was 6.96 in H₂O indicating a slight acidity to neutral in reaction. The pH values in water suspension were higher than corresponding values in IM KCl Solution, indicating that the soils in their natural state were negatively charged (Villapando and Greatz, 2001). Organic carbon content was 0.33%, while the total N content was 0.05% rated as low and as very low according to Landon (1984) respectively. The low level of total N and organic carbon (below 1%) could be attributed to low content of organic matter in the soil.

The total N level was directly proportional to the organic carbon content in the soils of the study area. Ayolagha and Onuegbu (2002) also reported that, the higher the organic carbon the higher the total N in the soil as the soil organic matter is the sole source of nitrogen in the soil. The exchangeable bases values (Ca=0.37, Mg=0.82, K=0.74 and Na=0.32) in the soil were rated as low to moderate, while micronutrients (Cu=0.25, Zn=0.12 and Mn=33.77) were rated as low to high (Landon 1984) and available phosphorus (10.86 mg kg^{-1}) was moderate to high. The low content for these exchangeable bases (especially Ca and Mg) was due to low CEC of the soil resulting in the low content of clay and organic matter (Adamu, 2013). The textural class of the soil was sandy loamy.

The BS percentage (16.68 and 18.15%) was low and this may be due to the low content of organic matter in the surface soils, as organic matter is the natural store of the base elements and other plant nutrient elements from where they are slowly released into the soil solution (Ogban, 2012). The values of Fe and Mn in these soils are rated as medium to high. Also Alloway (2008) and Oluwolafe (2012) reported high content of zinc in basic igneous rocks, such as basalts due to zinc occurring in ferromagnesian minerals. The low levels of other micronutrients may be due to continuous residues removal, and over grazing. The EC values were 0.02 dSm, which indicates that the soil is non-saline. The values of soil chemical properties indicated low fertility status indicating that the soils were low in fertility. Therefore, there is need to apply fertilizers to the soil in order to boost its productivity.

Soil analysis before sowing indicated that the values of the soil chemical properties were low thus translating low in soil fertility status which requires addition of fertilizers to increase its fertility and productivity. FYM analysis indicated to have

contained 21.98% of the total nitrogen and 1.21 mg kg⁻¹ of the available phosphorous. This implies that the application of FYM has supplied the soil with 22 kg total N ha⁻¹ and 1.21 kg available P ha⁻¹ which are not yet adequate for maize production.

Table 4.1: Physico-chemical properties of the experimental soils used before sowing

Soil Properties	Measured Values	
	2014	2015
Clay (%)	12.12	14.12
Silt (%)	3.64	3.68
Sand (%)	84.24	80.24
Text. Class	S	LS
pH (H ₂ O)	7.08	6.96
pH (KCL)	5.68	5.16
Org.C (%)	0.21	0.33
Total N (%)	0.04	0.05
Avail. P.mg kg ⁻¹	6.68	10.86
CEC cmol kg ⁻¹	10.20	12.40
Ex.Ca cmo kg ⁻¹	0.37	0.37
Ex. Mg cmol kg ⁻¹	0.80	0.82
Ex. K cmol kg ⁻¹	0.33	0.74
Ex. Na cmol kg ⁻¹	0.20	0.32
BS (%)	16.68	18.15
Ex. Cu mg kg ⁻¹	0.28	0.25
Ex. Zn mg kg ⁻¹	0.19	0.12
Ex. Fe mg kg ⁻¹	21.20	33.77
Ex. Mn mg kg ⁻¹	31.50	27.50
EC dS/m	0.02	0.02

4.4.2 Effects of N, P and Fym on plant height

Table 4.2 shows that, the application of different levels of nitrogen, phosphorus and farm yard manure had no significant effects ($P < 0.05$) on plant height of maize throughout the first and second weeks after sowing until the third and fourth weeks after sowing. The pots which received treatments T₂₁ (N₁₅₀P₀ FYM₁₀) and T₂₇ (N₁₅₀P₈₀ FYM₁₀) statistically produced the tallest plants of 115 and 115.4 cm at 3rd and 4th WAS, closely followed by T₂₄ (N₁₅₀P₄₀ FYM₁₀), and T₂₅ (N₁₅₀P₈₀FYM₀) while the control pots produced the shortest plants. There was a corresponding increase in the growth of

maize as the rate of manure increased. The pots which received higher dosage of FYM, N and P rates gave the tallest plant (115.4 cm) and the control treatment produced the shortest plant of 56.7 cm at the end of four weeks experiment (Appendices. 4.2).

The findings in this experiment are in agreement with those of Makinde (2007) and Ayoola and Makinde (2009) who reported better plant height of maize after the use of integrated N, P and FYM. The use of 120 kg N ha⁻¹ resulted in taller maize plants with superior number of leaves and leaf area index, vigorous growth, thick canopy, efficient light interception, and higher dry matter production (Titiloye 1982; Zhao *et al.*, 2009; Sumi and Kutayam, 2000; Oad *et al.*, 2004).

4.4.3 Effects of N, P and Fym on number of leaves

The number of leaves produced by the maize plants at week interval stages of growth is presented in Table 4.3. The number of leaves followed a similar trend with plant height as the application of different rates of N, P and FYM significantly ($p < 0.05$) affect leaves number at 3 and 4 WAS. It was observed that at 1 and 2WAS all pots with different N, P and FYM treatments have similar number of leaves.

Table 4.2: Effects of N, P and Fym application on the maize plant height at 1-4 weeks after sowing

Treatments	2014				2015			
	Weeks after sowing				Weeks after sowing			
	1	2	3	4	1	2	3	4
N ₀ P ₀ FYM ₀	8.50a	35.47ab	35.50ab	40.25a	16.9a	40.9a	51.4ab	56.7a
N ₀ P ₀ FYM ₅	10.17a	43.67ab	43.25abc	49.25abcde	19.5a	46.2a	60.2abc	70.8abc
N ₀ P ₀ FYM ₁₀	9.35a	41.57ab	44.50abc	49.75abcdef	17.9a	43.6a	60.1abc	66.7ab
N ₀ P ₄₀ FYM ₀	8.97a	29.92b	45.75bc	45.00ab	20.7a	56.0a	79.0abc	90.2bcdefg
N ₀ P ₄₀ FYM ₅	7.25a	41.50ab	40.75abc	44.75ab	25.7a	48.3a	69.8abc	84.0bcd
N ₀ P ₄₀ FYM ₁₀	8.40a	43.60ab	45.50bc	56.25cdefg	24.7a	47.6a	72.3abc	86.2bcde
N ₀ P ₈₀ FYM ₀	9.56a	41.77ab	46.50bc	47.50gh	26.5a	52.9a	73.8abc	87.8bcde
N ₀ P ₈₀ FYM ₅	10.00a	45.95ab	47.70bc	56.26bcdef	24.7a	59.0a	77.5abc	99.0defg
N ₀ P ₈₀ FYM ₁₀	9.15a	44.20ab	44.50bc	56.26ab	12.9a	38.1a	61.1abc	84.3bcd
N ₇₅ P ₀ FYM ₀	8.50a	43.00ab	38.75ab	45.00gh	21.5a	44.3a	50.7a	50.9a
N ₇₅ P ₀ FYM ₅	9.00a	41.57ab	46.50bc	66.00gh	26.9a	54.1a	78.4abc	97.8defg
N ₇₅ P ₀ FYM ₁₀	9.62a	45.55ab	47.25bc	66.50gh	24.8a	54.8a	67.9abc	102.3defg
N ₇₅ P ₄₀ FYM ₀	10.75a	36.62ab	41.50abc	49.25abcd	20.7a	53.2a	78.6abc	102.5defg
N ₇₅ P ₄₀ FYM ₅	7.87a	44.20ab	48.00bc	61.50g	25.2a	62.3a	84.4bc	102.4defg
N ₇₅ P ₄₀ FYM ₁₀	8.92a	41.12ab	39.50ab	61.75gh	14.8a	46.9a	66.6abc	86.5bcde
N ₇₅ P ₈₀ FYM ₀	8.10a	40.67ab	39.50bc	56.75dfgh	14.6a	47.6a	79.1abc	112.6efg
N ₇₅ P ₈₀ FYM ₅	11.25a	44.95ab	47.25bc	66.25gh	26.4a	56.5a	81.3abc	110.3def
N ₇₅ P ₈₀ FYM ₁₀	12.05a	46.96ab	47.75bc	63.25gh	9.2a	38.6a	73.1abc	95.6cdefg
N ₁₅₀ P ₀ FYM ₀	9.22a	39.55b	32.00a	43.75ab	18.5a	42.2a	56.7abc	65.0ab
N ₁₅₀ P ₀ FYM ₅	10.25a	43.77ab	44.00bc	62.25g	25.3a	62.7a	85.2c	104.1defg
N ₁₅₀ P ₀ FYM ₁₀	8.82a	38.80ab	45.25bc	63.75gh	27.0a	57.0a	86.1c	115.0g
N ₁₅₀ P ₄₀ FYM ₀	10.67a	46.37ab	46.75bc	66.00gh	12.9a	43.1a	62.6abc	88.8bcdef
N ₁₅₀ P ₄₀ FYM ₅	11.00a	43.37ab	46.75bc	62.00gh	16.1a	39.8a	66.4abc	89.7bcdefg
N ₁₅₀ P ₄₀ FYM ₁₀	9.87a	41.42ab	48.25bc	67.00gh	13.8a	42.8a	70.5abc	94.0cdefg
N ₁₅₀ P ₈₀ FYM ₀	12.37a	48.25b	51.79c	68.50h	29.1a	52.0a	81.5abc	101.4defg
N ₁₅₀ P ₈₀ FYM ₅	10.62a	50.12b	51.75c	66.00h	11.8a	45.6a	76.3abc	102.6defg
N ₁₅₀ P ₈₀ FYM ₁₀	11.42a	46.67b	51.50c	66.75h	20.4a	61.3a	86.6c	115.4fg

Means with the same letter(s) in the columns are not the significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of probability.

The application of FYM, N and P rates (N₁₅₀P₈₀FYM₁₀ and N₇₅P₄₀ FYM₅) produced statistically similar number of leaves; this was followed by T25 (N₁₅₀P₈₀FYM₀) while the control plants had the lowest number of leaves. These results are supported by those of Achieng *et al.* (2010) and Shah *et al.* (2009) who reported that plant height, number of grains per cob, 1000-grain weight, grain yield and harvest index of maize gave higher values, when N and FYM were combined as opposed to the application of two sources of nutrients differently. Growth parameters like plant height, number of leaves per plant, stem diameter, leave area per plant, and fresh and dry matter yields were influenced by the application of nitrogen (Ayub *et al.*, 2002).

Table 4. 3: Effects of N, P and Fym application on the maize leaves number at 1-4 weeks after sowing

Treatments	2014				2015			
	Weeks after sowing				Weeks after sowing			
	1	2	3	4	1	2	3	4
N ₀ P ₀ FYM ₀	3.00a	5.00a	5.50a	6.50a	2.00a	3.50a	5.00a	6.00a
N ₀ P ₀ FYM ₅	4.25a	5.75a	6.50abcd	7.75abc	3.75a	4.75a	6.00abcd	7.00abc
N ₀ P ₀ FYM ₁₀	3.50a	5.00a	6.00ab	7.00abc	3.50a	4.25a	5.83abc	6.67abc
N ₀ P ₄₀ FYM ₀	3.50a	6.25a	7.25abcd	7.50abc	3.50a	5.50a	7.50abcd	7.50abc
N ₀ P ₄₀ FYM ₅	3.00a	5.00a	6.50abcd	8.00abc	2.50a	4.50a	6.25abcd	7.75abc
N ₀ P ₄₀ FYM ₁₀	3.00a	5.25a	6.75abcd	7.50abc	3.00a	4.75a	6.50abcd	7.38abc
N ₀ P ₈₀ FYM ₀	3.50a	5.50a	7.00abcd	8.00abc	3.75a	5.00a	6.75abcd	7.75abc
N ₀ P ₈₀ FYM ₅	4.00a	6.00a	7.75abcd	8.25abc	3.88a	6.25a	7.25abcd	8.00abc
N ₀ P ₈₀ FYM ₁₀	2.00a	4.75a	6.50abcd	7.75abc	1.75a	3.50a	6.25abcd	7.50abc
N ₇₅ P ₀ FYM ₀	3.50a	5.50a	6.50abcd	6.75a	3.25a	4.25a	6.25abcd	7.50ab
N ₇₅ P ₀ FYM ₅	3.75a	6.75a	7.50abcd	8.00abc	3.25a	4.75a	7.00abcd	7.00abc
N ₇₅ P ₀ FYM ₁₀	4.00a	5.50a	7.75abcd	8.75abc	3.88a	5.25aa	7.50abcd	7.50abc
N ₇₅ P ₄₀ FYM ₀	3.50a	6.00a	8.50bc	9.00abc	3.50a	6.00a	8.00cd	8.50abc
N ₇₅ P ₄₀ FYM ₅	3.75a	5.50a	7.25abcd	8.25abc	3.50a	5.75a	6.50abcd	8.50abc
N ₇₅ P ₄₀ FYM ₁₀	1.75a	5.00a	6.75abcd	9.25abc	1.50a	3.00a	6.50abcd	7.75abc
N ₇₅ P ₈₀ FYM ₀	2.00a	5.75a	7.25abcd	9.50bc	1.50a	3.25	6.75abcd	9.00bc
N ₇₅ P ₈₀ FYM ₅	3.75a	5.50a	7.25abcd	9.00abc	3.50a	5.25a	7.50abcd	9.00abc
N ₇₅ P ₈₀ FYM ₁₀	1.50a	4.50	7.00abcd	9.00abc	1.25a	3.25a	6.50abcd	8.75abc
N ₁₅₀ P ₀ FYM ₀	3.00a	5.00a	5.75a	7.00abc	3.00a	4.25	5.50ab	8.50abc
N ₁₅₀ P ₀ FYM ₅	3.75a	5.00a	8.25abc	8.50abc	3.50a	5.00a	7.75cd	6.50abc
N ₁₅₀ P ₀ FYM ₁₀	3.50a	5.75a	8.00abcd	9.25abc	3.50a	5.25	7.00abcd	8.25abc
N ₁₅₀ P ₄₀ FYM ₀	1.50a	4.00a	6.75abcd	8.25abc	1.25a	4.75a	6.50abcd	8.75abc
N ₁₅₀ P ₄₀ FYM ₅	1.50a	4.75a	6.75abcd	9.25abc	1.13a	3.25a	6.50abcd	8.00abc
N ₁₅₀ P ₄₀ FYM ₁₀	2.00a	4.50a	7.00abcd	8.25abc	3.00a	4.25a	6.50abcd	9.00abc
N ₁₅₀ P ₈₀ FYM ₀	4.00a	5.00a	8.50abcd	9.50bc	4.50a	6.25a	8.00cd	7.75bc
N ₁₅₀ P ₈₀ FYM ₅	1.75a	5.00a	8.00abcd	9.75c	1.75a	5.50a	7.25abcd	9.00c
N ₁₅₀ P ₈₀ FYM ₁₀	3.75a	6.00a	8.75cd	9.75bc	3.75a	6.50a	8.50d	9.00ab

Means with the same letter(s) in the columns are not the significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of probability.

4.4.4 Effects of N, P and Fym on stem girth

Table 4.4 shows the effect of applying different rates of nitrogen, phosphorus and farmyard manure fertilizers on stem girth of the maize plants. In 2014 the stem girth of T₂₇ (N₁₅₀P₈₀ FYM₁₀) had the highest stems girth of 4.90 cm while 4.80 cm and 4.73 cm were recorded from the pots which received T₂₅ (N₁₅₀P₈₀ FYM₀) and T₂₁ (N₁₅₀P₀FYM₁₀), respectively and the control plant had the least stem girth of 2.10 cm. Similar results were obtained in 2015 with regards to stem girth in which treatment T₂₇ recorded the highest thick plant. The results from the applied treatments

on stem girth at the end of the screen house study revealed that some treatments had significantly increased stem girth ($P < 0.05$). For instance, Treatment T₂₇ (N₁₅₀ P₈₀ FYM₁₀) recorded higher stem girth values in both years at 4 WAS. This was followed by T₂₆ (N₁₅₀ P₈₀ FYM₅) while control pot recorded the least stem girth value in all experiments. In both years most of the treatments produced similar stem girth values. The application of nitrogen, phosphorus and farmyard manure at higher rates (N₁₅₀P₈₀ FYM₁₀) produced significantly larger stem girth values at 4 WAS.

Table 4.4: Stem girth of maize plant as affected by nitrogen, phosphorus and farmyard manure in 2014 and 2015

Treatments	2014	2015
	Stem girth (cm) pot ⁻¹	Stem girth (cm) pot ⁻¹
N ₀ P ₀ FYM ₀	2.10a	2.65ab
N ₀ P ₀ FYM ₅	3.30cdefg	3.05abcde
N ₀ P ₀ FYM ₁₀	3.23cdefg	2.90abcd
N ₀ P ₄₀ FYM ₀	2.55abc	3.60abcdef
N ₀ P ₄₀ FYM ₅	2.96abcde	3.60bcdef
N ₀ P ₄₀ FYM ₁₀	3.23cdefg	3.95abcde
N ₀ P ₈₀ FYM ₀	2.85abcd	3.85abcdef
N ₀ P ₈₀ FYM ₅	2.77abc	3.85def
N ₀ P ₈₀ FYM ₁₀	3.10bcdef	3.85cdef
N ₇₅ P ₀ FYM ₀	2.18a	2.60a
N ₇₅ P ₀ FYM ₅	3.93fghig	3.90cdef
N ₇₅ P ₀ FYM ₁₀	4.23hijk	3.90cdef
N ₇₅ P ₄₀ FYM ₀	3.15cdef	3.90def
N ₇₅ P ₄₀ FYM ₅	3.75defgh	4.00efg
N ₇₅ P ₄₀ FYM ₁₀	3.90efghi	3.95def
N ₇₅ P ₈₀ FYM ₀	3.85efgh	4.20efg
N ₇₅ P ₈₀ FYM ₅	4.13ghijk	4.05efg
N ₇₅ P ₈₀ FYM ₁₀	4.58hijk	4.45efg
N ₁₅₀ P ₀ FYM ₀	2.20bc	2.80abc
N ₁₅₀ P ₀ FYM ₅	4.53hijk	4.10ef
N ₁₅₀ P ₀ FYM ₁₀	4.73ijk	4.45fg
N ₁₅₀ P ₄₀ FYM ₀	4.43hijk	4.10def
N ₁₅₀ P ₄₀ FYM ₅	4.40hijk	4.55efg
N ₁₅₀ P ₄₀ FYM ₁₀	4.45hijk	4.75ef
N ₁₅₀ P ₈₀ FYM ₀	4.80jk	4.75fg
N ₁₅₀ P ₈₀ FYM ₅	4.60hijk	4.30efg
N ₁₅₀ P ₈₀ FYM ₁₀	4.90k	5.85g

Means with the same letter(s) in the columns are not the significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of probability.

Plant height, number of leaves and stem girth were generally influenced by the combined application of nitrogen, phosphorus and farmyard manure at various rates in both 2014 and 2015 seasons. The results of this experiment are in agreement with the results obtained by Titiloye (1982). Similarly, an increase in the number of leaves per plant due to combined nutrient application was reported by Makinde (2007). Biological yield is one of the measures of plant growth and reflects the relative growth rate as regard to net assimilation rate (Khan *et al.*, 2008). Biological yield was significantly affected by the application of fertilizer at two locations during 2009 and 2010 (Achieng *et al.*, 2010). The increase in biological and stalk yield could reflect the better growth and development of maize plants due to balanced and more available nutrients throughout the growing period. These results agree with those of Khan *et al.* (2008) who reported that declining N uptake with progression of plant growth was partly due to high assimilation rate from an increase in plant biomass with plant growth. It was also reported that the concentration of N in the leaf stem and roots of maize declined asymptotically from first to the last sampling dates (Aflakpui *et al.*, 1998). As crops grow, concentration of nutrient per unit of dry mass normally decreases with time as more structural materials are produced due to the nutrient concentration dilution effect (Gregory, 1997). The effect of the farmyard manure application increased the parameters measured due to a gradual release of available nutrients throughout the period of growth.

4.4.5 Effect of nitrogen, phosphorus and farmyard manure on root, shoot and total dry matter yield of maize

Maize biomass production (root and shoot DMY) was measured at the end of each screen house experiment and the results are presented in Table 4.5. In both years the application of different rates of nitrogen, phosphorus and farmyard manure had significant effects on the root, shoot, and dry matter yields of maize (Table 4.5).

In the 2014 experiment, the highest root, shoot and DM yield were obtained from pots that received T₂₇ followed by those pots which received T₂₄ and these were significantly higher than the absolute control and the pots which were treated with other nutrients levels. The highest total DM yields of 13.23 g pot⁻¹ was obtained from the plants treated with N₁₅₀ kg ha⁻¹, P₄₀ kg ha⁻¹+FYM₁₀ t ha⁻¹, respectively. In the second screen house experiment (2015), the root, shoot and total DM yield ranged from 3.59, 11.52 and 15.26 g pot⁻¹ to 9.23, 24.43 and 30.20 g pot⁻¹ respectively (Table 4.5). With regards to root biomass; this was higher in the pot which received T₁₁ followed by T₈ and T₁₄ with the least values recorded from the control (3.59 g pot⁻¹). The highest shoot biomass was obtained from the plants treated with the highest rates of all types of fertilizers T₂₇ (24.43 g pot⁻¹) followed by T₁₄ and T₂₀.

In the second pot experiment, the total DM yields ranged from 15.26 to 30.20 g pot⁻¹ with heavier DM significantly produced by the pot which was treated with T₂₇ followed by T₁₄ and T₂₀, while the control pots produced significant lower total DM value (Appendix. 4.3). The highest DM yield was observed in the pots which were treated with treatments at full rates. This could have resulted from increased absorption of N, P and K which may have contributed to the dry weight of maize. Bokhtair and Sakurai (2005) also reported the increase in DM yield from a combined use of different organic and inorganic sources of nutrients as the levels increase up to the recommended rates by sugarcane.

As presented in Appendix 4.4, biomass production and P uptake increased with an increase in FYM rate in both seasons; this could probably be due to the fact that addition of organic manure in the soil improves the soil physical properties such as soil texture, soil structure and soil moisture retention capacity and hence, encourages good

root growth and development thus leading to higher biomass yields. Also Akintunde *et al.* (1993) reported nitrogen application facilitated better photosynthetic activity and higher partitioning of dry matter in maize crop.

Table 4.5: Effect of rates of nitrogen, phosphorus and farmyard manure on dry matter yield

Treatments	2014			2015		
	Dry Matter Yield (g Pot ⁻¹)			Dry Matter Yield (g Pot ⁻¹)		
	Root	Shoot	Total DMY	Root	Shoot	Total DMY
N ₀ P ₀ FYM ₀	0.536abc	1.59ab	2.14a	3.59ab	11.52a	15.26a
N ₀ P ₀ FYM ₅	0.878abcdef	4.29abcde	5.18abcdef	4.51abc	14.33abcd	18.85abcd
N ₀ P ₀ FYM ₁₀	0.909abcdef	4.79bcdef	5.71abcdefg	4.17abc	13.42abc	18.09abc
N ₀ P ₄₀ FYM ₀	0.502abcd	2.70abc	3.26ab	5.32abcd	18.35cde	23.67cde
N ₀ P ₄₀ FYM ₅	0.813abcdef	3.58abcd	4.41abcde	6.22abcd	19.04cdef	25.25de
N ₀ P ₄₀ FYM ₁₀	1.007abcdef	4.15abcde	5.16abcdef	6.31abcd	17.10bcde	23.41bcde
N ₀ P ₈₀ FYM ₀	0.798abcde	5.59cdefg	6.34bcdefg	6.09abcd	18.87cdef	24.90cde
N ₀ P ₈₀ FYM ₅	0.792abcdef	4.09abcd	4.89abcde	7.74de	19.99cde	27.72e
N ₀ P ₈₀ FYM ₁₀	0.976abcdef	3.99abcd	4.97abcde	6.01abcd	18.70cde	24.71cbe
N ₇₅ P ₀ FYM ₀	0.234a	1.78ab	2.11a	3.43a	12.74ab	16.17e
N ₇₅ P ₀ FYM ₅	0.994abcdef	7.32efgh	8.32defgh	9.28e	21.28ef	30.56e
N ₇₅ P ₀ FYM ₁₀	1.517cdefghi	8.14ghi	9.14ghi	6.81cde	21.28ef	28.09e
N ₇₅ P ₄₀ FYM ₀	0.615abcde	3.30abc	4.83abc	6.67cde	20.34ef	27.01e
N ₇₅ P ₄₀ FYM ₅	1.246abcdefg	7.30fghi	9.16fgh	7.50de	22.19ef	29.68e
N ₇₅ P ₄₀ FYM ₁₀	1.246abcdefgh	7.86fghi	9.11fgh	6.31abcd	18.92ef	25.23de
N ₇₅ P ₈₀ FYM ₀	1.214cdefgh	6.60defgh	7.82cdefgh	6.09abcd	19.73ef	25.82de
N ₇₅ P ₈₀ FYM ₅	1.889fghi	8.58ghi	10.47hi	6.25abcd	21.13ef	27.38e
N ₇₅ P ₈₀ FYM ₁₀	1.549cdefghi	8.93hi	10.49hi	5.61abcd	19.75ef	25.37de
N ₁₅₀ P ₀ FYM ₀	0.336ab	1.47e	2.95a	3.91abc	12.95ef	16.86ab
N ₁₅₀ P ₀ FYM ₅	1.301abcdefghi	7.54fgh	8.85efgh	6.71cde	22.09ef	28.80e
N ₁₅₀ P ₀ FYM ₁₀	1.428abcdef	8.23ghi	9.66ghi	6.70cde	20.70ef	27.44e
N ₁₅₀ P ₄₀ FYM ₀	1.209abcdef	8.02fghi	8.96ghi	5.99abcd	20.97ef	26.56e
N ₁₅₀ P ₄₀ FYM ₅	1.418abcdefghi	7.94fghi	9.36hi	6.01abcd	20.48ef	26.49e
N ₁₅₀ P ₄₀ FYM ₁₀	1.647defghi	9.60hi	11.26hi	5.72abcd	20.65ef	26.38e
N ₁₅₀ P ₈₀ FYM ₀	1.594cdefghi	9.46hi	11.12hi	6.37bcd	21.14ef	27.51e
N ₁₅₀ P ₈₀ FYM ₅	1.667efghi	9.49hi	11.16hi	5.81abcd	21.22ef	27.03e
N ₁₅₀ P ₈₀ FYM ₁₀	2.328gi	10.89i	13.23i	5.77abcd	24.34f	30.20e

Means with the same letter(s) in the columns are not the significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of probability.

Furthermore, the improved soil physical conditions such as soil texture, soil structure and water holding capacity usually associated with organic amendments could have supported higher crop performance and grain yields of most crops (Pan *et al.*, 2009; Tiwari *et al.*, 2002). These results are supported by those of Achieng *et al.* (2010), and Shah *et al.* (2009) who reported that plant height, number of grains per cob, 1000-seed grain weight, grain yield and harvest index of maize gave higher values, when N and FYM were integrated as opposed to the application of the two sources of nutrients separately. As reported by Razwan *et al.* (2007) and Wakene *et al.* (2001a), the integration of organic fertilizer with inorganic fertilizer increased the positive interaction of the applied fertilizer thereby increased plant productivity. The findings in this experiment are in agreement with those of Makinde (2007) and Ayoola and Makinde (2009) who reported an increase in maize plant height by the use of organic and inorganic nutrient sources thus indicates positive interaction of the amendments.

4.4.6 Effects of N, P and Fym on N and P uptakes by the maize plants

The effects of nitrogen, phosphorus and farmyard manure on the uptakes of N and P by maize plants are presented in Table 4.6. Plants treated with $N_{150} + P_{80} + FYM_5$ and $N_{75} + P_{80} + FYM_5$ had significant higher nitrogen and phosphorus uptake in 2014 while the lowest uptakes values of 1.04 and 0.08 % were observed in treatments T_5 and control treatment respectively (Appendix 4.5). N uptake ranged from 1.032 and 0.367% to 2.94 and 2.55% in the two experiments, while P uptake ranged from 0.077 to 0.037% (Appendix 4.6).

The highest nitrogen and phosphorus uptakes in 2014 from a combination of fertilizers treatment are similar to the findings of Lawal *et al.* (2010) who reported that application of fertilizers at different rates above the control resulted in the highest nitrogen, phosphorus and potassium uptakes by white yam. These results indicated that

an integrated nutrients management (INM) that combines organic sources of nutrients and inorganic fertilizers (nitrogen, phosphorus and farm yard manure) enhanced maize performance in the study area and this is in agreement with the findings of Adediran *et al.* (1999), Oyinlola and Onekebhagbe, (2008), Adeoye *et al.* (2008), Ayoola and Makinde (2009) and Ojeniyi (2010).

Table 4.6: Effect of nitrogen, phosphorus and farmyard manure on N and P uptakes on maize plant

Treatments	2014		2015	
	Shoot N (%)	Shoot P (%)	Shoot N (%)	Shoot P (%)
N ₀ P ₀ FYM ₀	1.400abcde	0.077a	0.367b	0.050b
N ₀ P ₀ FYM ₅	1.155ab	0.249ab	0.507b	0.091ab
N ₀ P ₀ FYM ₁₀	1.260abcd	0.336b	0.630b	0.140ab
N ₀ P ₄₀ FYM ₀	1.260abcd	0.250ab	0.507b	0.095ab
N ₀ P ₄₀ FYM ₅	1.032a	0.201ab	0.472b	0.147ab
N ₀ P ₄₀ FYM ₁₀	1.155ab	0.308ab	0.437b	0.174ab
N ₀ P ₈₀ FYM ₀	1.068a	0.206ab	0.542b	0.150ab
N ₀ P ₈₀ FYM ₅	1.260abcd	0.242ab	0.455b	0.136ab
N ₀ P ₈₀ FYM ₁₀	1.225abc	0.369b	0.507b	0.119ab
N ₇₅ P ₀ FYM ₀	2.292hijkl	0.155ab	1.277b	0.037ab
N ₇₅ P ₀ FYM ₅	1.802defghi	0.164ab	0.595b	0.057b
N ₇₅ P ₀ FYM ₁₀	1.802defghi	0.312ab	0.577b	0.107ab
N ₇₅ P ₄₀ FYM ₀	2.450gilm	0.158ab	0.712b	0.053b
N ₇₅ P ₄₀ FYM ₅	1.750cdefgh	0.302ab	0.630b	0.093ab
N ₇₅ P ₄₀ FYM ₁₀	1.907efghij	0.337ab	0.682b	0.126ab
N ₇₅ P ₈₀ FYM ₀	2.188fghijkl	0.290ab	1.190ab	0.101ab
N ₇₅ P ₈₀ FYM ₅	1.660bcdefg	0.386b	1.108ab	0.167ab
N ₇₅ P ₈₀ FYM ₁₀	1.575abcdef	0.316ab	1.272ab	0.177ab
N ₁₅₀ P ₀ FYM ₀	2.188ghijkl	0.164ab	1.412ab	0.042b
N ₁₅₀ P ₀ FYM ₅	2.555lm	0.200ab	1.102ab	0.054b
N ₁₅₀ P ₀ FYM ₁₀	2.345ijkl	0.306ab	0.928ab	0.133ab
N ₁₅₀ P ₄₀ FYM ₀	2.485jklm	0.156ab	1.067ab	0.110ab
N ₁₅₀ P ₄₀ FYM ₅	2.363ijkl	0.309ab	1.242ab	0.108ab
N ₁₅₀ P ₄₀ FYM ₁₀	2.205ghijkl	0.296ab	1.470ab	0.212ab
N ₁₅₀ P ₈₀ FYM ₀	2.083ghijkl	0.220ab	1.785ab	0.222ab
N ₁₅₀ P ₈₀ FYM ₅	2.940m	0.325ab	2.555a	0.295e
N ₁₅₀ P ₈₀ FYM ₁₀	1.943efghijk	0.370b	1.890ab	0.308e

Means with the same letter(s) in the columns are not the significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of probability.

4.5 Conclusions and Recommendations

4.5.1 Conclusions

In conclusion, the soils of the study area were low in major macronutrients. This suggests poor soil fertility that may require some extenuating measures to improve. The results of the study also indicated that the combined application of nitrogen, phosphorus and farmyard manure had a significant effect ($P < 0.05$) on all agronomic growth parameters like plant height, number of leaves and stem girth of maize, thus implies the success of combined nutrients management for maize production in the study area.

The results indicated further that the combined application of organic and inorganic amendments reveals a significant influence ($P < 0.05$) on dry matter yields and nutrient uptakes (N and P) of maize.

4.5.2 Recommendations

The study recommends the followings;

- i. Field studies to confirm the results from the study are advocated
- ii. For enhanced maize growth and biomass production therefore, the combined application of nitrogen, phosphorus and farm yard manure at reduce rates (75 kg N ha^{-1} , 40 kg P ha^{-1} plus FYM 5 t ha^{-1}) is therefore recommended at Solomon Mahlangu Campus farm, SUA, Morogoro, Tanzania.

4.6 References

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CHAPTER FIVE

5.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1 General Conclusions

The soils at the Solomon Mahlangu Campus farm were described and distinguished on the basis of parent materials and forms macro relief, geological formation, slope, drainage class, vegetation, and land use, morphological and physical characteristics. Soil colour varied from brown (7.5YR 4/2) through dark brown (7.5YR 4/4) to reddish brown (2.5YR 4/6). The soil structure varied from being weak to moderate sub angular blocky with dominant sand texture. The results of this study have indicated that, the predominant soil textural classes of the study area were sand; sandy clay loam, sandy clay and loamy sand. The general characteristics of the soils were high sand and low silt contents. Most of the profiles had greater than 60 % sand, 20 % clay and less than five percent (5 %) silt. The analytical results indicated that soil pH ranged from 5.2 to 6.9 which are slightly acidic to nearly neutral in reaction. The soil physico-chemical properties in all the land mapping units indicate that in some areas there are deficiencies of major nutrients and therefore the risky to sustainable crop production including maize crop production in the area.

The suitability assessment result showed that there was no highly suitable (S1) land for maize cultivation in the area. The area was moderately suitable (S2), marginally suitable (S3) and currently non-suitable (N1) for maize production. Even though some land qualities such as mean annual rainfall and temperature are adequate for maize, but most of the soil characteristics such as levels of organic carbon and CEC are low.

The results of the screen house study shows that the combined application of nitrogen, phosphorus and farmyard manure had a significant effect ($P < 0.05$) on all agronomic

growth parameters such as plant height, number of leaves, and stem girth of maize, thus implying the success of combined nutrients management for maize production in the study area. The results also indicates that the combined application of organic and inorganic amendments reveals a significant influence ($P < 0.05$) on dry matter yields and nutrient uptakes (N and P) of maize.

The study indicates further that:

- i. All the soils belong to the soil order Ultisols and Ustalfs at suborder level in the Soil Taxonomy while Alisols in the Reference Soil Group (RSG) - Tier 1 for the World Reference Base for Soil Resources soil legend.
- ii. At great group and subgroup levels P1 was classified as Rhodustults and Typic Rhodustults, P1 and P2 as Haplustults and Typic Haplustults, whereas, P4 was classified as Haplustults and Arenic Haplustults (Soil Taxonomy), which correspond to Haplic RhodicAlisols, HaplicAlisols, Haplic Chromic and HaplicAlisols (World Reference Base) in the Tier 2 for RSG soil name for the P1, P2, P3 and P4, respectively.
- iii. None of the four mapping units fell under highly suitable (SI) class, for maize production.
- iv. The major limitations in the surveyed area are low fertility status and moisture content.
- v. There was significant ($P < 0.05$) positive correlation between the clay % and the soil's content of CEC, Zn, Cu, K, Mg, Na and EC, there was also a significant relationship between the OC and pH in H₂O and KCL and Equally, TEB and BS were significantly ($P < 0.001$) and positively correlated ($r = 0.9993$).

- vi. The combined treatments produced yields which were significantly higher than the values obtained by control. The highest biomass yields of 30.2 g pot⁻¹ were obtained by a combined application of treatments at 150 kg N⁻¹, 80 kg P⁻¹ plus FYM 10 t ha⁻¹. The control obtained the lowest biomass yields of 15.26 g pot⁻¹ respectively.
- vii. The combined treatments of organic and inorganic manure had significantly higher nutrient uptake values than the control. The highest nutrient uptakes of 2.94% N pot⁻¹ and 0.32% P pot⁻¹ was obtained under the combined application of N, P and FYM at 150 kg N⁻¹, 80 kg P⁻¹ plus FYM 5 t ha⁻¹.

5.2 Recommendations

The following recommendations were suggested in order to improve soil productivity and sustain production of maize crop in the area (SMC farm) under investigation:

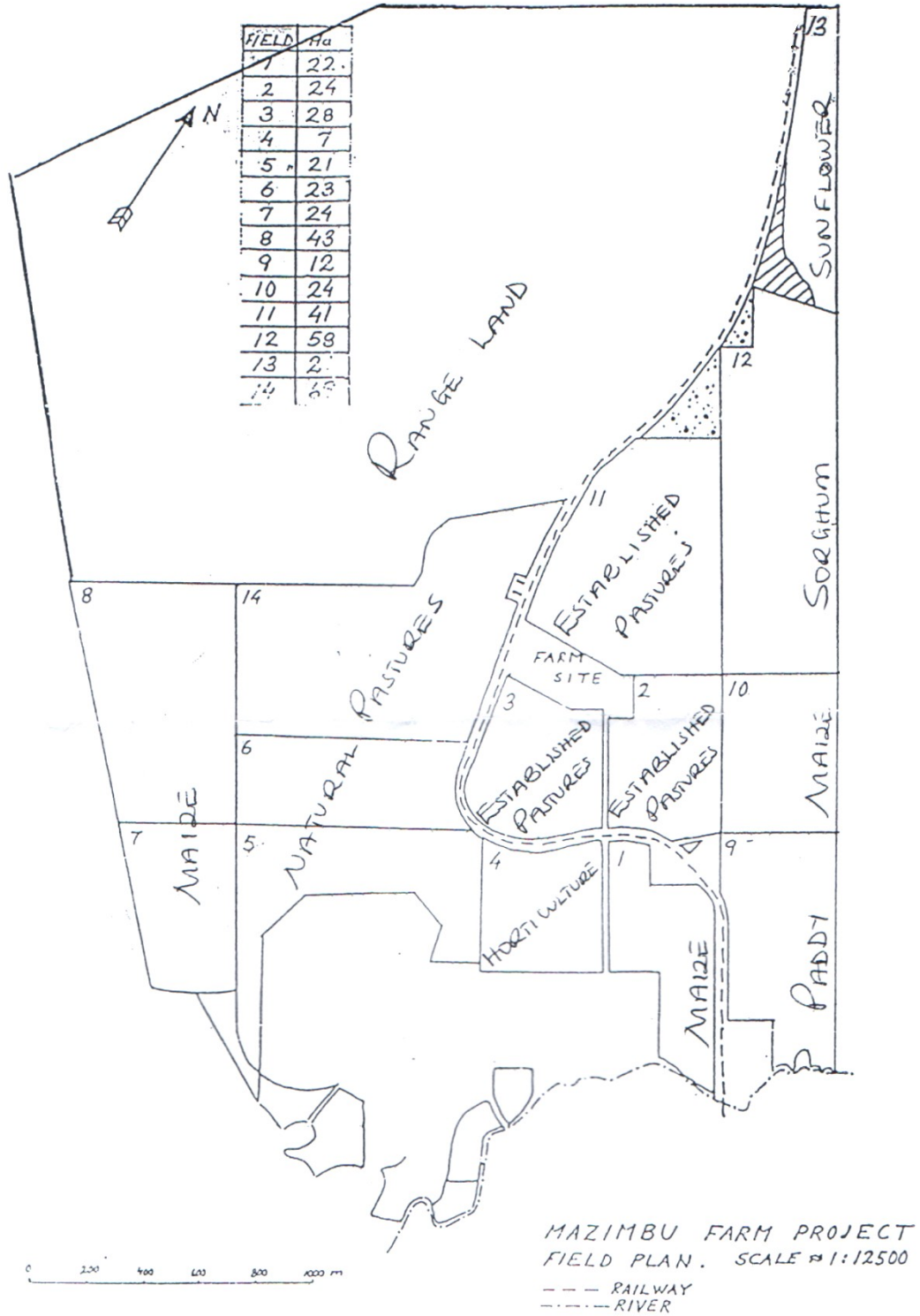
- i. The low TN and OC contents in the soils need to be amended through N-fertilizer management.
- ii. An integrated nutrients management (INM) should be adopted which embraces a holistic approach of integrated use and management of organic and inorganic nutrient sources in a sustainable way.
- iii. Thus, to enhance performance of maize in the study area; application of a combination of fertilizers (nitrogen, phosphorus and farmyard manure) at moderate rates (75 kg N ha⁻¹, 40 kg P ha⁻¹ plus FYM 5 t ha⁻¹) would be cost effective and sufficient for maize dry matter yield and nutrient uptakes (N and P) in the test soil.
- iv. Periodic soil tests of the site are very imperative to properly monitor and evaluate the soil fertility status of other potential maize growing areas in the

same agro-ecological zone to understand the deficiency the soil fertility indices and prevent soil fertility decline and degradation.

- v. Field studies should be done to confirm the results of this study.
- vi. Further studies are needed in similar abandoned farms in other agro-ecological zones for sustainable maize production in Tanzania.
- vii. Maintaining high level of organic matter in the soil to improve physical condition of soil such as soil structure and CEC content to make soil support good plant growth.
- viii. A more detail soil survey of the site is advocated to put the land into best uses, make predictions about the behavior of soils and evaluates/predicts the effects of land use on the environment of the study area.

APPENDICES

Appendix 2.1: Sketch map of the study area



Appendix 2.2: Morphological and Physico-chemical

Descriptions of Profile 1

Profile number: P 1 MU- 1 Mapping unit: MU 1 Agro-ecol. zone:

Region: Morogoro

District: Morogoro Urban

Map sheet no.: 183/3

Coordinates: 34⁰⁷⁴0⁸⁵°E 9⁰⁵⁰0^{75.8}°S

Location: SUA FARM- Solomon Mahlangu Campus, Morogoro Municipality

Elevation: 500 m above sea level. Parent material: colluvium derived from mafic metamorphic rocks. Landform: plain; flat or almost flat, slope: moderate 3%; gently sloping, mid slope,

Surface characteristics: Sealing: none. Run off: None. Erosion: Very slight sheet erosion. Ground water level: >200 cm, Modified ground water level: None. Deposition: none.

Natural drainage class: well drained. Natural vegetation: Natural grasses, *Acacia*, *Eucalyptus sp* and shrubs.

Land use systems: maize cultivation, deforestation and grazing.

STR: hyperthermic SMR: ustic

Described by Adamu Uzaifa Karfi and Tumaini Mwasyika on 19/3/2014

Ap 0 - 27 cm: brown (7.5YR4/4) dry, dark brown (7.5YR 3/2) moist; sand; slightly hard dry, very friable moist, non sticky and non plastic wet; weak, fine sub angular and angular blocks; many fine and few medium pores; very few coarse, few medium, many fine and very fine roots; very few termite nests, abrupt smooth boundary to

Bt1 27 -35 cm: Reddish brown (5YR4/4) dry, yellowish red (5YR4/6) moist; sandy clay loam; hard dry, friable moist, sticky and plastic wet; moderate, fine angular, medium sub angular to coarse sub angular and angular blocks; few fine clay cutans; many fine and few medium pores; few fine and very few very fine roots; very few termites nests, clear smooth boundary to

Bt 2 35 - 77 cm: Red (2.5YR4/6) dry, dark reddish brown (2.5YR3/4) moist; sandy clay loam; slightly hard dry, friable moist, sticky and plastic wet; strong, medium to course sub angular blocks; few faint clay cutans; many fine and few medium pores; very few fine and very fine roots; very few termite nest, diffuse smooth boundary to

Bt3 77 - 120 cm: red (2.5YR4/6) dry, reddish brown (2.5YR4/4) moist; sandy clay loam; slightly hard, very friable moist, slightly sticky and slightly plastic wet; strong medium to course sub angular blocks,; many fine and few medium pores, few faint clay cutans; few medium continuous quartz's and feldspars, very few fine and very fine roots. diffuse and smooth boundary to Bt4

Bt4 120 - 167+: red (2.5YR4/8) dry, red (2.5YR4/6) moist; sandy clay loam; hard, friable moist, slightly sticky and slightly plastic wet; strong medium sub angular blocks,; many fine pores, few fine and medium faint clay cutans.

ANALYTICAL DATA FOR PROFILE SMC-P1

Horizon	Ap	Bt1	Bt2	Bt3	Bt4
Depth (cm)	0-27	27-35	35-77	77-120	120-162
Clay %	8.12	24.12	28.12	28.12	30.12
Silt %	1.64	1.64	1.64	1.64	1.64
Sand %	90.24	74.24	70.24	70.24	68.24
Textural class	S	SCL	SCL	SCL	SCL
Silt/clay ratio	0.2	0.7	0.06	0.06	0.05
BD gcm ⁻³	nd	1.56	1.52	1.55	nd
Moisture %	nd	2.68	6.06	4.08	nd
pH H ₂ O 1:2.5	7.23	6.29	6.81	6.99	7.14
pH KCl 1:2.5	5.84	5.54	5.05	5.99	6.54
Organic C (%)	0.29	0.33	0.29	0.12	0.02
Total N (%)	0.04	0.04	0.04	0.01	0.02
Organic M (%)	0.5	0.57	0.5	0.2	0.03
C:N ratio	8.36	7.89	8.36	8.36	1.05
Avail. P (mg/kg)	11.52	2.75	2.84	6.15	2.65
CEC (cmol(+)/kg)	9.0	11.8	13.3	15.4	15.4
Exch. Ca (cmol(+)/kg)	1.3	3.16	1.77	2.23	5.03
Exch. Mg (cmol(+)/kg)	0.58	2.13	2.20	2.58	2.62
Exch. K (cmol(+)/kg)	0.28	0.21	0.10	0.10	0.10
Exch. Na (cmol(+)/kg)	0.21	0.22	0.24	0.3	0.35
TEB (cmol(+)/kg)	2.37	5.73	4.31	5.21	8.12
CEC _{clay}	110.8	48.9	47.3	54.8	51.1
BS %	26.35	48.54	32.63	33.85	52.66
Extr. Cu (mg/kg)	0.4	0.4	0.61	0.73	0.64
Extr. Zn (mg/kg)	0.31	0.61	0.11	0.11	0.08
Extr. Fe (mg/kg)	11.26	20.68	17.02	12.3	7.07
Extr. Mn (mg/kg)	29	31.5	27.75	24	20.25
EC (dSm ⁻¹)	0.02	0.03	0.02	0.02	0.04

nd= not determined

Appendix 2.3: Morphological and Physico-chemical

Descriptions of Profile 2

Profile number: P 2 MU- 2 Mapping unit: MU 2 Agro-ecol. zone:
 Region: Morogoro
 District: Morogoro Urban
 Map sheet no.: 183/3
 Coordinates: 34⁰72⁰16"E/9⁰50⁰34.7 S
 Location: SUA FARM- Solomon Mahlangu Campus, Morogoro Municipality
 Elevation: 509 m above sea level. Parent material: colluvium derived from mafic metamorphic rocks. Landform: plain; flat or almost flat, slope: moderate 2%; gently sloping, mid slope,
 Surface characteristics: Sealing: none. Run off: None. Erosion: Very slight sheet erosion. Ground water level: >200 cm, Modified ground water level: None. Deposition: none.
 Natural drainage class: well drained. Natural vegetation: Natural grasses, Acacia, *Eucalyptus sp* and shrubs.
 Land use systems: maize cultivation, deforestation and grazing.
 STR: hyperthermic SMR: ustic

Described by Adamu Uzaifa Karfi and Tumaini Mwasika on 21/3/2014.

Ap 0 - 46 cm: brown (7YR4/2) dry, brown (7YR 3/2) moist; loamy sand; soft dry, very friable moist, non sticky and non plastic wet; weak, fine sub angular and angular blocks; few fine and many medium pores; very few coarse, few medium, many fine and few very fine roots; very few termite nests, clear smooth boundary to

Bt1 46 - 120 cm: brown (7.5YR5/4) dry, brown (7.5YR4/4) moist; many medium to fine bright scattered reddish mottles; sandy clay loam; hard dry, very friable moist, non sticky and non plastic wet; weak, fine medium sub angular blocks; few distinct fine clay cutans; many fine and common medium pores; very few medium, few fine and very few very fine roots; very few cracks, clear smooth boundary to

Bt2 120 - 162+cm: light brown (7.5YR6/4) dry, brown (7.5YR5/4) moist; many medium to fine slightly bright scattered reddish and grey mottles; sandy clay; hard dry, friable moist, slightly sticky and slightly plastic wet; strong, few fine, medium to coarse sub angular blocks; many fine and few medium pores; very few fine and very few medium roots

ANALYTICAL DATA FOR PROFILE SMC-P2

Horizons	Ap	Bt1	Bt2
Depth (cm)	0-46	46-120	120-162
Clay %	12.12	24.12	38.12
Silt %	3.64	1.64	1.64
Sand %	84.24	74.24	60.24
Textural class	LS	SCL	SC
Silt/clay ratio	0.3	0.7	0.04
BD gcm ⁻³	1.64	1.66	1.69
Moisture %	5.77	7.17	7.28
pH H ₂ O 1:2.5	6.76	6.34	6.22
pH KCl 1:2.5	5.86	4.68	4.5
Organic C (%)	0.49	0.27	0.27
Total N (%)	0.04	0.04	0.04
Organic M (%)	0.84	0.47	0.47
C:N ratio	13.94	7.8	7.8
Avail. P (mg/kg)	6.73	3.38	4.61
CEC (cmol(+)/kg)	9.2	11.2	15.0
Exch. Ca (cmol(+)/kg)	1.3	0.37	0.37
Exch. Mg (cmol(+)/kg)	1.03	1.75	2.91
Exch. K (cmol(+)/kg)	0.25	0.3	0.39
Exch. Na (cmol(+)/kg)	0.24	0.4	1.1
TEB (cmol(+)/kg)	2.58	2.82	4.78
BS %	28.03	25.21	31.84
CEC _{clay}	75.9	46.4	39.3
Extr. Cu (mg/kg)	0.4	0.4	0.76
Extr. Zn (mg/kg)	0.28	0.08	0.11
Extr. Fe (mg/kg)	25.39	43.19	64.14
Extr. Mn (mg/kg)	18.28	13.28	12.75
EC (dSm ⁻¹)	0.02	0.01	0.05

Appendix 2.4: Morphological and Physico-chemical

Descriptions of Profile 3

Profile number: P 3 MU- 3 Mapping unit: MU 3 Agro-ecol. zone:

Region: Morogoro

District: Morogoro Urban

Map sheet no.: 183/3

Coordinates: 346928, UTM 9250335

Location: SUA FARM- Solomon Mahlangu Campus, Morogoro Municipality

Elevation: 522 m above sea level. Parent material: colluvium derived from mafic metamorphic rocks. Landform: plain; flat or almost flat, slope: moderate 2%; gently sloping, mid slope,

Surface characteristics: Sealing: none. Run off: None. Erosion: Very slight sheet erosion. Ground water level: >200 cm, Modified ground water level: None.

Deposition: none.

Natural drainage class: well drained. Natural vegetation: Natural grasses, Acacia, *Eucalyptus sp* and shrubs.

Land use systems: maize cultivation, deforestation and grazing.

STR: hyperthermic SMR: ustic

Described by Adamu Uzaifa Karfi and Tumaini Mwasyika on 19/3/2014

Ap 0 - 19 cm: brown (7.5YR4/3) dry, brown (7.5YR 4/2) moist; loamy sand; slightly hard dry, very friable moist, non sticky and non plastic wet; weak, fine subangular and angular blocks; few fine and many medium pores; very few animal burrows; gradual smooth boundary to

Bt1 19 - 40 cm: brown (7.5YR4/3) dry, brown (7.5YR4/2) moist; sandy clay loam; slightly hard dry, friable moist, non sticky and non plastic wet; moderate, fine and medium sub angular and angular blocks; very few fine clay cutans; many fine and few medium pores; very few medium, very few fine and very fine roots; clear smooth boundary to

Bt2 40 - 100 cm: Reddish brown (5YR4/4) dry, reddish brown (5YR4/3) moist; sandy clay; hard dry, friable moist, non sticky and non plastic wet; moderate, fine to medium sub angular blocks; few fine faint clay cutans; many fine and very few medium pores; very few medium and fine roots; very few termite nests, diffuse smooth boundary to

Bt3 100 - 175+ cm: Yellowish red (5YR4/6) dry, reddish brown (5YR4/3) moist; clay; very hard, friable moist, slightly sticky and slightly plastic wet; moderate fine, medium and coarse sub angular and blocks,; many fine and very few medium pores, few faint clay cutans; few fine and very fine roots.: very few termite nests

ANALYTICAL DATA FOR PROFILE SMC-P3

Horizons	Ap	Bt1	Bt2	Bt3
Depth (cm)	0-19	19-40	40-100	100-175
Clay %	12.12	26.12	44.12	54.12
Silt %	1.64	1.64	1.64	1.64
Sand %	86.24	72.12	54.24	44.24
Textural class	LS	SCL	SC	C
Silt/clay ratio	0.14	0.06	0.04	0.03
BD gcm ⁻³	1.51	nd	1.54	1.51
Moisture %	2.99	nd	9.45	12.51
pH H ₂ O 1:2.5	7.12	6.92	6.84	5.06
pH KCl 1:2.5	5.53	5.42	5.49	4.27
Organic C (%)	0.51	0.39	0.31	0.16
Total N (%)	0.04	0.04	0.05	0.04
Organic M (%)	0.84	0.67	0.54	0.27
C:N ratio	12.07	9.29	6.37	4.46
Avail. P (mg/kg)	9.3	2.05	2.02	3.75
CEC (cmol(+)/kg)	11.2	13.8	16.8	17.8
Exch. Ca (cmol(+)/kg)	0.37	0.84	1.3	1.77
Exch. Mg (cmol(+)/kg)	0.74	1.72	2.65	3.16
Exch. K (cmol(+)/kg)	0.36	0.52	1.25	5.00
Exch. Na (cmol(+)/kg)	0.18	0.28	0.77	0.98
TEB (cmol(+)/kg)	1.64	3.35	5.97	10.91
BS %	14.76	24.31	35.56	61.31
CEC _{clay}	92.4	50.9	38.1	32.9
Extr. Cu (mg/kg)	0.46	0.46	0.55	0.61
Extr. Zn (mg/kg)	0.23	0.1	0.12	0.13
Extr. Fe (mg/kg)	18.06	19.11	15.45	23.3
Extr. Mn (mg/kg)	15.28	14.65	8.40	3.90
EC (dSm ⁻¹)	0.02	0.04	0.04	0.09

nd = not determined

Appendix 2.5: Morphological and Physico-chemical

Descriptions of Profile 4

Profile number: P 4 MU- 4 Mapping unit: MU 4 Agro-ecol. zone:

Region: Morogoro

District: Morogoro Urban

Map sheet no.: 183/3

Coordinates: 34°69'77"E/ 9°49'97.2S

Location: SUA FARM- Solomon Mahlangu Campus, Morogoro Municipality

Elevation: 521 m above sea level. Parent material: colluvium derived from mafic metamorphic rocks. Landform: plain; flat or almost flat, slope: moderate 4%; gently sloping, mid slope,

Surface characteristics: Sealing: none. Run off: None. Erosion: Very slight sheet erosion. Ground water level: >200 cm, Modified ground water level: None.

Deposition: none.

Natural drainage class: well drained. Natural vegetation: Natural grasses, Acacia, *Eucalyptus sp* and shrubs.

Land use systems: maize cultivation, deforestation and grazing.

STR: hyperthermic SMR: ustic

Described by Adamu Uzaifa Karfi and Tumaini Mwasika on 19/3/2014

Ap 0 - 38 cm: brown (7.5YR5/3) dry, brown (7.5YR 4/2) moist; loamy sand; soft dry, very friable moist, non sticky and non plastic wet; weak, fine sub angular and angular blocks; very few fine and many medium pores; few medium, few fine, few very fine roots; clear smooth boundary to

Bt1 38 - 79 cm: Light brown (7.5YR6/4) dry, brown (7.5YR5/4) moist; common fine bright spot reddish mottles; sandy loam; slightly hard dry, very friable moist, non sticky and non plastic wet; weak, fine angular and sub angular blocks; very few fine and many medium pores; few fine, few medium and very few very fine roots; very few termite nests; clear smooth boundary to

Bt2 79 - 138 cm: Light brown (7.5YR6/4) dry, brown (7.5YR5/3) moist; sandy clay loam; hard dry, slightly friable moist, non sticky and non plastic wet; moderate, medium to coarse sub angular blocks; very few fine faint clay cutans; many fine and few medium pores; very few fine and very fine roots; very few termite nests; diffuse smooth boundary to

Bt3 138 - 161+ cm: Pink (7.5YR7/4) dry, light brown (7.5YR6/4) moist; sandy clay loam; hard dry, slightly friable moist, slightly sticky and non plastic wet; moderate medium to coarse sub angular blocks; many fine and few medium pores; very few fine and medium roots.

ANALYTICAL DATA FOR PROFILE SMC-P4

Parameters	Ap	Bt1	Bt2	Bt3
Depth (cm)	0-38	38.79	79-138	138-161+
Clay %	8.12	16.12	34.12	28.12
Silt %	5.64	1.64	3.64	1.64
Sand %	86.24	82.24	62.24	70.64
Textural class	LS	SL	SCL	SCL
Silt/clay ratio	0.69	0.1	0.11	0.06
BD gm ⁻³	1.47	1.5	1.78	nd
Moisture %	1.42	3.38	6.4	nd
pH H ₂ O 1:2.5	7.25	6.78	6.95	8.95
pH KCl 1:2.5	5.32	4.58	5.2	7.75
Organic C (%)	0.14	0.29	0.27	0.04
Total N (%)	0.03	0.04	0.04	0.03
Organic M (%)	0.23	0.5	0.47	0.07
C:N ratio	4.9	2.17	1.3	5.62
Avail. P (mg/kg)	4.97	2.17	1.3	5.62
CEC (cmol(+)/kg)	11.4	13.2	10.8	16.6
Exch. Ca (cmol(+)/kg)	0.37	0.37	0.84	2.7
Exch. Mg (cmol(+)/kg)	0.38	1.23	3.27	3.5
Exch. K (cmol(+)/kg)	0.14	0.13	0.17	0.3
Exch. Na (cmol(+)/kg)	0.12	0.6	0.34	0.64
TEB (cmol ⁽⁺⁾ /kg)	1.02	2.33	4.62	7.13
BS %	8.96	17.66	42.8	42.98
CEC _{clay}	140.4	81.9	31.65	59.0
Extr. Cu (mg/kg)	0.16	0.25	0.64	0.37
Extr. Zn (mg/kg)	0.19	0.08	0.14	0.08
Extr. Fe (mg/kg)	17.54	32.2	27.49	4.97
Extr. Mn (mg/kg)	7.53	3.65	4.40	2.90
EC (dSm ⁻¹)	0.01	0.02	0.06	0.05

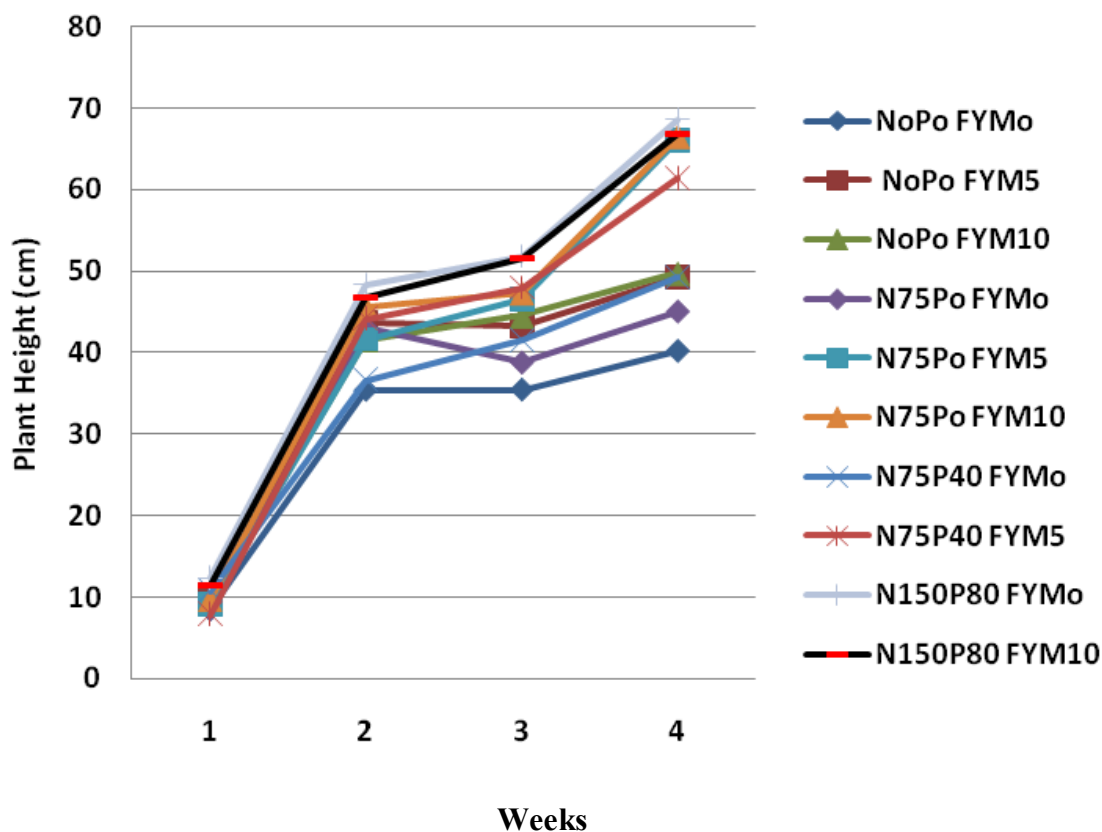
nd = not determined

Appendix4.1: Treatment layout for the pot experiment

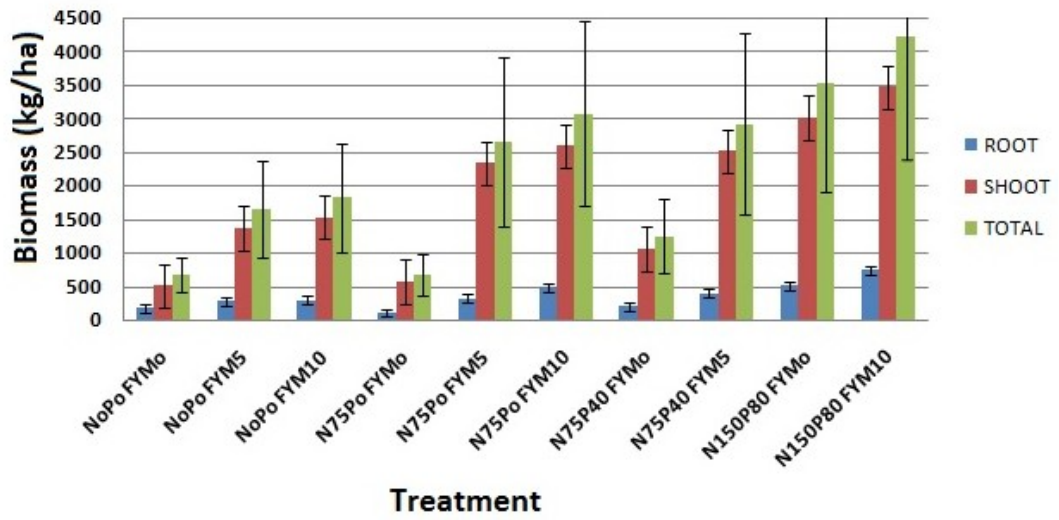
Treatments	Rates in kg or t/ha	Treatments	Rates in kg or t/ha	Treatments	Rates in kg or t/ha
1	N ₀ P ₀ FYM ₀	10	N ₇₅ P ₀ FYM ₀	19	N ₁₅₀ P ₀ FYM ₀
2	N ₀ P ₀ FYM ₅	11	N ₇₅ P ₀ FYM ₅	20	N ₁₅₀ P ₀ FYM ₅
3	N ₀ P ₀ FYM ₁₀	12	N ₇₅ P ₀ FYM ₁₀	21	N ₁₅₀ P ₀ FYM ₁₀
4	N ₀ P ₄₀ FYM ₀	13	N ₇₅ P ₄₀ FYM ₀	22	N ₁₅₀ P ₄₀ FYM ₀
5	N ₀ P ₄₀ FYM ₅	14	N ₇₅ P ₄₀ FYM ₅	23	N ₁₅₀ P ₄₀ FYM ₅
6	N ₀ P ₄₀ FYM ₁₀	15	N ₇₅ P ₄₀ FYM ₁₀	24	N ₁₅₀ P ₄₀ FYM ₁₀
7	N ₀ P ₈₀ FYM ₀	16	N ₇₅ P ₈₀ FYM ₀	25	N ₁₅₀ P ₈₀ FYM ₀
8	N ₀ P ₈₀ FYM ₅	17	N ₇₅ P ₈₀ FYM ₅	26	N ₁₅₀ P ₈₀ FYM ₅
9	N ₀ P ₈₀ FYM ₁₀	18	N ₇₅ P ₈₀ FYM ₁₀	27	N ₁₅₀ P ₈₀ NM ₁₀

N= Nitrogen, P= Phosphorus and FYM= Farm Yard Manure The subscript indicates the levels of nutrients to apply.

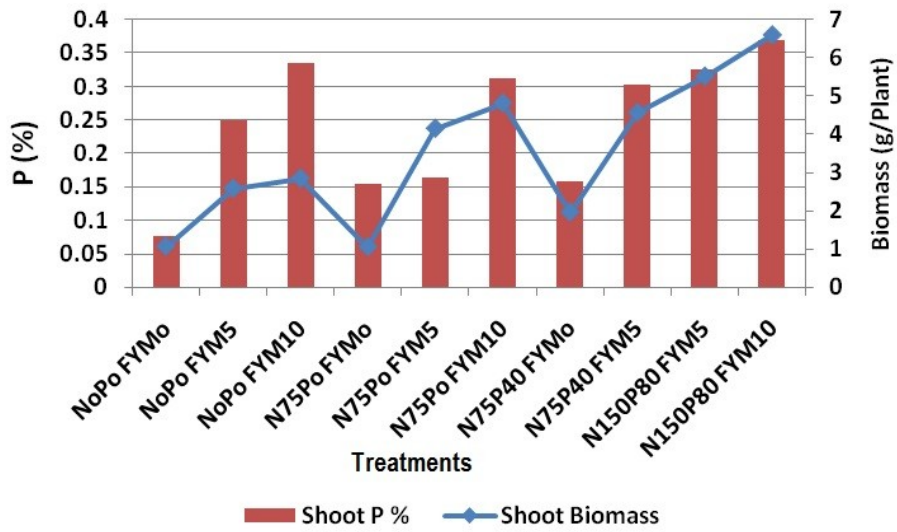
Appendix 4.2: Trend of plant heights of some treatments (2014)

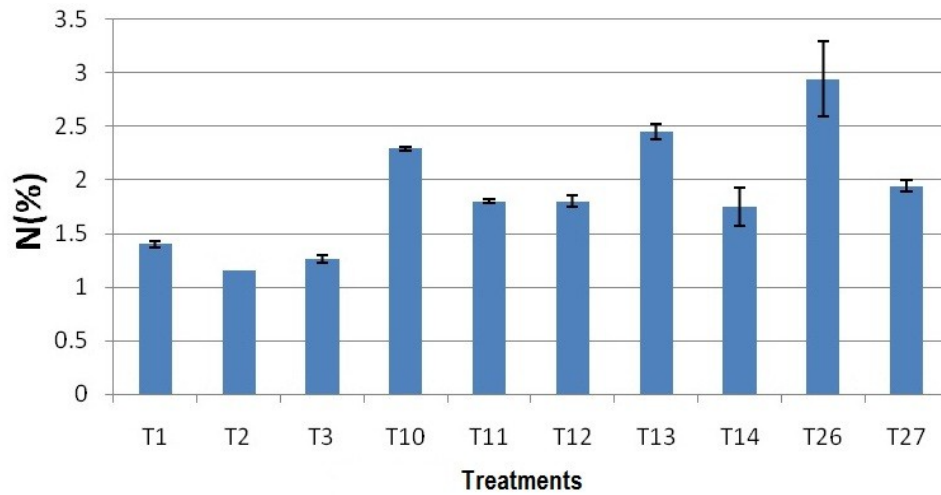


Appendix 4.3: Biomass yield (g/plant)



Appendix 4.4: Shoot Phosphorus uptake and biomass yields



Appendix 4.5: Shoot N uptake (%) (2014)**Appendix 4.6: Shoot P uptake (%) (2014)**