

**IMPACT OF *DOLICHOS LABLAB* AND *MUCUNA PRURIENS* COVER CROPS
ON SOIL FERTILITY CHARACTERISTICS AND MAIZE YIELD IN KARATU,
ARUSHA REGION, TANZANIA**

ANTIPAS PATRICK BWAKILA

27 MAR 2014

**A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN
MANAGEMENT OF NATURAL RESOURCES FOR SUSTAINABLE
AGRICULTURE OF SOKOINE UNIVERSITY OF AGRICULTURE.**

MOROGORO, TANZANIA.



2012

ABSTRACT

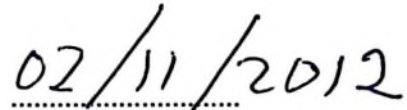
The present study was carried out in Karatu District, Arusha Region during 2006 – 2010 periods to investigate the effect of Mucuna and Lablab cover crops on soil fertility characteristics and maize crop yields. Three Divisions namely Mbulumbulu, Karatu, Rhotia and Endabash were selected for the study, each forming a replication. The experimental design consisted of five treatment combinations: Lablab cover crop alone, Mucuna cover crop alone, Maize alone, maize with Lablab and maize with Mucuna replicated three times in a RCBD. Treatments were randomly assigned to 5 treatment plots of each block and replicated in 3 blocks making a total of 15 treatment plots per study site and 45 in total. Soil samples for nutrient analysis for each plot were collected and analysed for nitrogen (N), phosphorus (P), potassium (K), organic carbon (OC), pH and moisture content at the initial stage and at the different stages of maize crop development. The findings indicated that the soils of agriculture land in Karatu District were generally sandy to sandy loam with low fertility status. Also it was found out that, the physical and chemical soil characteristics of the farm land remained stable with little change during the experimental period. Maize yield data was recorded in all treatments immediately after harvesting. Cover crops significantly increased maize yields at all times of the 5 years period probably because of their leguminous nature which add N by the N-fixing characteristics. All the cover crops significantly increased soil nitrogen and other plant nutrients having *Mucuna pruriens* producing the highest results. The study, therefore, recommends the promotion and judicious use of cover crops, especially, Mucuna in the farming systems of Karatu District.

DECLARATION

I, Antipas Patrick Bwakila, do hereby declare to the senate of Sokoine University of Agriculture, Morogoro, Tanzania, that this dissertation is my own original work, and that it has neither been submitted nor concurrently being submitted for a degree award in any other Institution.

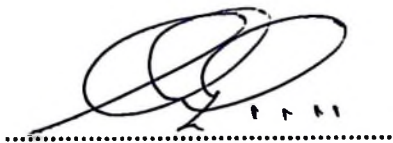


Antipas P. Bwakila
(MSc. Candidate)



Date

The above declaration confirmed



Prof. Lulandala L.L.L.
(Supervisor)



Date

COPYRIGHT

No part of this dissertation may be reproduced, stored in any retrieval system or transmitted in any form or by any means without prior written permission of the author or Sokoine University of Agriculture in that behalf.

ACKNOWLEDGEMENTS

First and foremost I would like to express my sincere thanks to the Almighty God for the strength and good health and that of my family, which enabled me to concentrate on this study.

I am grateful to the Agriculture Research Institute of the Ministry of Agriculture and Food Security, Tanzania, for giving me the opportunity to undertake this study.

I wish to express my sincere gratitudes to Professor L.L.L Lulandala, my supervisor, whose clear guidance and encouragement from the time of developing the research proposal to the thesis writing up were instrumental in the successful accomplishment of this study.

I am grateful to the Northern Zone Director of the Agriculture Research Institute, Selian, Arusha, Dr. L.M. Mugendi for his effort of giving me encouragement during my research work.

My sincere appreciations go to the staff of the Selian Agriculture Research Institute, Arusha, section of soil laboratory service who were ready to assist me whenever I requested them. Their constant encouragement during the soil processing and analysis made the work environment conducive in times of difficulties.

I would like to extend my hearty appreciation to Mr. Wilfredy Mariki and Mrs. Marietha Owenya from SARI for providing me transport that was taken me to research sites in Karatu, guidance and advise since the development of the proposal up to the completion of this study.

I indeed, remain indebted to my beloved mother Yuliana Emily Mlazono, my son Alquam and Kleist Bwakila, my daughter Basila Bwakila for the patience, inspiration and heartfelt encouragement during my whole period of the study.

Many thanks are due to all other parties which helped me in one way or another during this study. As it is difficult to mention all of them individually, I sincerely appreciated their individual and collective contributions.

DEDICATION

This dissertation is dedicated to the Holy Spirit of the living God, who single handedly instructed, supervised, guided and provided me with strength to accomplish this work (Zachariah 4:6). My mother Yuliana Emily Mlazongo who was ever present, provided me with the inspiration and love which laid the foundation of my success.

TABLE OF CONTENTS

ABSTRACT	ii
DECLARATION	iii
COPYRIGHT	iv
ACKNOWLEDGEMENTS.....	v
DEDICATION	vii
TABLE OF CONTENTS	viii
LIST OF TABLES.....	xii
LIST OF FIGURES.....	xiii
LIST OF ABBREVIATIONS AND SYMBOLS.....	xiv
CHAPTER ONE.....	1
1.0 INTRODUCTION.....	1
1.1 Background information.....	1
1.2 Problem statement and justification of the study.....	4
1.3 Objectives of the study	5
1.3.1 General objective.....	5
1.3.2 Specific objectives.....	5
The specific objectives were:	5
CHAPTER TWO.....	6
2.0 LITERATURE REVIEW	6
2.1 Cover crops.....	6
2.1.1 Lablab (Dolichos lablab)	6

TABLE OF CONTENTS

ABSTRACT	ii
DECLARATION	iii
COPYRIGHT	iv
ACKNOWLEDGEMENTS	v
DEDICATION	vii
TABLE OF CONTENTS	viii
LIST OF TABLES	xii
LIST OF FIGURES	xiii
LIST OF ABBREVIATIONS AND SYMBOLS	xiv
CHAPTER ONE	1
1.0 INTRODUCTION	1
1.1 Background information.....	1
1.2 Problem statement and justification of the study	4
1.3 Objectives of the study	5
1.3.1 General objective.....	5
1.3.2 Specific objectives.....	5
The specific objectives were:	5
CHAPTER TWO	6
2.0 LITERATURE REVIEW	6
2.1 Cover crops.....	6
2.1.1 Lablab (Dolichos lablab)	6

2.1.2	Mucuna (<i>Mucuna pruriens</i>).....	6
2.3	Cropping calendar	7
2.4	Characterization of the agricultural land soils.....	7
2.4.1	Characteristics of the agricultural land soils.....	7
2.4.2	Characteristics of the soils at the various stages of maize plants development.....	8
2.4.3	Nutrients –Nitrogen and Phosphorus.....	9
2.4.3.1	Soil nitrogen	9
2.4.3.2	Soil Phosphorus.....	9
2.4.3.3	Soil Organic Carbon	10
2.4.3.4	Soil pH	11
2.4.3.5	The trend in the overall soil characteristics of the agricultural land	11
2.5	Improvement of crop yields (maize)	12
2.5.1	Effect of cover crops on maize yields	12
2.5.2	Maize yields trend under different cover crops	15
2.5.3	The cumulative effects of cover crops on maize yields.....	17
CHAPTER THREE.....		19
3.0	MATERIALS AND METHODS	19
3.1	Materials	19
3.1.1	Location of Study Area.....	19
3.1.2	Description of Study Area	21
3.1.2.1	Climate.....	21
3.1.2.2	Population	21

3.1.2.3	Vegetation	21
3.2	Methods	22
3.2.1	Experimental design	22
3.2.2	Data collection.....	23
3.2.2.1	Soil samples for soil fertility monitoring	23
3.2.2.2	Soil sampling for soil moisture content assessment	23
3.2.2.3	Measurement of maize yield	24
3.2.2.4	Soil characterization	24
3.2.2.5	Characterization of cover crops.....	24
3.2.2.6	Soil nitrogen	25
3.2.3	Data analysis	25
3.2.3.1	Laboratory soil analysis for soil fertility characterization	25
3.2.3.2	Statistical data analysis	26
CHAPTER FOUR	27
4.0	RESULTS	27
4.1	Characterization of the agricultural land soils of Karatu District, Arusha, Tanzania.....	27
4.1.1	Soil characteristics of the agricultural land of Karatu District, Arusha.	27
4.1.2	Soils characteristics from Mbulumbulu, Rhotia and Endabash, at the various stages of maize plants development.....	27
4.1.3	The trend in the overall soil characteristics of the agricultural land of Karatu District.....	29
4.2	The effect of cover crops on the yields of intercropped maize in the district. .	30
4.2.1	The effect of cover crops on maize yields	30

4.2.2	The maize yields trend under different cover crops over the 5 years (2006 - 2010) of the study.....	30
4.2.3	The cumulative effects of cover crops on maize yields.....	31
CHAPTER FIVE.....		32
5.0	DISCUSSION.....	32
5.1	Soil fertility characteristics of the agricultural land of Karatu District.....	32
5.2	The effect of cover crops on the yield of intercropped maize	34
CHAPTER SIX.....		38
6.0	CONCLUSIONS AND RECOMMENDATIONS.....	38
6.1	Conclusions.....	38
6.2	Recommendations.....	38
REFERENCES.....		40

LIST OF TABLES

Table 1:	Soil characteristics of the three study sites at 0 – 20 cm soil depth.....	27
Table 2:	Nutrient contents of the used cover crops	28
Table 3:	Soil characteristics from Mbulumbulu village at 0 – 20 cm soil depth	28
Table 4:	Soil characteristics at Rhotia village at 0 – 20 cm soil depth	28
Table 5:	Soil characteristics of Endabash village at 0 – 20 cm soil depth.....	29
Table 6:	The mean soil chemical characteristics of the three study sites at the various plants' development stages.....	29
Table 7:	The mean overall trend of soil characteristics of the agricultural land in Karatu District over the past 5 years.....	30
Table 8:	The current maize grain yields (t/ha) under the different cover crops at the three study sites of Karatu District	30
Table 9:	The effect of cover crops on maize yields for different treatments for 2006 – 2010	31
Table 10:	Accumulative effect of cover crops on maize yields between years.....	31

LIST OF FIGURES

Figure 1:	Map of the study area.....	20
Figure 2:	The layout of the experiment at each replication site.....	22

LIST OF ABBREVIATIONS AND SYMBOLS

$^{\circ}\text{C}$	Degree Centigrade
ADP	Adenosine Diphosphate
AF	Agroforestry
Al	Aluminium
ANOVA	Analysis of variance
AP	Available Phosphorus
ATP	Adenosine Triphosphate
C	Carbon
C/N	Carbon/nitrogen
CA	Conservation Agriculture
CC	Cover crops
Cm	Centimetre
CO ₂	Carbon dioxide
DM	Dry matter
DMRT	Duncan's multiple range test
DOPA	Dihydroxyphenylalanine
ET	Evaporation and transpiration
GDP	Gross domestic product
GML	Green manure legume
Ha	Hectare
IK	Indigenous knowledge
K	Potassium
Kg ha ⁻¹	Kilogramme per hectare

Kg K ha⁻¹	Kilogramme of potassium per hectare
Kg N ha⁻¹	Kilogramme of nitrogen per hectare
Kg	Kilogram
M	Meter
Mg DM ha⁻¹	Milligramme dry matter per hectare
Mha	million hectares
mm	Millimeter
MPa	Mega Pasclas
N	Nitrogen
N₂	Dinitrogen
N₂O	Nitrous oxide
NH₄⁺	Ammonium ion
NO	Nitrogen monoxide
NO₂⁻	Nitrate ion
NO₃⁻	Nitrate ion
OC	Organic Carbon
P	Phosphorous
pH	Negative logarithm of hydrogen ion concentration
RCBD	Randomized Complete Block Design
SARI	Selian Agriculture Research Institute
SOM	Soil organic matter
SSA	Sub-Saharan Africa
WCC	Winter Cover Cropping

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Cover crops (CC) can maintain or increase crop yields by reducing soil erosion, increasing soil organic matter, improving soil physical properties, reducing water runoff, reducing the need for chemical inputs and maintaining or improving water quality (Holderbaum *et al.*, 1990; Meissinger *et al.*, 1991). Soil erosion is the physical removal of top soil by agents of erosion mainly water and wind (Morgan, 1986; Lal, 1997). According to the United Nations Environmental Program (1980), cited by Ahn (1981) crop productivity from about 20 million hectares each year becomes uneconomic because of soil erosion and other soil-induced degradation. In Tanzania, soil erosion and overall land degradation has been identified to have been serious problem since the 1920's (Kauzeni *et al.*, 1987). The use of cover crops, mulch and crop residues can reduce soil erosion and water loss through evaporation while increasing moisture availability to crops and hence improved crop yield (Li *et al.*, 2008; Thukkaiyannan *et al.*, 2005). The process of land degradation varies and is not easily detected or measured. However, both central and local governments recognized land degradation as a major issue for the country (Kauzeni *et al.*, 1987). As a result, various soil conservation programmes were established in different parts of the country on the trial basis to combat the problem. Demonstration plots, conservation orders and directives (e.g. destocking of livestock, planned fires) were first introduced by the colonial governments. Initially, these measures were concentrated in mountainous areas where land degradation was most apparent (FAO, 1986). These areas included Uluguru, Usambara, Pare and Meru mountains. The local authorities in these areas were charged with administering the orders. Meanwhile experiments were carried out in agricultural

research stations to quantify soil and water losses. These experiments were expected to provide insights to conservation activities (FAO, 1986).

In spite of all these land conservation programmes, land degradation is still a big problem in Tanzania. Possible reasons for this persistence include the top down approach adopted, and concentrating more on mechanical measures in preventing soil erosion and water runoff and sometimes ignoring the contribution of indigenous knowledge (IK) in addressing the problem (Kikula *et al.*, 1990). The problem of soil erosion in Tanzania has been reported by a number of researchers (Rapp *et al.*, 1992; Ngatunga, 1981; and Yanda, 1995). Blackwell *et al.* (1991), estimated that about 50% of the land in Tanzania is subject to erosion. Karatu District for example, is experiencing serious soil erosion by water (Allan, 1989; JICA, 1995 and Maggogo *et al.*, 1996). However, the form and causal factors of the problem vary with the soil physical conditions, rainfall pattern, and land use practices. Factors contributing to severe soil erosion by water in Karatu District have been identified to be the presence of steep slopes with shallow soil depth, high rainfall intensities, deforestation, extensive slash and burn cultivation practices and uncontrolled fires (Schmied, 1989).

Tanzania is among the countries experiencing low crop production, while agriculture continues to be the backbone of its economy. More than 80% of the economically active population is engaged in food production and agriculture constitutes the country's principal source of income, providing about 50% of its Gross Domestic Product (GDP) and more than 90% of its export earnings (Allan, 1989; Schmied, 1989; Maggogo *et al.*, 1996). Smallholder farmers in Tanzania are confronted by a set of difficult conditions that threaten their ability to feed themselves and their families. Over the past two decades,

Tanzania experienced a series of periodic droughts that required food relief from international agencies. Structural reforms imposed a condition for development aid such as removal of subsidies on farm inputs, reduced farmers access to materials required to improve agriculture production. Therefore, continuous cropping with little external inputs has been the most affordable alternative farming practice for the majority of smallholder farmers in Tanzania, a practice that has led to fertility depletion in many areas (Smaling *et al.*, 1997).

Crop production in Tanzania is affected by a number of factors but declining soil fertility and inadequate moisture are among the major ones. One of the factors causing soil degradation is the removal, burning or grazing of crop residues, leaving the soil exposed to climatic hazards such as rainfall, sun and wind. This practice has led to the loss of organic matter and caused serious soil compaction and pulverization of the top soil during the last decades (Benites *et al.*, 1998). Over the years, crop yields have declined significantly due to land degradation combined with the reduced ability of rainwater infiltration and storage. As a consequence dry spells and droughts have a much more marked impact on crop development and yields (Rockstrom *et al.*, 2001).

The problem of soil erosion caused by deforestation in Karatu district is compounded by rapid population growth (Schmied, 1989). Due to this rapid increase in population more land has been brought under cultivation and tree cutting for charcoal and fuel wood to meet daily energy requirements have increased considerably (JICA, 1995). Soil productivity in Karatu district is also constrained by aridity (low rainfall) with population continuing to increase in all parts of Karatu District, the need to reverse these declining crop production trends has become more urgent (KILIMO/FAO, 1997).

1.2 Problem statement and justification of the study

Production of maize in Karatu District is constantly low, but high population increase seems to create a challenge to meet food demands for the increasing population (Dragne, 1990). Low fertility soils in many parts of Karatu District cause decline in food production. Soil productivity in the District is constrained by low rainfall and land degradation (Lohay, 1998). Although limited total production increase had taken place, this had been obtained by cultivation of more poor and marginal lands while the productivity of most of the available land has been declining (Chikoye, 1999). Since 2002, therefore, the Selian Agriculture Research Institute (SARI) initiated a research project to investigate the use of cover crops to arrest land degradation by improving overall soil conditions and its productivity. This is an on-going project that involves the on-station soil fertility experimentation and social research components. The project had already completed the three year social research part (2002 – 2005) and results published in 2006, while the experimental research part that started in 2005 is on-going and is expected to end in this year (2012). The present study, therefore, intended to determine the impact of the eight year experimental work on determining the influence of the legume cover crops on soil fertility characteristics (i.e. physical, chemical and moisture), biomass of cover crops and resulting of maize yields. The information gathered will help the extension agents, policy makers and farmers to make informed decisions on using cover crops as means of arresting land degradation and improve crop yields in the district and other areas with similar conditions.

1.3 Objectives of the study

1.3.1 General objective

The overall objective of the study was to make an analysis on the five year data (2006 – 2010) on the effect of *Dolichos lablab* and *Mucuna pruriens* cover crops to conserve and improve soil fertility characteristics and maize crop yields in Karatu District, Arusha, Tanzania.

1.3.2 Specific objectives

The specific objectives were:

- (i) To determine soil moisture conserving ability and the soil fertility characteristics of the agricultural land soils of Karatu District
- (ii) To determine the effect of *Dolichos lablab* and *Mucuna pruriens* cover crops on improving yields of intercropped maize in Karatu District.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cover crops

2.1.1 Lablab (*Dolichos lablab*)

Lablab also known as dolichos, is the herbaceous legume adapted to altitudes ranging from 0 – 1900 m above sea level. It has fast growth rate, producing a lot of biomass containing 41 kg N (Palm *et al.*, 1997). However, high rainfall after planting considerably retards its growth rate. The plant has medium to deep rooting system that enables it to survive dry spells. However, the potentials of lablab are limited by high susceptibility to pest and diseases.

2.1.2 Mucuna (*Mucuna pruriens*)

Mucuna also known as velvet bean is a leguminous crop that grows better at altitudes ranging from 0 to 1900m a.s.l. It is reported to produce a lot of biomass and suppress weed and root knot nematodes (Palm *et al.*, 1997). Mucuna has been reported to produce root biomass ranging between 100 and 400kg ha⁻¹ in the top of 0-20 cm soil at the age of 4 months in Benin (Karsky and Eteka, 2000). Analytical results of mucuna leaves from various location of East Africa have shown that the material have N content ranging between 2.50 and 2.54%, phosphorous content between 0.09 and 0.24%, lignin content between 6.04 and 10.94%, and soluble polyphenol between 0.46 and 4.73%. Generally, mucuna has low lignin and polyphenol contents and narrow C/N ratio hence has high decomposition rate (Tian *et al.*, 1992). On average, mucuna has a potential of supplying 35 kg N Mg⁻¹ dry matter (Palm *et al.*, 1997).

2.3 Cropping calendar

Maize is important cereal crops growing in Karatu are planted during February to March and harvested in July to August. Maize as it is the staple food crop in the area is grown and total cereal production (Hawassi, 1997). However the crop face a number of problems including low soil fertility, poor husbandry, low land productivity, insects (especially maize stalk borers) and diseases (especially maize leaf blight pathogen) (Mattee *et al.*, 1996).

2.4 Characterization of the agricultural land soils

2.4.1 Characteristics of the agricultural land soils

Decline in soil fertility is worsened by poor crop management practices and low nutrient applications are fundamental impediment to agricultural growth of eastern Africa (Smaling *et al.*, 1997). Sanchez (2000) reported that lack of volcanic rejuvenation has caused the continent to undergo various cycles of weathering, erosion, and leaching, leaving soil poor in nutrients in Sub-Saharan Africa. Moyo (2003) reports that soil erosion and nutrient leaching lead to losses of up to 20kg ha⁻¹ of the major soil nutrients (nitrogen, phosphorus and potassium). In many parts of Ghana, for example there are numerous problems associated with the declining productivity of the soil due to frequent soil tillage and removal of crop material/residue. Further in Ghana, 69% of the total land surface is prone to severe erosion which costs 2% of the annual Gross Domestic Product (GDP).

Conventional tillage reduces percolation which leads to deprivation of water and nutrients to plants (Deborah, 2001). It pulverizes the soils and leads to structure deterioration, loss of soil water, which results in reduced yields (Eilitta *et al.*, 2004). Crops grown on shallow

conventionally ploughed fields keep their roots concentrated near the surface; consequently, these crops become water stressed during dry periods (Stevens, 2000). Conventional ploughing can be a threat to farming in semi-arid areas (Bancy and Kithinji, 2002). Conservation tillage reduces soil manipulation, saves on labour requirement and improves soil productivity by minimizing compaction and improves soil moisture storage within the plough layer thus reducing soil and water losses (Marjatta *et al.*, 2004).

2.4.2 Characteristics of the soils at the various stages of maize plants development

Mahalakshmi and Bidinger (1985) reported that drought stress at seed filling stage reduced seed yield up to 50%. The measurement of seed yield components showed that seed yield decline was mainly due to reduction of seed number per ear and seed weight. There weren't significant differences between ear numbers per plant in drought stress treatments. Kumari (1988) also reported that drought stress in millet decreased seed yield through reduction in seed number per ear and seed weight. Seed number reduction could be as a result of stress effect on pollination and floret abortion (Bradford, 1994). In this condition less endosperm cells are produced in seeds (Bradford, 1994). Mastroilli *et al.* (1995) also reported that seed filling stage is less susceptible to drought than ear emergence stage.

Sakala *et al.* (2003) asserted that, nitrogen release from a better leaf quality is rapid. Rapid release of N enhance early N uptake by crops. However, this may lead to N loss through leaching and higher crop demand during tasselling/flowering of the maize crop. Maize is usually more sensitive to soil moisture deficit between tasseling and silking stages of growth (Cakir, 2004). However, total soil N is not a good indicator of soil fertility due to the fact that very little fraction of N becomes available for crop uptake (Chamshama *et al.*, 1998).

2.4.3 Nutrients –Nitrogen and Phosphorus

2.4.3.1 Soil nitrogen

Nitrogen is a plant nutrient that is needed in larger quantities than others. In Tanzania, N taken out of the soil through crop harvests annually has been estimated to range from 20 to 40kg ha⁻¹ whereas removal of K and P ranges from 16.6 to 33.2 and 3.5 to 6.6 kg ha⁻¹, respectively (Smaling *et al.*, 1997). Nitrogen is, therefore, a major limiting nutrient particularly in cereal production (Tisdale *et al.*, 1990 and Sanchez *et al.*, 1997) and its deficiency is common all over Tanzania (Samki, 1989). This is reflected in crop yield responses to different rates of N fertilizer obtained on different soils (Mowo *et al.*, 1993).

2.4.3.2 Soil Phosphorus

In recent years, there has been increased interest in agricultural practices associated with the application of phosphorus fertilizers. Phosphorus in plants performs unique functions of energy transfer via formation of pyrophosphate bond. Phosphorus compounds, Adenosine Diphosphate (ADP) and Adenosine Triphosphate (ATP) act as energy currency within the plants and involve a wide range of plant processes from permitting cell division to developing good root system (Meena *et al.*, 2007). Phosphorus is removed from the soil by plant uptake or lost through soil erosion and runoff. Crops remove varying amounts of phosphorus from the soil (Manunta *et al.*, 2001). Also, the availability of phosphorus in soils is often limited by fixation reactions, which convert the mono phosphate ion into various insoluble forms (Di *et al.*, 1994). The importance of organic matter and accordingly organic carbon in the soil has been recognized for centuries as the key to soil fertility and productivity. Organic manures and other products of farming and related industries contribute to plant growth through their favorable effect on the physical, chemical and biological properties of soils (Reddy *et al.*, 2005 and Meena *et al.*, 2007).

Besides, previous research reports indicates that the availability of soil phosphorus is enhanced by adding organic matters, it has currently been established that such effect is due to chelating of polyvalent cations by organic acids and other decay products (Reddy *et al.*, 2005 and Mohanty *et al.*, 2006). The decomposition of soil organic matter from leguminous cover crops not only supplies nutrients, but can also increase plant available nutrients in the soil through several processes (Palm *et al.*, 1997).

To circumvent phosphorus deficiency, Phosphate Solubilizing Microorganisms (PSM) could play an important role in supplying phosphate to plants in a more sustainable way (Khan *et al.*, 2007). The significance of P release rate from soils in P availability for different crops, has been reported in several investigations (Steffens, 1994; Toor and Bahl, 1999).

2.4.3.3 Soil Organic Carbon

As previous researches report, there is a relationship between the availability of phosphorus in the soil and soil organic matter (Reddy *et al.*, 2005; Mohanty *et al.*, 2006), soil organic carbon (OC) can be used to estimate soil Available Phosphorus (AP). Despite the considerable amount of research done which shows the relationship between soil AP and soil OC, very limited work has been conducted to develop a soil AP pedotransfer function based on soil OC. Soil organic matter enhances the formation of aggregates, which stabilizes soil and reduce runoff and erosion (Sainju *et al.*, 1997). Increased aggregation and porosity can promote root growth by decreasing soil bulk density (weight per unit volume) and reducing resistance to root penetration. Soil organic matter improves soil tilt, reduces crusting, and increases the rate of water infiltration (Roberson *et al.*, 1998).

2.4.3.4 Soil pH

Generally, most compost has a pH in the neutral range, organic matter content ranges from 30% to 60%, moisture content ranges from 30% to 50%, and the concentrations of N, P, K, and salts are higher than those typically found in agricultural soils (He *et al.*, 1992). Generally, compost amendment of soils decreases bulk density while increasing porosity, water holding capacity, soil aggregation, microbial levels, organic carbon levels, salts, nutrients, metals, and pH. According to the literature review, compost addition appears to have a varied effect on soil pH. A study by Hernando *et al.* (1989) found that pH increased with the addition of compost but that the increase in pH was likely due to the high calcium content of the compost. Cuevas (2000) however, found no significant change in pH with addition of composted municipal solid waste. In contrast, Zinati *et al.* (2001) found a decrease in the soil pH with the addition of compost prepared from 100% yard trimmings and food wastes and compost prepared from 100% bio solids. Soil erosion depletes soil productivity resulting in adverse physical, chemical and biological soil properties and therefore, affecting crop yields (Bancy and Kithinji, 2002).

2.4.3.5 The trend in the overall soil characteristics of the agricultural land

In general, water transport below the rooting zone requires that the soil water content exceeds field capacity and the water balance is positive, which means that water inputs with rainfall exceed evapotranspiration. Therefore, nutrient losses through leaching are generally higher in humid than in dry climates (Nelsen and Stevenson, 1993). Macropore flow may also protect nutrients present in smaller soil pores from being leached by rapid channelling away surplus water (Van Noordwijk *et al.*, 1991)

Wu *et al.* (1997) reported that Nutrient depletion occurs primarily through crop removal in harvested products and residues, by leaching and soil erosion. The quantities of nitrogen, phosphorus and potassium removed by crops can be estimated with reasonable reliability. However nutrients lost through leaching and soil erosion are more difficult to assess. Losses by leaching are important for nitrogen and potassium, whereas soil erosion is an important pathway of loss for all nutrients, but particularly for phosphorus. Overall, the total amount of N leached throughout the long term trial is supported by findings of other research trials, reporting similar N leaching rate of 100 kg N ha⁻¹ (Fox *et al.*, 2001). Low depletion rates are characteristics of semi-arid environments where the soils were usually already poor in nutrients.

Nutrient depletion in the soil is a good indicator of declining soil fertility, the rate of nutrient depletion varies with soil properties. The proportion of nutrient loss is normally greater in sand soil, while the total nutrient loss is greater in clay soils (Sanchez *et al.*, 1997). This is largely because Soil Organic Matter (SOM) particles are less protected from microbial decomposition in sand soils than in loamy or clay ones (Sanchez, 1995 and Swift *et al.*, 1994).

2.5 Improvement of crop yields (maize)

2.5.1 Effect of cover crops on maize yields

On severely depleted soils, previously reported to have poor maize yield, significant increases of yield have been reported. In an experiment in Rachuonyo, Kenya, *Dolichos Lablab* as cover crop together with conservation tillage gave maize grain yields of 2.6 t ha⁻¹ against 1.8 t/ha of control (Nzabi, 2000). In Arusha and Arumeru, Tanzania, conservation tillage together with *Dolichos lablab* gave overall maize yield of 2.8 t ha⁻¹,

while conventional tillage gave 2.7 t ha⁻¹ respectively (Mwalley and Mawenya, 2002). In Laikipia, Kenya, conventional tillage gave maize grain yields of 4.2 t ha⁻¹ and conservation tillage gave 5.1 t ha⁻¹ (Kambutho and Muthua, 2002). In Ethiopia conservation tillage with cover crop gave maize grain yields of 1.9 t/ha while conventional tillage without cover crop had 1.0 t ha⁻¹ (RELMA, 2002). Odhiambo (2011) found that, in South Africa, overall, legume treatments, with or without N fertilizers produced between 19 to 58% more grain yield than control (-N). Odhiambo and Netshivdza (2008) found that potential to increase maize yield in smallholder farms in Limpopo province, green manure legumes screened, mucuna, lablab and sunhemp seemed to be the most suitable green manure legume cover crops for this area and should be planted in the early summer season to maximize biomass production and N accumulation.

A study by Rao and Mutuva (2000) in semi-arid Kenya revealed an increase of 30-49% of maize yield for annual grain legume based cropping system than continuous sole maize, making the system attractive to farmers in semi-arid tropics. Studies conducted in the mid altitude areas of Uganda have shown that *Crotalaria ochroleuca* and *Mucuna pruriens* green manures can increase maize yield by 36% and 42% respectively (Fischler *et al.*, 1999). In Kenya, averaged over two years, *C.ochroleuca* and *Mucuna pruriens* green manures improved maize grain yield by 1.5 t ha⁻¹ compared to no incorporation 0.9 t ha⁻¹ (Ojiem *et al.*, 2000), while in southern Cameroon, Hauser and Nolte (2002), obtained maize yields greater than 4 t ha⁻¹ after a short-term fallow with mucuna. In Tanzania, farmers have used *Dolichos lablab* to increase their maize yield from 12.4 to 45 bags ha⁻¹ (1116 to 4050 kg ha⁻¹) (Lupatu and Kilimwiko, 1991).

In South Africa green manure legumes gave grain yield increases of between 77 -134% and 55 - 70% above the control, in 2007/8 and 2008/9 seasons, respectively. These yield increases were fairly high compared with yield obtained in studies elsewhere (Fischler *et al.*, 1999; Ojiem *et al.*, 2000). In Benin, the adoption of the legumes is not extensive but the data indicates that lablab (*Dolichos Lablab*) is preferred to increase maize yields than *Mucuna pruriens* (Versteeg *et al.*, 1998). In a rotational cropping system in the sub-humid highlands of East Africa, Fischler (1996) showed that preceding mucuna or lablab increased the maize grain yield by 50 or 40%, respectively.

Working in a derived savanna of West Africa, Carsky *et al.* (1999), evaluated improved fallows using mucuna and lablab in which the residue was left on the surface at one site and most residue was burned early in the season at the second site. The mean N fertilizer replacement value from legume rotation was 14 kg N ha⁻¹ in the site where all the residue was left on the ground compared to 6 kg N ha⁻¹ where most of the residue was burned early in the dry season with no N applied to the maize test crop. Maize grain yields were 365 (residue on surface) and 235 (residue burned) kg ha⁻¹ higher than natural fallow, respectively.

A complementary study in South Africa (Nyambati, 2002) found that defoliation reduces the quality of the *Mucuna* residue and may enhance the efficiency of N uptake by succeeding maize. Also, at the time of residue defoliation and incorporation, relay-cropped Lablab produced a higher seed yield than a second crop of common beans. Grain yield of maize, following a one season fallow with mucuna, was reported to be 60 % higher, as compared with sole maize (Fischler and Wortmann, 1999).

Giller *et al.* (1997) reported increased maize yield and growth in the legume based system in the presence of adequate water in the soil which resulted in higher N availability to maize from the organic residue and residual effects of biological nitrogen fixed by the legume (legume effects). The magnitude of maize growth and yield in Conservation Agriculture (CA) treatments were better compared to those of conventional plots. Similar observations were made by Ikerra *et al.* (2001) in Malawi, where short duration follows intercropped with legumes, increased maize yield compared to unfertilized sole maize plots. Differences in root and litter biomass production were also reported by Nyakanda *et al.* (1998) and accounted for maize production increase in plots with higher roots and litter biomass. It is well documented, leguminous cover crops release nutrients too quickly, similar to the use of inorganic fertilizers (Sakala *et al.*, 2003).

2.5.2 Maize yields trend under different cover crops

Studies have shown that, in order to maintain maize productivity in the smallholder systems, the integration of the small amounts of nitrogenous (N) fertilizers applied by the farmers along with N from Green Manure Legume (GML) cover crops may offer a strategy to meet the N needs of the smallholder farmers. Short duration conservation agriculture (CA) with cover crops and grain legumes has been shown to considerably increase succeeding maize yields (Balasubramanian and Nguimgo, 1993; Carsky *et al.*, 2001). Maize grain yields of greater than 4 Mg ha⁻¹ were obtained in southern Cameroon after a short term CA with *Mucuna pruriens* (Hauser and Nolte, 2002). Green manuring may also help maintain or build organic matter which will in turn help improve the soil's structure, pore size, water holding capacity and inorganic fertilizer use efficiency (through increased cation exchange capacity).

In terms of maize grain yield following green manure incorporation, overall, legume treatments, with or without N fertilizers produced between 19 to 58% more grain yield than control (-N). Studies conducted in the mid altitude areas of Uganda have shown that *Crotalaria ochroleuca* green manure can increase maize yield by 39% (Fischler *et al.*, 1999). The N concentrations of mucuna and lablab fractions in the conservation agriculture study were generally lower than those reported by Ibewiro *et al.* (2000). This could be due to differences in environmental conditions prevailing during plant growth and the stage at which the residue was sampled which can result in biomass of differing quality (Handayanto *et al.*, 1995). The modest trend toward greater maize yield following incorporation of lablab residue compared to mucuna concurs with the results of Wortmann *et al.* (2000) and is in agreement with observed trend toward enhanced N uptake following lablab residue, which was of lower quality (lower N and higher lignin concentration) than mucuna. The results of this study are in contrast with those by Van Noordwijk and Purnomisidi (1992), who reported that mucuna had a greater litter biomass than lablab ($P < 0.001$). Root mass was not affected by treatments, but lablab root comprised a higher percentage of total biomass (10%) than mucuna (5%), in agreement with Tian and Kang (1998). The greater amounts of mucuna biomass suggest that it was more adapted to growth under shading by maize and to the dry conditions following maize harvest than lablab. Legume biomass under the intercrop were in the lower end of the range reported by Wortmann *et al.* (2000) from the highlands of East Africa when mucuna and lablab were grown in rotation with maize. Tian *et al.* (2000) found that after 1 year of residue application, there were no differences between mucuna and lablab in maize grain yield, when the legume residue was applied for two consecutive years, resulted in higher maize grain yield than the natural fallow control.

2.5.3 The cumulative effects of cover crops on maize yields

In Turkey, leguminous cover crop were reported to improve soil water quality compared with bare fallow by reducing erosion during fall, spring, and increasing maize yields (Sainju and Sing, 2002). In considering tillage treatments, soil N did not always affect maize yield and amount of maize N-uptake, however, when comparing year over treatments, soil N was increased after each treatment performed from year to year (Sarrantonio and Scott, 2001). Similar results were observed by Wani *et al.* (1999), who observed that legumes can increase the content of soil N and improve maize yields in the long run in comparison with the short run. In Southwestern Ontario, Canada, Miguez and Bollero (2005) conducted a review of corn yield response to cover crops and did not consistently find a decrease in corn yields in the Midwestern Corn Belt and that many studies reported no effect on yield. Furthermore, they found that the response or lack of response was not dependent on N fertilizer rate. In North America contrast, Vyn *et al.* (2000) found no corn yield reduction following a rye cover crop when 150 kg N ha⁻¹ was applied and substantial corn yield reductions when no fertilizer was applied. Mixed responses were observed by Kessavalou and Walters (1997) in Nebraska, who measured lower corn yields in one of the three years.

In Northern Ghana the yield of maize grain was not significantly increased by intercropping with cover crops whose growth in the maize was not as good as expected (Cheruiyot *et al.*, 2007), but Western Kenya, maize yield increase of up to 62% was reported by intercropping with *Dolichos lablab* (Jama *et al.*, 2006). Under water – limited and warm environments, application of cover crop usually increases crop yield due to reduce temperature and increase soil moisture retention (Maurya and Lal, 1998). The

increase in yields is supported by studies conducted by Ramakrishna *et al.* (2006) where a higher maize yield was observed in cover crop than control plots.

Although the use of green manures in Malawi was first initiated more than 70 years ago (Sakala, 2000), intensive research on green manures gained momentum in the 1990s. Large increases in growth and yield of crops sown after incorporation of green manures have been reported, for example, maize yields have more than doubled by incorporation of a 3-month-old green manure of *Mucuna pruriens* var. *utilis* or *Crotalaria juncea* grown in alluvial soil on the island of Java, Indonesia (Hairiah and van Noordwijk, 1989). Maize yields increased with the application of green manures and inorganic fertilizers separately or in combination. However, the combination of 35 kg N ha⁻¹ and any of the three green manures produced the highest efficiency in the first year of green manure application as well as in the second year, when residual effects of the green manures were being tested (Sakala *et al.*, 2000). This study has demonstrated that herbaceous legumes can substantially increase maize production. Festus *et al.* (2009) provided evidence of the potential contribution of cover crops legumes to maize productivity that can now be harnessed for sustainable smallholder agriculture in Africa

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Location of Study Area

Karatu District is one of the five districts of Arusha region. It was formed out of the old Mbulu District Council in 1995. Karatu District has four divisions, which are Karatu, Mbulumbu, Endabesh and Eyasi (DALDO, 2005).

The district is located South of the equator between latitudes 3°10' and 4°00'South and longitudes 34°47' and 35°56'East. Altitude is 1400 m above sea level. Karatu District shares borders with Mbulu to the South and Iramba and Meatu to the North West, Ngorongoro to the North and Monduli and Babati District to the South East (Figure 1). The district is estimated to have approximately 3,300 square kilometers, with Lake Eyasi occupying 1,600 square kilometers (DALDO, 2005). The distance from Arusha to Karatu is 184 km and from Dar es Salaam to Karatu is 786 km, can be reached through road, from Dar es Salaam to Karatu is tarmac road .

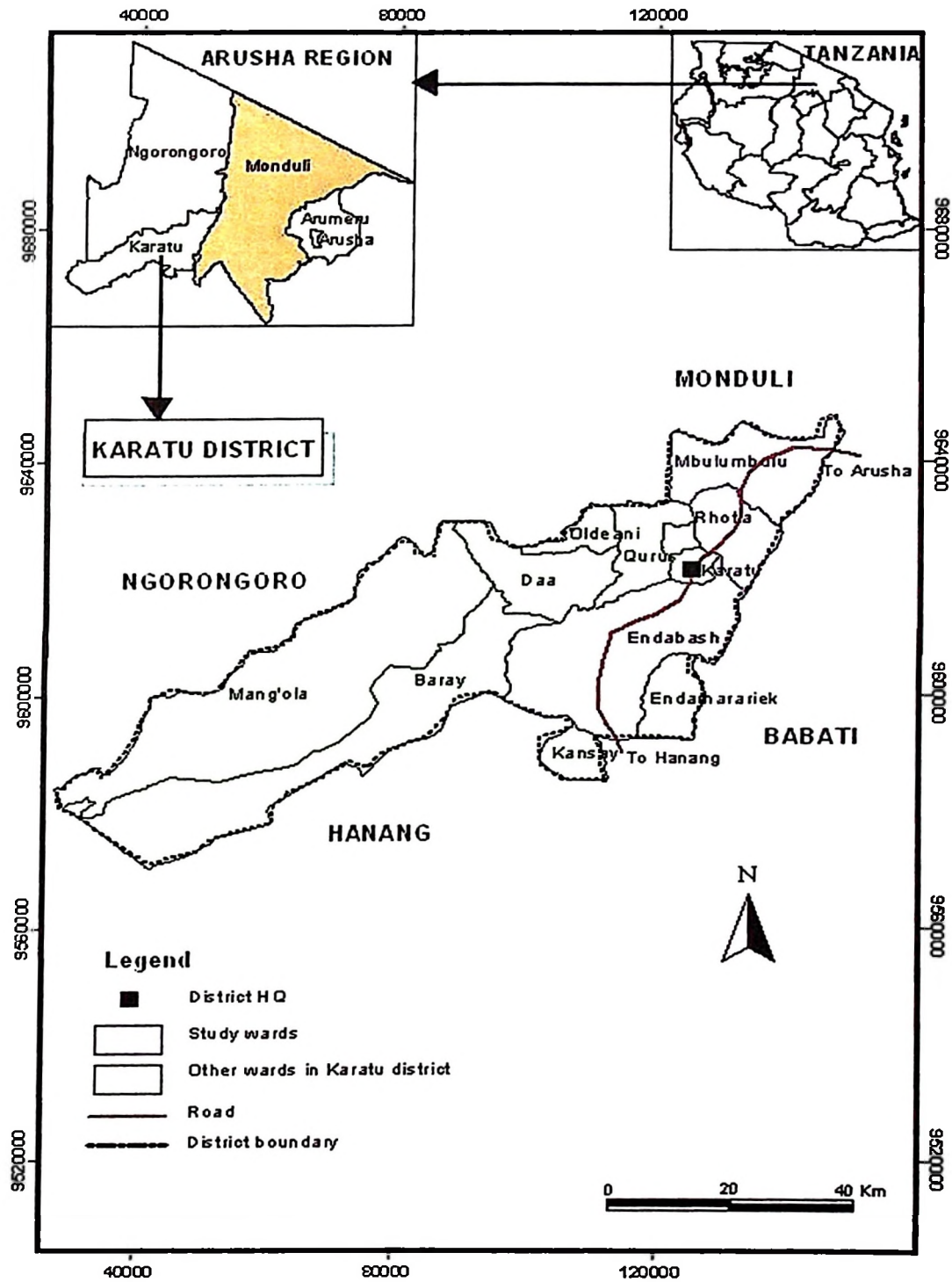


Figure 1: Map of the study area

3.1.2 Description of Study Area

3.1.2.1 Climate

The climate varies from one area to another in the district. In Eyasi basin, for example, the annual rainfall is between 300-400mm while in Karatu town it ranges from 900mm to 1000mm. The district experiences four seasons, which are, short rainy season extending from November to December; hot and dry season from January to March; the long rainy season is between March to mid May and the long and cold season is from June to October. The wettest month is April when the rain intensity can be very high, which may result into more erosion when soil is bare (DALDO, 2005).

3.1.2.2 Population

According to the 2002 census, Karatu District had a population of 178,434 with 92,895 male and 85,539 females (URT, 2002). The estimated current population is 201,634, with a growth rate of 1.3% per year. The majority of the people living in the district belong to the Iraqw tribe, while other smaller tribes are Barbaig and Hadzabe whose occupation is pastoralism, hunting and fruits gathering, respectively.

3.1.2.3 Vegetation

The Northern part of Karatu has a well developed mountain forest of Ngorongoro conservation area, while the southern side is mainly agricultural land. In general more than half of the district is cultivated and the rest is forest, bush and short vegetation grasses (Laizer, 2000). Pastures available in the district are elephant grass, couch grass, star grass, and type of forest available is low land forest in Mbulumbulu Division and mountain forest in Karatu, Endabesh and Eyasi Divisions

3.2 Methods

3.2.1 Experimental design

The research programme consists of five treatment combinations indicated below.

- T 1 Lablab cover crop
- T2 Mucuna cover crop
- T3 Maize without cover crop (control)
- T4 Lablab (*Dolichos lablab*) + maize
- T5 Mucuna (*Mucuna pruriensis*) + maize

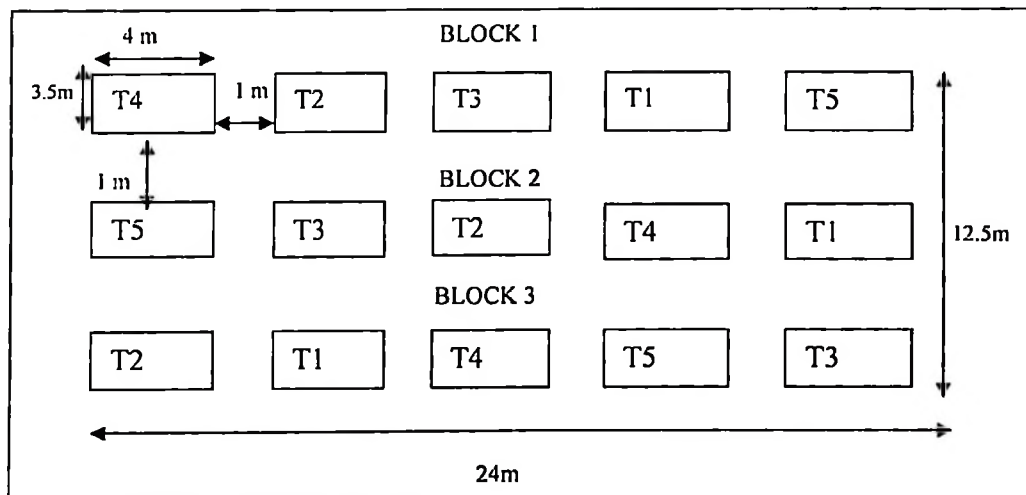


Figure 2: The layout of the experiment at each replication site

At each establishment occasion the treatments were randomly assigned to 5 treatment plots of each block and replicated in 3 homogenous agro-ecological units (blocks 1, 2 and 3) to make a total of 15 treatment plots. The maize seeds were sown in rows at spacing of 0.80 m between the rows and 0.60 m within the rows. Triple super phosphate at the rate of 30 kg P ha⁻¹ was being applied during planting. A total of five rows are planted per plot and six holes per row. Three seeds were planted per plant hill, and three weeks after

germination, the plants were thinned to two per stand making a total of 41,666 plants per hectare. Top dressing was carried out five weeks after planting using Urea fertilizer at the rate of 80 kgN ha⁻¹ (Igbadum *et al.*, 2005). Seeds of the cover crops were sown in a single line between the maize rows, at a spacing of 40 cm and seeding rate of two seeds per hole.

3.2.2 Data collection

3.2.2.1 Soil samples for soil fertility monitoring

Soil samples for nutrient analysis were collected during planting, flowering and maturity stages of maize crop development in all the five seasons. The samples were analysed at the Selian Agriculture Research Soil Laboratory for nitrogen (N), phosphorus (P), potassium (K), organic content (OC), pH and moisture content. Soils were collected at the depth of 0-15 cm and 16-30 cm from four randomly selected points of each treatment plot, bulked, mixed thoroughly and then sub-sampled and packed in polythene bags kept in cool boxes at two to four degree centigrade (while in the field and during transportation in order to reduce evaporation and microbial activities) for laboratory analysis (Anderson and Ingram, 1993).

3.2.2.2 Soil sampling for soil moisture content assessment

Soil samples for moisture analysis were taken three times during the cropping season, at the seeding, flowering and maturity of the maize crop. A core soil-sampling auger was used for sampling the soil (0 - 20 cm depth). The soils lots were mixed, sub – sampled, packed in moisture boxes, sealed with masking tape and taken to the laboratory for weighing and oven drying. Soil sampling was intended to capture soil moisture content after rain and during dry spells. Dried in an oven temperature 40-200°C with the lid

unfitted. The next day, remove from oven, fit the lid, cool in desiccators for at least 30 minutes and re-weigh.

3.2.2.3 Measurement of maize yield

Maize yield data was recorded in all treatments immediately after harvesting. The sample was taken from 3 middle rows at a length of [3m x 2.4m =7.2 m² area]. The yield data per sample area was computed to tonnes per hectare.

3.2.2.4 Soil characterization

Soil characterization involves analysis of physical and chemical characteristics of composite samples collected from the top 0 – 20 cm and genetic horizons of the soil profile. Soil physical characteristics analyzed included soil particle distribution, soil bulk density and soil moisture characteristics. The chemical characteristics included N, P, K, OC and pH. These were obtained from laboratory analysis, following internationally accepted procedures and were used to classify the soil. The soil was classified according to World reference Base for Resources (FAO, 1998) and Soil Taxonomy (Soil Survey Staff, 1998) classification systems.

3.2.2.5 Characterization of cover crops

Characteristics of cover crops that may influence soil moisture and nitrogen availability were evaluated. Chemical composition of the cover crop residues obtained in the first season of the field study was determined by chemical analysis. Mineralization behaviour was studied in the laboratory under an incubation study.

3.2.2.6 Soil nitrogen

Nitrogen is a plant nutrient that is needed in larger quantities than others. In Tanzania, N take out of the soil through crop harvest annually has been estimated to range from 20 to 40kg ha⁻¹ whereas removal of K and P ranges from 16.6 to 33.2 and 3.5 to 6.6 kg ha⁻¹, respectively (Smaling *et al.*, 1997). Nitrogen is therefore, a major limiting nutrient particularly in cereal production (Tisdale *et al.*, 1990; Sanchez *et al.*, 1997) and its deficiency is common all over Tanzania (Samki, 1989). This is reflected in crop yield responses to different rates of N fertilizer obtained on different soils (Mowo *et al.*, 1993).

3.2.3 Data analysis

3.2.3.1 Laboratory soil analysis for soil fertility characterization

The particle size distribution was determined by the hydrometer methods as described by Gee and Bauder (1986). The bulk density of the soil was determined as described by Anderson and Ingram (1993) and water retention characteristic determined using the pressure plate membrane procedure as described by Klute (1986). Soil pH was determined electronically in the 1:2.5 soil: existing ration (McLean, 1982), organic carbon by wet digestion as described by Nelson and Sommers (1982) and total N by micro – Kjeldahl digestion method by Bremner and Mulvaney (1982). Soil available P was determined by the Bray 1 method as described by Okalebo *et al.* (2002), using ascorbic acid for colour development (Murphy and Riley, 1996). Exchangeable bases were extracted with neutral ammonium acetate (Anderson and Ingram, 1993). Potassium in the extract was determined photometrically as described by Thomas (1982).

Soil samples for fertility characterization (maize and cover crops), were air dried and sieved through a 2 mm sieve before being subjected to laboratory analysis. Soil particle

size analysis was carried out by the hydrometer method as described by Bouyoucos (1996).

3.2.3.2 Statistical data analysis

Data on soil fertility characteristics and maize grain yields were analyzed for variance using the statistical model for Randomized Completely Block Design (RCBD). The results of statistical analysis were presented in an Analysis of Variance (ANOVA) table to test for significance by using M-Stat. The differing means were separated by means of the Duncan's Multiple Range Test (DMRT).

CHAPTER FOUR

4.0 RESULTS

4.1 Characterization of the agricultural land soils of Karatu District, Arusha, Tanzania.

4.1.1 Soil characteristics of the agricultural land of Karatu District, Arusha.

The results of the soil characteristics of the three study sites in the district are presented in Table 1. They generally range from sandy loam to sandy clay loam with low fertility and have neutral reaction - probably reflecting the more less evenly distributed sandy soils of the district.

Table 1: Soil characteristics of the three study sites at 0 – 20 cm soil depth

Parameter	Sites			Mean	Soil rating
	Mbulumbulu	Rhotia	Endabash		
Total N	0.15 b	0.17 a	0.12 c	0.15 b	Low
Available P	7.08 a	6.06 c	5.72 d	6.29 b	Medium
Exchangeable K	0.39 a	0.36 b	0.34 c	0.36 b	Low
OC	2.35 a	2.32 b	2.31 b	2.35 a	Medium
pH	6.72 b	6.65 c	6.80 a	6.72 b	Neutral
Soil moisture	45.03 a	38.76 c	43.82 b	42.40 b	
Soil texture	Sandy clay loam	Sandy loam	Sand clay loam		

Values within the same row with the same following letter do not differ significantly (P<0.05)

4.1.2 Soils characteristics from Mbulumbulu, Rhotia and Endabash, at the various stages of maize plants development

The results of the characteristics of the agricultural land from the three study sites at the different stages of maize crop development are presented in Tables 2 - 5 and their average conditions are presented in Table 6. To, also, note that other than total soil N which showed the highest value at the seedling stage, the rest of the nutrients had highest

concentrations at the maize maturity stage while all nutrients, including soil moisture content, had the lowest concentrations at the flowering stage.

Table 2: Nutrient contents of the used cover crops

Crop	Soil characteristics					
	N	P	K	OC	pH	Moisture
Lablab alone	0.18 a	7.1 a	0.38 a	2.39 a	6.82 a	43.9 a
Mucuna alone	0.20 a	6.9 a	0.40 a	2.41 a	6.73 b	44.6 a
Maize alone	0.11 c	6.2 c	0.31 c	2.32 c	6.60 d	32.1 c
Maize + Lablab	0.17 b	6.8 b	0.35 b	2.38 b	6.74 b	38.4 b
Maize + Mucuna	0.19 a	6.7 b	0.37 b	2.36 b	6.69 c	40.5 b

Values within the same row with the same following letter do not differ significantly (P<0.05)

Table 3: Soil characteristics from Mbulumbulu village at 0 – 20 cm soil depth

Characteristics	Soil characteristics of Mbulumbulu village			
	Seedlings	Flowering	Maturity	Soil rating
Total N (%)	0.18 a	0.13 c	0.15 b	Low
Available P (mg/kg)	6.92 d	7.08 c	7.24 a	Medium
Exchangeable K (mg/k)	0.37 c	0.39 b	0.42 a	Low
Soil OC (%)	2.30 c	2.36 b	2.38 a	Medium
Soil pH (Water)	6.76 a	6.64 b	6.55 c	Neutral
Soil moisture (%)	43.61 a	38.35 c	42.64 a	

Values within the same row with the same following letter do not differ significantly (P<0.05)

Table 4: Soil characteristics at Rhotia village at 0 – 20 cm soil depth

Characteristics	Soil characteristics of Rhotia village			
	Seedlings	Flowering	Maturity	Soil rating
Total N (%)	0.19 a	0.13 c	0.18 a	Low
Available P (mg/kg)	5.86 d	6.28 a	6.04 c	Medium
Exchangeable K (mg/kg)	0.36 b	0.37 b	0.39 a	Low
Soil OC (%)	2.30 b	2.34 a	2.30 b	Medium
Soil pH (Water)	6.66 b	6.62 c	6.73 a	Neutral
Soil moisture (%)	47.32 a	38.42 c	44.26 b	

Values within the same row with the same following letter do not differ significantly (P<0.05)

Table 5: Soil characteristics of Endabash village at 0 – 20 cm soil depth

Characteristics	Soil characteristics of Endabash village			Soil rating
	Seedlings	Flowering	Maturity	
Total N (%)	0.16 a	0.09 c	0.12 b	Low
Available P (mg/kg)	6.10 a	5.38 d	5.68 c	Medium
Exchangeable K (mg/kg)	0.36 b	0.34 c	0.39 a	Low
Soil OC (%)	2.35 a	2.25 d	2.33 b	Medium
Soil pH	6.78 c	6.71 d	6.95 a	Neutral
Soil moisture (%)	41.56 b	39.56 c	43.81 a	

Values within the same row with the same following letter do not differ significantly ($P < 0.05$)

Table 6: The mean soil chemical characteristics of the three study sites at the various plants' development stages.

Characteristics	Soil characteristics			Soil rating
	Seedlings	Flowering	Maturity	
Total N (%)	0.17 a	0.13 c	0.15 b	Low
Available P (mg/kg)	6.29 c	6.25 d	6.48 a	Medium
Exchangeable K (mg/kg)	0.36 b	0.36 b	0.39 a	Low
Soil OC (%)	2.31 b	2.31 b	2.34 a	Medium
Soil pH	6.69 b	6.64 c	6.73 a	Neutral
Soil moisture %	44.16 a	38.78 c	43.57 b	

Values within the same row with the same following letter do not differ significantly ($P < 0.05$)

4.1.3 The trend in the overall soil characteristics of the agricultural land of Karatu District

Results of the trend of soil characteristics on the agricultural land soils of Karatu District during the past 5 years and overall average status are presented in Tables 7. It will be noted that the physical and chemical soil characteristics of the farm land soil of Karatu District have remained stable with little change over various times - probably because of the sandy nature of the soils that are readily permissive to leaching and erosion.

Table 7: The mean overall trend of soil characteristics of the agricultural land in Karatu District over the past 5 years.

Year	N (%)	P (mg/kg)	K (mg/kg)	OC (%)	pH (Water)
2006	0.15 b	6.29 d	0.36 c	2.35 c	6.42 c
2007	0.16 b	6.22 e	0.40 a	2.42 a	6.48 b
2008	0.19 a	6.36 a	0.38 b	2.38 b	6.53 a
2009	0.18 a	6.32 c	0.41 a	2.27 e	6.41 c
2010	0.16 b	6.34 b	0.38 b	2.33 d	6.39 d

Values in the same column with the same following letter do not differ significantly (P<0.05)

4.2 The effect of cover crops on the yields of intercropped maize in the district.

4.2.1 The effect of cover crops on maize yields

The results of the current maize grain yields data under various cover crops are presented in Table 8. It will be noted that the intercropped cover crops significantly promoted maize grain yields with mucuna being the most effective - probably due to their N-nutrient addition by the N-fixing cover crop plants and amelioration of the soil environment.

Table 8: The current maize grain yields (t/ha) under the different cover crops at the three study sites of Karatu District

Treatment	Sites			Average
	Mbulumbulu	Rhotia	Endabash	
Sole maize	0.51 c	0.62 c	0.59 c	0.57 c
Lablab + maize	2.76 b	3.37 a	2.48 b	2.87 b
Mucuna + maize	3.33 a	2.79 b	3.01 a	3.04 a

Values in the same column with the same following letter do not differ significantly (P<0.05)

4.2.2 The maize yields trend under different cover crops over the 5 years (2006 - 2010) of the study.

Results of the effects of cover crops on maize grain yields during the past 5 years are presented in Table 9. It will be noted that the cover crops significantly increased maize yields at all the times during the 5 year period. This was due to the leguminous cover

crops which were subsequently incorporated into the soil fix - N and increased other plant nutrients in the soil and ameliorated the soil physical conditions with the *Mucuna pruriens* being the most effective.

Table 9: The effect of cover crops on maize yields for different treatments for 2006 - 2010

Cover crop treatments	Maize Grains (t/acre)				
	2006	2007	2008	2009	2010
Sole maize	0.50 c	0.22 c	0.63 c	0.67 c	0.57 c
maize + Lablab	1.32 b	0.33 b	1.60 b	2.07 b	2.87 b
maize + Mucuna	1.60 a	0.43 a	1.77 a	2.30 a	3.04 a

Values in the same column with the same following letter do not differ significantly (P<0.05)

4.2.3 The cumulative effects of cover crops on maize yields

Results of the cumulative effect of cover crops on maize yields during the 5 years of study are presented in Tables 10. It will be noted that on yearly basis, the cover crops highly promoted maize yields but the effect was not cumulatively maintained - probably due to the rapid decomposition and mineralization of the cover crop residues with sandy nature of the soil permitting leaching of the nutrients at the start of each rain season.

Table 10: Accumulative effect of cover crops on maize yields between years

Cover crop treatments	Maize Grains (t/acre)				
	2006	2007	2008	2009	2010
Sole maize	0.50 b	0.22 c	0.63 a	0.67 a	0.57 b
maize + Lablab	1.32 c	0.33 d	1.60 b	2.07 a	2.87 a
maize + Mucuna	1.60 c	0.43 d	1.77 c	2.30 b	3.04 a

Values within the same row with the same following letter do not differ significantly (P<0.05)

CHAPTER FIVE

5.0 DISCUSSION

5.1 Soil fertility characteristics of the agricultural land of Karatu District

The results of the soil characteristics of the soils of the agricultural land of the three study sites of the district are presented in Tables 1 to 7. The results indicate that the district is general characterized by low soils fertility (Table 1). This is probably due to the effect of soil erosion and leaching. The results are in conformity with the findings of Smaling *et al.* (1997) and Sanchez (2000) for Sub-Saharan Africa and Moyo (2003) for Ghana. The results of both authors indicated that soil erosion and nutrient leaching lead to losses of up to 20kg ha⁻¹ of the major soil nutrients of nitrogen, phosphorus and potassium due to the looseness of the sandy soil and poor farming practices in these areas. In many parts of Ghana, there are numerous problems associated with the declining productivity of the soil due to frequent soil tillage and removal of crop material/residue. The results that low fertility was associated with low soil moisture agrees with findings of Eilitta *et al.* (2004) and Stevens (2000) who found that shallow and conventionally ploughed soils resulted in structure deterioration and loss of soil water, which results in reduced yields.

The results of lower nutrients values at the maize crop flowering stage and highest values at the maturity stage, probably reflects the higher plants nutrients demand at the flowering stage while they build up their concentrations again at the lower nutrients demand at the plants maturity when, also, the nutrients from the decomposing nutrient rich leguminous cover crops get released (Tables 2 – 6). The importances of sufficient nutrients and moisture at the critical stages of plants development have similarly been emphasized by the findings of Mahalakshmi and Bidinger (1985); Kumari (1988); Bradford (1994) and

Mastrorilli *et al.* (1995). Sakala *et al.* (2003) report the significance of N that gets made available by being released from rapidly decomposing leguminous cover crops especially when there is sufficient moisture (Cakir, 2004). Chamsham *et al.* (1998), however, cautions that while N is important to plant development total soil N should not be taken to be the sole indicator of soil fertility.

The indication by the study showed that during seedlings stage total N had the highest value in the soil solution (Table 6), probably reflects the presence of its just having been released from the decomposing litter and not yet being much used by the young maize plants. During the tasseling and maturity stages the soil N was low because of its having been up taken by the plants as consequently reflected by its highest concentration in the maize plants. Nitrogen nutrient is needed in larger quantities during flowering of the maize plants than other nutrients. The study conforms to the findings of Tisdale *et al.* (1990) and Sanchez *et al.* (1997). In Tanzania, N, taken out of the soil through crop harvest annually has been estimated to range from 20 to 40kg N ha⁻¹ whereas the removal of K ranges from 16.6 to 33.2 and P from 3.5 to 6.6 kg ha⁻¹, respectively (Smaling *et al.*, 1997).

This study showed medium availability P and OC (Table 6) in the soil. This confirms the results of various research works about the benefits of leguminous cover crops on extractable P. Availability of phosphorus in soils is often limited by fixation reactions, which convert the mono phosphate ion into various insoluble forms (Di *et al.*, 1994). Besides, previous researches reporting of the availability of soil P being enhanced by adding organic matters which influence the chelating of polyvalent cations by organic acids and other decay products (Reddy *et al.*, 2005; Mohanty *et al.*, 2006). The

decomposition of soil organic matter from leguminous cover crops not only supplies the N nutrient, but can also increase the availability of other plant nutrients in the soil through several processes (Palm *et al.*, 1997).

The study similarly showed the influence of the organic matter from the cover crops on the maintenance of soil pH at the near neutral level (Table 6). Similar results have been reported by He *et al.* (1992). Several processes can affect the change of soil pH with the most commonly cited is effect of nitrogen supply. Hernando *et al.* (1989) found that soil pH increased from the acidic condition to neutral level with the addition of compost, indicating that much increase was likely due to the high calcium content of the compost. Cuevas *et al.* (2000) and Zinati *et al.* (2001), however, found no significant change in pH with addition of composted solid waste. The results on the overall mean trend of soil characteristics over the five years of the study, however, showed a more or less stable state because of the erosion and leaching of nutrients from the sandy soils during each rainfall season. The findings are in line with the results of Neilsen and Stevenson (1993) and Fox *et al.* (2001), who found significantly higher leaching during the first three years after soil was loosened. Wu *et al.* (1997) reported that Nutrient depletion occurs primarily through crop removal in harvested products and residues, by leaching and soil erosion. This means that under the conditions similar to those of the present study, the application of cover crops should form a continuous process in order to sustain the systems productivity.

5.2 The effect of cover crops on the yield of intercropped maize

The effect of cover crops on maize grain yields (Table 8) showed that intercropping maize with mucuna was the most effective. Maize yield data reported in this study clearly demonstrate that the maize yields increased significantly in maize intercropped with

leguminous cover crops were corresponded with the amount of nutrients recycled through cover crop biomass. Similar results were observed by Nzabi (2000); Mwalley and Mawenya (2002); Kambutho and Muthua (2002) and RELMA (2002) who reported more increase in maize yield in CA systems than in continuous sole maize, making the system attractive to farmers in semi-arid tropics. Odhiambo (2011) and Odhiambo and Netshivdza (2008), found that there was a high potential to increase maize yield in smallholder farms by using green manure legume cover crops.

A study by Rao and Mutuva (2000) in semi-arid Kenya revealed an increase of 30-49% of maize yield for annual grain legume based cropping systems compared to continuous sole maize, while studies conducted in the mid altitude areas of Uganda have shown that green manure can increase maize yield by 36% and 42% (Fischler *et al.*, 1999). Incorporation green manure in Kenya, averaged over two years improved maize grain yield by 1.5 t ha⁻¹ compared to no incorporation 0.9 t/ha⁻¹ (Ojiem *et al.*, 2000), while in southern Cameroon, Hauser and Nolte (2002) obtained maize yields greater than 4 t ha⁻¹ after a short-term fallow with mucuna. In Tanzania, farmers have used *Dolichos lablab* to increase their maize yield from 12.4 to 45 bags ha⁻¹ (Lupatu and Kilimwiko, 1991).

In South Africa green manure legumes gave grain yield increases of between 77 -134% and 55 - 70% above the control, in 2007/8 and 2008/9 seasons, respectively. These yield increases were fairly high compared with those obtained in studies elsewhere (Fischler *et al.*, 1999; Ojiem *et al.*, 2000). In Benin, the adoption of the legumes is not extensive but the data indicates that *Dolichos lablab* is preferred to increase in maize yields than *Mucuna pruriens* (Versteeg *et al.*, 1998).

Study conducted by Giller *et al.* (1997) and Ikerra *et al.* (2001) reported that maize intercropped with legumes increased maize yield compared to sole maize plots. It is well documented, leguminous cover crops release nutrients too quickly, similar to the use of inorganic fertilizers. (Sakala *et al.*, 2003).

The trend in the cover crop effects on maize grain yields during the past 5 years (Table 9) showed that cover crops significantly promoted maize yields with mucuna cover crop showing highly results probably because the cover crops continued being incorporated into the soil to increase soil nutrients and ameliorate the soil conditions as a result increased maize yields. This observation is in agreement with literature on the effect of residue quality on N release and uptake by the recipient crop. Studies conducted in Uganda Fischler *et al.* (1999) and Hauser and Nolte (2002) which showed that overall legume treatments, with or without N fertilizers increased grain yield compared to control (-N). Mucuna and lablab fractions in the conservation agriculture study were generally lower in N than those reported by Ibewiro *et al.* (2000). This could be due to differences in environmental conditions prevailing during plant growth, which can result in biomass of differing quality (Handayanto *et al.*, 1995). The results of this study were contrasts those of Van Noordwijk and Purnomisidi (1992) that, mucuna had a greater litter biomass than lablab ($P < 0.001$). The greater amounts of mucuna biomass suggest that it was more adapted to growth under shading by maize and to the dry conditions following maize harvest than lablab.

Results of the cumulative effect of cover crops on maize yields during the past 5 years of the study reveal that on the yearly basis, the cover crops highly promoted maize yields but the effect was not cumulatively maintained (Tables 10). Similar observations were

reported made by Sainju and Sing (2002) who showed that leguminous cover crops can improve soil water quality compared to bare fallow by reducing erosion during fall, spring, and increasing maize yields.

In Southwestern Ontario, Canada, the review of Miguez and Bollero (2005) reported that corn yield response to cover crops did not consistently decrease corn yields in the Midwestern Corn Belt and that many studies reported no effect on yield, while in Nebraska, Kessavalou and Walters (1997) observed who measured lower corn yields in one of the three years. In Northern Ghana the yield of maize grain was not significantly increased by intercropping with cover crops whose growth in the maize was not as good as expected (Cheruiyot *et al.*, (2007), but in Western Kenya, maize yield increase of up to 62% was reported by intercropping with *Dolichos lablab* (Jama *et al.*, 2006). The increase in maize yields following the intercropping with herbaceous legumes is also supported by the studies of Ramakrishna *et al.* (2006), Hairiah and van Noordwijk (1989) and Sakala *et al.* (2000). Festus *et al.* (2009) observed that provided such findings evidence of the potential contribution of cover crop legumes to maize productivity that can now be harnessed for sustainable smallholder agriculture in Africa.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the indicated results and preceding discussion, the following conclusions are made:

- Soil characteristics of the Karatu District's agricultural land, generally range from sandy loam to sandy clay loam with low fertility and of neutral reaction.
- Physical and chemical characteristics of the farm land soil of Karatu District had remained stable with little change over various times because of the sandy nature of the soils that are readily permissive to leaching and erosion.
- Total soil N showed the highest value at the maize seedling stage, while the rest of the nutrients had highest concentrations at the maturity stage. All nutrients, including soil moisture content, had the lowest concentrations at the flowering stage.
- Intercropped cover crops significantly promoted maize grain yields with Mucuna being the most effective.
- Cover crops significantly increased maize yields and other plant nutrients in the soil at all the times of the 5 years period.
- On yearly basis, the cover crops highly promoted maize yields but the effect was not cumulatively maintained due to the mineralization of the cover crop with sandy nature of the soil permitting leaching of the nutrients at the start of each rain season.

6.2 Recommendations

Based on the above conclusions from the study the following recommendations are drawn for immediate application.

- The use of cover crops in the farming systems should be promoted to the farmers in semi-arid areas such as Karatu District especially by using Mucuna as a cover crop to improve soil quality, promote crop yields, protect soil degradation and thus reduce input costs.
- Since the study revealed that the maize flowering stage demanded more nutrients than the seedling and maturity stages, any intervention to improve maize yield in Karatu District should focus on the use of cover crops that synchronize the supplying of nutrients to plants with the flowering stage of the involved crop.
- Based on the fact that the researched cover crops performed well in supplying nutrients for increased maize yields, still more research need to be carried out to verify the potential of other leguminous cover crops in promoting crop production in the study area and recommend them accordingly.

REFERENCES

- Ahn, P. M. (1981). The effects of large-scale mechanized agriculture on the physical properties of West Africa soils. *Ghana Journal of Agricultural Science* 3: 93 – 97.
- Allan, W. (1989). *The African Husbandman*. Greenwood Press, WestPoint, Connecticut. 199pp.
- Anderson, J.M. and Ingram, J.S. (1993). *Tropical soil biology and fertility. A hand book of Methods*. Commonwealth Agricultural Bureau, Oxon, UK. 221pp.
- Balasubramanian, V. and Blaise, N. K. A. (1993). Short season fallow management for sustainable production in Africa. In: *Technologies for sustainable agriculture in the tropics*. (Edited by Ragland, J. and Lal, R.), ASA Special Publisher, Madison, pp. 279 – 293.
- Bancy, M. M. and Kithinji, M. (2002). *Integrated soil fertility and management assessment of the KUSA profile, Lake Victoria Basin*. Final Report, RELMA, Nairobi, Kenya. 36pp.

- Benites, J., Chuma, E., Fowler, R., Kienzle, J., Molapong, K., Manu, J., Nyagumbo, I., Steiner, K. and Van Veenhuizen, R. (Eds.) (1998). Conservation tillage for sustainable agriculture. *Proceedings from the International Workshop on Conservation Tillage for Sustainable Agriculture, 22 - 27 June 1998, Harare, Zimbabwe.* 59pp.
- Blackwell, J.M., Goodwillie, R.N. and Webb, R. (1991). *Environment and Development in Africa.* Selected Case Studies. EDI, No. 6, World Bank, Washington, DC. 127pp.
- Bouyoucos, G. J. (1996). Hydrometer method improved for making particle soil analysis of soils. *Agronomy journal* 54: 464 – 465.
- Bradford, K. J. (1994). Water stress and the water relations of seed development: A critical review. *Crop Science* 34: 1 – 11.
- Bremner, J. M. and Mulvaney, C. S. (1982). Total nitrogen. In: *Methods of soil analysis.* Chemical and Microbiological properties, Agronomy Monograph No. 9. USA. 165pp.
- Cakir, R. (2004). Effect of water stress at different development stages on vegetative and reproductive growth of corn. *Field Crops Research* 89: 1 – 16.

- Carsky R.J., Becker, M. and Hauser, S. (2001). Mucuna cover crop fallow systems. potentials and limitations. In: *Tian, G. (Eds.) Sustaining soil fertility in West Africa*. American Society of Agronomy Inc., Madison, WI, USA. pp. 111 – 136.
- Carsky, R.J., Oyewole, B. and Tian, G. (1999). Integrated soil management for the savanna zone of west Africa: Legume rotation and fertilization. *Nutrition Cycl. Agroecosystem* 55: 95 – 105.
- Chamshama, S. A. O., Mugasha, A. G., Klovstad, A., Haveraaen, O. and Maliondo, S.M.S. (1998). Growth and yield of maize alley cropped with *Leucaena leucocephala* and *Faidherbia albida* in Morogoro, Tanzania. *Agroforestry Systems* 40: 215 – 225.
- Cheruiyot, E.K., Mwonga, S.M., Mumera, L.M. and Tabu, I.M. (2007). Rapid decay of dolichos (*Lablab purpureus*) residue leads to loss of nitrogen benefit to succeeding maize. *Australia Journal Expert Agriculture* 47: 130 – 137.
- Chikoye, D. (1999). *Methods of Assessing Ground Cover by Herbaceous Cover Crops*. CIEPCA Newsletter, Issue No. 4. 6pp.
- Cuevas, G. (2000). Composted MSW effects on soil properties and native vegetation in a degraded semiarid shrubland. *Compost Science & Utilization* 8: 303 – 309.

- Deborah, J. (2001). *Water Harvesting and Soil Moisture Retention. A Study Guide for Farmer Field School, South Africa.* 19pp.
- Di, H. J., Harrson, R. and Campbell, A. S. (1994). Assessment of methods for studying dissolution of phosphate fertilizers of different solubility in soil. I. An isotopic method. *Fertilizer Research* 38: 1 – 9.
- DALDO (2005). *Annual Agricultural and Livestock Department Progress Report, Karatu District Council, Arusha, Tanzania.* 10pp.
- Dragne, H.E. (1990). Erosion and productivity in Africa. *Journal of Soil and Water Conservation* 45: 431 – 436.
- Eilitta, M., Arteaga, F. L. and Diaz, M. (2004). *Cultivating Maize with Mucuna in the Los Tuxtlas Region of South-Eastern Veracruz. Green Manure Cover Crop Systems of Smallholder Farmers, Mexico.* pp. 114 – 115.
- FAO (1998). World Reference Base for Soil Resources. *World Soil Resource Report No. 84. Food and Agriculture Organization of United Nations.* International Society of Soil Science, Rome, Italy. 88pp.
- FAO (1986). *The conservation and rehabilitation of Africa lands towards sustainable agriculture.* FAO Rome, Italy. pp. 8 – 35.

- Festus, K. A., Frank, P., Gudeta, S. and Oluyede, C. A. (2009). Evidence for impact of green fertilizers on maize production in sub-Saharan Africa: *Agroforestry Systems* 47:49–66.
- Fischler, M., Wortmann, C.S. and Feil, B. (1999). *Crotalaria ochroleuca* as a green manure in a maize-bean cropping systems in Uganda. *Field Crops Research* 61: 97 – 107.
- Fischler, M. (1996). Research on green manures for maize-bean systems in eastern Uganda: Agronomic performance and farmers' perceptions. *Agroforest System* 47: 123 – 138.
- Fischler, M. and Wortmann, C.S. (1999). Green manure for maize – bean systems in the Eastern Uganda: Agronomic performance and farmers' perceptions. *Agroforestry Systems* 47: 123 – 138.
- Fox, R.H., Zhu, Y., Toth, J.D., Jemison, J.M. and Jabro, J.D. (2001). Nitrogen fertilizer rate and crop management effects on nitrate leaching from an agricultural field in central Pennsylvania. In: *Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection. Proceedings of the second International Nitrogen Conference on Science and Policy, (Edited by Galloway, J. et al.)*, 6 – 20 June 2001 China. pp. 181 – 186.

- Gee, G.W. and Bauder, J. W. (1986). Particle size analysis. In: *Methods on soil analysis. Agronomy monograph No. 9.* (Edited by Klute, A.), America Society of Agronomy, Madison, Wisconsin. pp. 383 – 412.
- Giller, K.E., Cadish, G., Ehaliotis, C., Adams, E., Sakala, W.D. and Mafongoya, P.L. (1997). Building soil nitrogen capital in Africa. In: *Replenishing soil fertility in Africa. Buresh, R.J., Sanchez, P.A. and Calhoun, F. (Eds.),* SSSA Special Publication No. 51, Madison, Wisconsin. pp. 193 – 218.
- Hairiah, K. and Van Noordwijk, K.M. (1989). Root distribution of leguminous cover crops in the humid tropics and effects on subsequent maize crop. p. 157-169. In: *Nutrient management for food crop production in tropical farming systems.* Van der Heide, J. (Ed.), 19 – 24 October 1987. Institute Soil Fertility Haren, Netherlands. pp. 56 – 58.
- Handayanto, E., Cadisch, G. and Giller, K.E. (1995). Manipulation of quality and mineralization of tropical legume tree pruning's by varying nitrogen supply. *Plant Soil* 176: 149 – 160.
- Hauser, S. and Nolte, C. (2002). Biomass production and N fixation of five *Mucuna pruriens* varieties and their effect on maize yields in the forest zone of Cameroon. *Journal of Plant Nutrition and Soil Science* 165: 101 – 109.

- Hawassi, F. G. H. (1997). The Effect of Fertilizer Subsidy Removal on Fertilizer Use and Production of Maize in Mbinga District. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 87pp.
- He, X.T., Traina, S.J. and Logan, T.J. (1992). Chemical properties of municipal solid waste composts. *Journal of Environmental Quality* 21: 318 – 329.
- Hernando, S., Lobo, M.C. and Polo, A. (1989). Effect of the application of municipal refuse compost on the physical and chemical properties of a soil. *The Science of the Total Environment* 81(82): 589 – 596.
- Holderbaum, J. F., Decker, A. M., Meisinger, J. J., Mulford, F.R. and Vough, L. R. (1990). Fall-seeded legume cover crops for no-tillage corn in the humid East. *Agronomy Journal* 82(1): 117 – 124.
- Ibewiro, B., Sanginga, N., Vanlauwe, B. and Merckx, R. (2000). Nitrogen contributions from decomposing cover crop residues to maize in a tropical derived savanna. *Nutrition Cycl. Agroecosystem* 57: 131 – 140.
- Igbadun, H. E., Mahoo, H. F., Tarimo, A.K. and Salim, B. A. (2005). Productivity of water and economic benefit associated with deficit irrigation scheduling in maize. *A paper presented at the Integrated River Basin Management Conference* held on 7 – 9 March 2005 at ICE hall, Sokoine University of Agriculture, Morogoro, Tanzania. pp. 18 – 28.

- Ikerra, S.T., Maghembe, J.A., Smithson, P.C. and Buresh, R.J. (2001). Dry season sesbania fallows and their influence on nitrogen availability and maize yield in Malawi. *Agroforestry Systems* 52: 13 – 21.
- Jama, B., Palm, C.A., Buresh, R.J., Niang, A., Gachengo, C. and Amadalo, B. (2006). Lablab as a green manure for soil fertility improvement in Western Kenya. *A review Agroforest System* 49: 201 – 221.
- JICA (1995). *Miombo Woodlands Agroecological Research Project: Annual Progress Report No. 96*. Kathmandu, Nepal. 369pp.
- Kambutho, P. G. and Muthua, J. M. (2002). Experiences from on-farm trials. *A report compiled for the Regional Land Management Unit (RELMA) countries experience sharing workshop*. A paper presented during Regional Workshop on Conservation tillage 15 – 19 April, 2002. Taj Pamodzi Hotel, Lusaka, Zambia. pp. 82 – 86.
- Karsky, R. J. and Eteka, A. C. (2000). Persistence of mucuna pruriens biomass during the dry season along an agroecological transect in Benin. Cover crops for natural resource management in West Africa. In: *Proceedings of a Workshop Organized by IITA and CIEPCA*. (Edited by Carsky, R.J., Eteka, A.C., Keatinge, J.D.J. and Manyong, V.M.), 26 – 29 October 1999, Cotonou, Benin. pp. 114 – 149.

Kauzeni, A. S., Kikula, I. S. and Shishira, E. K. (1987). Development Conservation in Tanzania. In: *History of Soil Conservation in the SADCC Region*. Report No. 8. SADCC Soil and Water Conservation and Land Utilization Programmes Coordinating Unit, Maseru, Lesotho. 20pp.

Kessavalou, A. and Walters, D.T. (1997). Winter rye as a cover crop following soybean under conservation tillage. *Agronomy Journal* 89(1): 68 – 74.

Khan, M.S., Zaidi, A. and Wani, P.A. (2007). Role of phosphate – solubilizing microorganisms in sustainable agriculture- *A review Agronomy Sustainable Development* 27: 29 – 43.

Kikula, I. S., Mung'ong'o, C. G. and Jengo, R. D. (1990). *Perspective of land degradation and conservation in Tanzania*. An Annotated Bibliography. Institute of Research Assessment, University of Dar es Salaam and Regional Soil Conservation Unit, Swedish International Development Authority, Nairobi, Kenya. pp. 2 – 3.

KILIMO/FAO (1997). *Plant Nutrition Program in Tanzania*. Synthesis of projects prominent findings and recommendations Agronomic Results. FAO, Dar es Salaam, Tanzania. 70pp.

Klute, A. (1986). Water retention: Laboratory methods. In: *Methods of soil analysis. Physical and Mineralogical Methods* 9(1): 635 – 660.

- Kumari, S. (1988). The effects of soil moisture stress on the development and yield of millet. *Agronomy Journal* 57: 480 – 487.
- Laizer, P. M. (2000). *Environmental Conservation in Tanzania*. Paper presented at the meeting on evaluation of SCAPA Project, Arusha, Tanzania. 2pp.
- Lal, R. (1997). Soil Degrative Effects of Slope Length and Tillage Methods on Alfisols in Western Nigeria. Runoff, Erosion and Crop Response. *Land Degradation and Development* 8(3): 201 – 220.
- Li, Q., Chen, Y., Liu, M., Zhou, X., Yu, S. and Dong, B. (2008). Effects of Irrigation and Straw Mulching on Microclimate Characteristics and Water Use Efficiency of Inter Wheat in North China. *Plant Production Science* 11(2): 161 – 170.
- Lohay, J. A. (1998). Participation of women in tree planting in Babati District, Tanzania. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 123pp.
- Lupatu, M. and Kilimwiko, L (1991). Natural fertilizers: New life for tired soils. Africa Farmer No. 6. Published by the Hunger Project Savaccon Gallery, New York, USA. pp. 97 – 105.

- Magoggo, J. L., Msanya, B. M. and Kimaro, D. N. (1996). *Environmental Profile for Agricultural Production and Development of Conservation Strategies in Mahenge Village, Mbinga District, Tanzania*. Technical Report No. 3. MWRP. Mbinga, Songea, Tanzania. 23pp.
- Mahalakshmi, V. and Bidinger, F.R. (1985). Flowering response of pearl millet to water stress during panicle development. *Ann. Appl. Biol.* 106: 571 – 578.
- Manunta, P., Kryzanowski, L. and Keyes, D. (2001). Mapping soil-available phosphorus: considering changes in crop yield and fertilizer sales. *Better Crops* 85: 8 – 10.
- Marjatta, E., Mureithi, J. and Derpsh, R. (2004). Green Manure/Cover Crop Systems of Smallholder Farmers. Experiences from Tropical and Sub-tropical Regions. *Biology and Fertility of Soils* 30: 298 – 305.
- Mastrorilli, M., Katerji, N. and Rana, G. (1995). Water efficiency and stress on grain sorghum at different reproductive stages. *Agriculture Water Manage* 28: 23 – 34.
- Mattee, A. Z., Mwaseba, D., Rutatora, D. F., Mdoe N.S.Y. and Kakeya, M. (1996). Farmer's strategies to Cope with Environmental Changes in Mbinga District; Implication for Research Interventions. In: *JICA, Miombo Woodlands Agroecological Research Project: Annual Progress Report* No. 96. Mbinga, Songea, Tanzania. 76pp.

- Maurya, R.P. and Lal, R. (1998). Effect of different cover crop on soil properties and on the root growth and yield of the maize. *Field crop research* 4: 33 – 45.
- McLean, E.O. (1982). Soil pH and lime requirements. In: *Methods of soil analysis Part 2. Agronomy monograph No. 9. (Edited by Page, A.L., Miller R.H. and Keney, P.R.)*, American Society of Agronomy, Madison, Wisconsin. pp. 199 – 223.
- Meena, S., Senthilvalavan, P., Malarkodi, M. and Kaleeswari, R.K. (2007). Residual effect of phosphorus from organic manures in sunflower - assessment using radio tracer technique. *Research Journal of Agriculture and Biological Sciences* 3: 377 – 379.
- Meissinger, J. J., Hargrove, W. L., Mikkelsen, R. L., Williams, J. R. and Benson, J. W. (1991). *Effects of Cover Crops on Ground Water Quality*. In: Cover crops for clean water. Soil and Water Conservation Society, Hargrove, pp. 121 – 130.
- Miguez, F. E. and Bollero, G.A. (2005). Review of corn yield under winter cover cropping systems using meta-analysis methods. *Crop Science* 45: 318 - 329.
- Mohanty, S., Paikaray, N.K. and Rajan, A.R. (2006). Availability and uptake of phosphorus from organic manures in groundnut (*Arachis hypogea* L.)-corn (*Zea mays* L.) sequence using radio tracer technique. *Geoderma* 133: 225 – 230.

- Morgan, R. P. C. (1986). *Soil Erosion and Conservation*. Longman and Wiley Publisher, New York. pp. 56 – 289.
- Mowo, J. G., Floor, J., Kaihura, F. B. S. and Magoggo, J. P. (1993). *Review of Fertilizer Recommendations in Tanzania*: National Soil Service, Soil fertility Report No. 6. 61pp.
- Moyo, A. (2003). Assessment of the effect of soil erosion on nutrient loss from granite-derived sandy soils under different tillage systems in Zimbabwe. Thesis for Award of PhD Degree at Harare, Zimbabwe. 238pp.
- Murphy, J. and Riley, J. P. (1996). A modified single solution method for determination of phosphate in natural water. *Analytical Chemistry Acta* 27: 31 – 36.
- Mwalley, J. and Mawenya, L. (2002). Promoting conservation farming among Small – Scale Land Users in North Eastern Tanzania (Arusha and Arumeru Districts). *A Paper Presented During Regional Workshop on Conservation Tillage 15 – 19 April 2002*. Taj Pamodzi Hotel, Lusaka, Zambia. 55pp.
- Neilsen, G. H. and Stevenson, D. S. (1993). Leaching of Soil Nitrogen, Phosphorus and Potassium in irrigated orchard lysimeters. *Soil Science Journal* 47: 692 – 696.
- Nelson, D. W. and Sommers, L. W. (1982). Organic carbon. In: *Methods of soil analysis Agronomy Monography No. 9*. (Edited by Page A.L., Miller R.H. and Keeney, P.R.), American Society of Agronomy, Madison, Wisconsin. pp. 561 – 573.

- Ngatunga, E. L. N. (1981). Soil Erosion Studies at Mlingano on the Eastern Usambara Uplands. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 213pp.
- Nyakanda, C., Maringa, I. K., Dzowela, B. H. and Murwira, H. (1998). *Biomass Production and Maize Yield under a Tree Based Improved Fallow of Sesbania and Pigeon Pea*. Soil fertility research for maize-based farming System, Malawi and Zimbabwe. 115 – 119pp.
- Nyambati, E.M. (2002). Management and nutritive evaluation of *Mucuna pruriens* and *Lablab purpureus*-maize relay intercrop in the sub-humid highlands of northwestern Kenya. Thesis for Award of PhD Degree at University of Florida. 270pp.
- Nzabi, A.W. (2000). *Rachuanyo Conservation Tillage experiment*. Annual Report, KARI – Kisii, Kenya. 57pp.
- Odhambo, J. J. O. (2011). Potential use of green manure legume cover crops in Smallholder maize production systems in Limpopo province, South Africa. *African Journal of Agricultural Research*. 6(1): 107 – 112.
- Odhambo, J. J. O. and Netshivhodza, M. H. (2008). Effect of green manure legume cover crops for improving soil fertility in smallholder farms. *Africa Journal Agriculture Research* 5(8): 316 – 324.

- Ojiem, J. O., Mureithi, J.G. and Okwuosa, E.A. (2000). Integrated management of legume green manure, farmyard manure and inorganic nitrogen for soil fertility improvement in western Kenya. In: *Proceedings of the Scientific Conference of the Soil Management and Legume Research Network Projects*. June 2000, Mombasa, Kenya. pp. 97 – 102.
- Okalebo, J.R., Gathua, K.W. and Woomer, P. L. (1993). Laboratory method of soil and plant analysis: *A working manual. Tropical Soil Biology and Fertility Programme* Nairobi, Kenya. 78pp.
- Okalebo, J. R., Gathua, K. W. and Woomer, P. L. (2002). *Laboratory method of soil and plant analysis*. A working manual. KARI, SSEA, TSBF, UNESCO-ROSTA, Nairobi, Kenya. 89pp.
- Palm, C. A., Myers, R. J. and Nandwa, S. M. (1997). Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: *Replenishing soil fertility in Africa* 51: 193 – 217.
- Ramakrishna, A., Tam, H. M., Wani, S. P. and Long, T. D. (2006). Effect of cover crops on soil temperature, moisture, weed infestation and yield of maize Northern Vietnam. *Field Crop Research* 95: 115 – 125.
- Rao, M. R. and Muthuva, M. N. (2000). Legumes for improving maize yields and income in semi-arid Kenya. *Agriculture, Ecosystems and Environment* 78(2): 123 – 137.

- Rapp, A., Berry, L. and Temple, P. (1992). Studies of Soil Erosion and Sedimentation in Tanzania. *Geografiska Annaler* 54(4): 225 – 279.
- Reddy, S. S., Reddy, V.C., Ananda, M.C. and Sivaraj, B. (2005). Direct effect of fertilizers and residual effect of organic manures on yield and nutrient uptake of maize (*Zea mays* L.) in groundnut-maize cropping system. *Crop Research* 29: 390 – 395.
- RELMA (2002). *Regional Workshop on Conservation Tillage 15th – 19th April, 2002*. Taj Pamodzi Hotel, Lusaka, Zambia. pp. 15 – 43.
- Roberson, E. B., Sarig, S. and Firestone, M. K. (1998). Cover crop management of polysaccharidemediated aggregation in an orchard soil. *Soil Science Society of America Journal* 55: 734 – 739.
- Rockstrom, J., Kaumbutho, P., Mwalley, P. and Temesgen, M. (2001). Conservation farming among small-holder farmers in E. Africa: Adapting and adopting innovative land management options. *Plant and Soil* 250: 113–119.
- Sainju, U. M., Sing B.P. and Whitehead, W.F. (1997). Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. *Soil and Till. Research* 63: 167–179.

- Sainju, U. M. and Singh, B. P. (2002). Winter cover crops for sustainable agricultural systems: Influence on soil properties, water quality, and crop yields. *Horticulture Science* 32: 21 – 28.
- Sakala, W. D., Kumwenda, J. D. T. and Saka, A. R. (2003). The potential of green manures to increase soil fertility and maize yields in Malawi. *Biological Agriculture and Horticulture* 21: 121 – 130.
- Sakala, W., Cadisch, G. and Giller, K.E. (2000). Interactions between residues of maize and pigeonpea and mineral N fertilizers during decomposition and N mineralization. *Soil Biol. Biochem* 32: 279 – 268.
- Sakala, W. D. (2000). A review of potential legumes for integrated nutrient management in maize-based systems in Malawi with emphasis on pigeonpeas. (Ritchie, J. M. Ed.), *Integrated crop management research in Malawi. Proceedings of final workshop on the Farming Systems Integrated pest Management Project*. Club Makokola, Mangochi, Malawi, 29 November - 3 December, 1999. Chatham, UK. pp. 29 – 32.
- Samki, J. K. (1989). Soil formation, classification and land evaluation of soil developed over gneiss, limestone and marine sediments in Mlingano, Tanga region, Tanzania. Thesis for Award of PhD Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 270pp.

Sanchez, P. A. (1995). *Properties and Management of Soils in the Tropics*. John Wiley and Sons Publisher, New York, USA. pp. 13 – 145.

Sanchez, P. A. (2000). Soil fertility management of the millet producing sandy soils of Sahelian West Africa. Nutrient stocks and flow in West Africa soils. In: *Proceedings a seminar on the use of local mineral resources for sustainable agriculture in West Africa*. IFDC-Africa, 21 November 2000. pp. 56 – 58.

Sanchez, P. A., Shepherd, K. D., Soule, M. J., Place, F. M., Buresh, R. J., Mokwenye, A. U., Kwesiga, F. R., Ndiritu, C. G. and Woome, P. L. (1997). Soil fertility replenishment in Africa. An investment in Natural Resource Capital. In: *Replenishing Soil Fertility in Africa*. (Edited by Buresh, R.J. Sanchez, P.A. and Calhoun, F.), Soil Science Society of America Special Publication, USA. pp. 1 – 46 .

Sarrantonio, M. and Scott, T. W. (2001). Tillage effects on availability of nitrogen to corn following winter green manure crop. *Soil Science Society Journal* 52: 161 – 168

Schmied, D. (1989). Subsistence cultivation, market production and agricultural development in Ruvuma Region, Southern Tanzania. Thesis for Award of PhD Degree at Bayreuth University, 135pp.

- Smaling, E. M. A., Nandwa, S. M. and Janssen, B. H. (1997). Soil fertility in Africa is at stake. In: *Replenishing Soil Fertility in Africa (SSSA)*. (Edited by Buresh, R. J., Sanchez, P. A. and Calhoun, F.), Soil Science Society of America, Madison, USA. pp. 47 – 67.
- Soil Survey Staff (1998). *Keys to Soil Taxonomy. 8th Edition*. United States Department of Agriculture and Natural Resource Conservation Service, Blackburg, Virginia. 326pp.
- Steffens, D. (1994). Phosphorus release kinetics and extractable phosphorus after long-term fertilization. *Soil Science Society Journal* 58: 1702 – 1708.
- Stevens, P. A. (2000). *Ripping With Draught Animals*. IMAG-DLO Experiences in Zambia. Conservation Tillage for Dry Farming, RELMA Report No. 3. 65pp.
- Swift, M. J., Seward, P. D., Frost, P. G. H., Qureshi, J. N. and Muchena, F. N. (1994). Long-term experiments in Africa. Developing a data base for sustainable land use under global change. In: *Long-term experiments in Agricultural and Ecological sciences*. (Edited by Leigh, R.A. and Johnson, A.E.), CAB International, Wallingford, Oxon UK. pp. 229 – 251.
- Thomas, G. W. (1982). Exchangeable cation. In: *Methods of soil analysis Part 2: Chemical and microbiological properties*. (Edited by Page A.L., Miller R.H. and Keeney, P.R.), American Society of Agronomy, Madison, Wisconsin. pp. 159 – 166.

- Thukkaiyannan, P., Sundarb, S. D. and Prabhakaran, N. K. (2005). Studies on the Irrigation Methods and Mulching on Roots Characteristics, Water Serving and Yield of Summer Irrigation Cotton. *Madras Agricultural Journal* 92 (9): 398 – 403.
- Tian, G., Kalawole, G.O., Kang, B.T. and Kirchhof, G. (2000). Nitrogen fertilizer replacement indexes of legume cover crops in the derived savanna of West Africa. *Plant Soil* 224: 287 – 296.
- Tian, G. and Kang, B.T. (1998). Effects of soil fertility and fertilizer application on biomass and chemical composition of legume cover crops. *Nutrition Cycl. Agroecosystem* 51: 231 – 238.
- Tian, G., Kang, B. T. and Brussard, L. (1992). Effect of chemical composition on N, Ca and Mg release during incubation of leaves from selected Agroforestry and fallow plants. *Biogeochemistry* 16: 103 – 119.
- Tisdale, S.L., Nelson, W.L. and Beaton, J.D. (1990). *Soil Fertility and Fertilizers*. 4th Edition. Macmillan Publishing Company, New York. 754pp.
- Toor, G.S. and Bahl, G.S. (1999). Kinetics of phosphate desorption from different soils as influenced by application of poultry manure and fertilizer phosphorus and its uptake by soybean. *Bioresidues Technology* 69: 117– 121.

- URT (2002). United Republic of Tanzania population census. [<http://www.tanzania.org.tz/census/report.htm>] site visited on 18/8/2010.
- Van Noordwijk, M., Heinen, M. and Hairiah, K. (1991). Old tree root channels in acid soils in the humid tropics: Important 327 for crop root penetration, water infiltration and nitrogen management. *Plant Soil* 134: 37–44.
- Van Noordwijk, K.M. and Purnomisidi, P. (1992). Litter fall in cassava based cropping systems in Lampung. *Agrivita* 15: 29 – 33.
- Versteeg, M. N., Amidji, F., Eteka, A., Gogan, A. and Koudokpon, V. (1998). Farmer's adoptability of mucuna fallowing and agroforestry technologies in the coastal savanna of Benin. *Agricultural Systems* 56: 260 – 287.
- Vyn, T. J., Faber, J. G., Janovicek, K. J. and Beauchamp, E. G. (2000). Cover crop effects on nitrogen availability to corn following wheat. *Agronomy Journal* 92: 915 – 924.
- Wani, S. P., Rupela, O. P. and Lee, K. K. (1999). Sustainable agriculture in the semi-arid tropics through biological fixation in grain legumes. *Plant Soil* 174: 29 – 49.
- Wortmann, C. S., McIntyre, B. D. and Kaizzi, C. K. (2000). Annual soil improving legumes: agronomic effectiveness, nutrient uptake, nitrogen fixation and water use. *Field Crops Research* 68: 75 – 83.

- Wu, J., O'Donnell, A.G., Syers, J.K., Adey, M.A. and Vitykon, P. (1997). Ley-arable rotations in sandy soils of north-east Thailand: Implication for organic matter management in tropical soils. *Forest Ecology and Management* 106: 205–210.
- Yanda, P. Z. (1995). Temporal and Spatial Variations in Soil Degradation in Mwisanga Catchment, Kondoa, Tanzania. Thesis for Award of PhD Degree at Stockholm University, Sweden. 306pp.
- Zinati, G. M., Li, Y. C. and Bryan, H. H. (2001). Utilization of compost increases organic carbon and its humin and fulvic acid fractions in calcareous soil. *Compost Science and Utilization* 9: 156 – 162.