COMPARATIVE IMPROVEMENT IN SOIL NITROGEN BY FIVE LEGUMINOUS COVER CROPS AT UYOLE AGRICULTURAL RESEARCH INSTITUTE, MBEYA, TANZANIA

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ABSTRACT

The study was carried out on station at Agricultural Research Institute- Uyole and on-farm at Mwandobela during the 2011/12 cropping season. The objective of this study was to improve crop productivity and soil fertility of smallholder farmers through use of five different leguminous cover crops. The study was carried out in two phases. The first phase was aimed at determining biological nitrogen fixation of the cover crops. The second phase was aimed at determining the rate and pattern of nitrogen release from decomposed cover crops under field condition. The field experimental design was a Latin square applying six treatments with six rows and columns. The treatments included *Canavalia ensiformis, Mucuna pruriens, Vigna unguiculata*, *Dolichos lablab*, *Glycine max* and *Zea mays* as reference crops. The decomposition experiment was conducted in a split - split plot with three replications. The main-plot factor were aboveground and underground incubation position; while the cover crops as sub-plot factor and the six sampling periods as sub–subplot. Data for field experiment were plant stand at emergence, plant height, ground coverage, days to 80% flowering, dry matter and nodulation. The results revealed that different legume cover crops have different potential of fixing N_2 and accumulating dry matter. Velvet bean had high N_2 fixing potential (101.9 kg N ha^{-1}) and accumulated high dry matter (19.5 t ha^{-1}) followed by cowpea (50.3 kg N ha^{-1} and 10.5 t ha^{-1}). There was an increasing trend of soil N with time of decomposition. However, faster rates of increasing soil N were observed at 12-15 weeks of decomposition for jack bean (0.09 - 0.13 % N), velvet bean (0.08 – 0.12 % N) and cowpea (0.11 – 0.12 % N) when placed both above and underground position.

DECLARATION

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

_____ _____

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The above declaration is confirmed

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DEDICATION

To my father the late Raphael Lugombo Mwakimbwala and my mother Sabina Martin Mwakababu, who realized that the best inheritance I could be given was to send me to school.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATION AND SYMBOLS

ACT	African Conservation Tillage Network
ANOVA	analysis of variance
ARI	Agriculture Research Institute
ATP	adenosine triphosphate
BACAS	Bureau for Agricultural Consultancy and Advisory Service
BNF	biological nitrogen fixation
C	carbon
CEC	cation exchange capacity
CIAT	Centro International de Agricultura Tropical
	International Center for Tropical Agriculture
cm	centimeter
cm^{-2}	per centimeter square
$cmolc(+)kg^{-1}$	cent mole concentration per kilogram
CV	coefficient of variation
DAP	days after planting
DNA	Deoxy-ribose nucleic acid
E	East
FAO	Food and Agriculture Organization of the United Nations
Fig.	Figure
g	gram
GM	grand mean
ha	hectare
IIRR	International Institute of Rural Reconstruction
kg	kilogram

LCC	legume cover crop
LSD	least significance difference
m	meter
Mc	moisture content
$mgkg^{-1}$	milligram per kilogram
$MJm^{-2}day^{-1}$	mega joules per meter square per day
N	nitrogen
NO_2	nitrogen dioxide
NO_3	nitrate
NTDS	No-Tillage with Direct Seeding
NTHD	No-Tillage with Heavy Disking
OC	organic carbon
OM	organic matter
P	phosphorus
pH	negative logarithm of hydrogen concentration
RCBD	randomized complete block design
RH	relative humidity
RTR	reduced tillage with rotary tiller
s/n	serial number
SADC	Southern African Development Community
SE	standard error
SHT	Southern Highland of Tanzania
SOM	soil organic matter
TSBF	Tropical Soil Biology and Fertility
TSP	triple super phosphate

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

1.1.1 Declining soil fertility

Problems of declining soil fertility are widespread due to continued cultivation of crops and limited replenishment of nutrients, contributing to reduced agricultural yields throughout the world including the Southern African Development Community (SADC) region. Soil fertility in the SADC region has been declining for a long time due to low/non-use of fertilizers (BACAS/SADC, 2008). Bationo *et al*. (2003) reported that nutrient depletion in this region has reduced the potential yields of some crops by two to four times.

Soil fertility is the most important single constraint to crop production. There are a number of factors that contribute to declining soil fertility in Tanzania (Mary and Majule, 2009). Continuous cultivation for many years of smallholder farms with little fertilizer input use, leaching and soil erosion have decreased the soil nutrient reserves to very low levels. Soil fertility depletion occurs mainly when the mining of soil nutrients exceeds their replenishment, resulting in a negative balance of plant nutrients. Mnkeni *et al*. (1992) in a study of farming systems in Tanzania reported that in all cropping systems more nutrients are leaving the system than are being added. Of all the plant nutrients, nitrogen (N) is most commonly deficient in soils (URT, 2000). In Tanzania, annual N depletion rates range from 20 to 40 kg N ha^{-1} (Smaling *et al.,* 1997). Soil fertility assessments in the Southern Highlands of Tanzania (SHT) showed that 77% of agricultural soils have very low to low N content (Malley *et al*., 2012). Nitrogen nutrient is the one most frequently limiting the growth of green plants (Hubbell and Kidder,

2003). These results from the continual loss of N from the reserve of combined or fixed N, which is present in soil and gradually made available for use by plants. The nutrient is continually depleted by many processes including microbial denitrification, soil erosion, leaching, chemical volatilization and removal of N-containing crop residues from the land. Moreover, most plants only utilize less than 50% of fertilizer N applied to the soil and the remaining is subjected to loss (Zhu, 2000; Zhu and Chen, 2002). The N reserves of agricultural soils must therefore be replenished periodically in order to maintain adequate (non-growth limiting) level for crop production. Application of N is therefore critical in order to improve soil fertility and increase food production. Among the strategies that have to be adopted so as to replenish and maintain soil N, include the use of inorganic fertilizers and organic soil amendments (Giller *et al*., 1994). Inorganic fertilizers have long been recognized as the quickest means of replenishing the fertility of soils.

The Ministry of Agriculture and Food Security (MAFS) has released fertilizer recommendations for most crops (Marandu *et al*., 2014). However, adoption of these recommendations has been slow due to high prices of fertilizers (Myaka *et al*., 2003) such that smallholder farmers cannot afford and apply them at recommended rates. Therefore, organic sources of improving soil fertility are becoming an increasingly important option for increasing soil fertility (Robertson *et al*., 2005).

Organic fertilizers including N-fixing plants such as herbaceous plants, woody legumes and leguminous cover crops (LCC) can be used to supplement soil N. The cover crops may be annual, biennial, or perennial herbaceous plants grown in a pure or mixed stands during all or part of the year or season (Sullivan, 2003). The legumes have great potential for improving soil fertility at relatively low cost as compared to chemical fertilizers

(Onim *et al.*, 1990; Chilagane, 1990; Hudgens, 2000). In a study conducted by CIAT (2003) on evaluating the innovation of LCC, farmers observed that use of LCC for improving soil fertility proved to be the most viable technology due to its cost effective, appropriate, simple and multi-purpose nature in meeting the varied needs of resource poor farmers. Moreover, it was reported that the use of LCC and shrubs offered a low input technology for the farmers, as most of them could not afford use of inorganic fertilizers - especially on low value crops like maize. Furthermore, the use of LCC has the potential to improve the chemical and physical characteristics of inherently poor soils (Carsky *et al*., 2001). The improvement of the soil structure helps to reduce the adverse effects of soil erosion and decreasing cation exchange capacity. Hence N_2 fixing legumes are emphasized in the present farming systems (Chivenge *et al.*, 2011). Zahran (1999) reported that symbiotic relationships have evolved between leguminous plants and a variety of N_2-fixing organisms and the contribution of biological N_2 fixation to soil N ranges from 0 to 500 kg N ha^{-1} per season (Peoples *et al*., 2009).

The maximum potential for N_2 fixation values of up to 360–450 kg N ha^{-1} have been suggested by several authors (Giller, 2001; Unkovich and Pate, 2000). Studies conducted in West Africa by Becker and Johnson (1998) reported that jackbean and velvet beans established during the dry season provided significant amount of N_2 to the crop, up to 270 kg N ha^{-1}. Bationo *et al*. (2000) reported that cowpea can fix up to 88 kg N ha^{-1} and this results in an increase of N_2 use efficiency by the succeeding cereal crop from 20% in the continuous cereal monoculture to 28% when cereals are in rotation with cowpea. Furthermore, the use of soil N increased from 39 kg N ha^{-1} in the continuous cereal monoculture to 62 kg N ha^{-1} in the rotation systems. Lablab can fix 15-40 kg N for each 1000 kg dry matter of shoots grown; this will depend upon effectively nodulated legumes, the growth rate of the legume and upon soil conditions (Humphreys, 1995).

However, there is comparatively little quantitative information on the amount of residual N from cover crops that is available to crops succeeding the LCC in rotation (Giller and Wilson, 1993). The current study intends to determine the amount of N fixed by jackbean (*Canavalia ensiformis* L.), velvet bean (*Mucuna pruriens* L.), cowpea (*Vigna unguiculata* L.), lablab (*Dolichos lablab* L.) and soybean (*Glycine max* L. Merril) as cover crops and decomposition rates of these legumes to release N_2 for a subsequent crop in the SHT.

1.2 Objectives

1.2.1 Overall objective

To improve crop productivity and soil fertility of smallholder farmers through use of five different leguminous cover crops.

1.2.2 Specific objectives

i. To evaluate quantities of N_2 fixed by different legume cover crops,
ii. To determine biomass production potentials of the cover crops,
iii. To evaluate the decomposition rate of the leguminous cover crops used in the study for N_2 contribution to soil.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Importance of Nitrogen in Plants

Nitrogen (N) is a vital plant nutrient and a major yield-determining factor required for high crop yields. The element N is the most important nutrient and it accounts for 75% of the crop yield. It is an essential nutrient for plant growth and makes up 1 to 4 percent of plants dry matter. Nitrogen is an important component of many important structural, genetic and metabolic compounds in plant tissues and cell organelles (Brady and Weil, 2002). The element is a major component of chlorophyll, the compound by which plants use sunlight energy to produce sugars from water and carbon dioxide (i.e. photosynthesis). Is a component of protein and nucleic acids such as DNA, the genetic material that allows cells (and eventually whole plants) to grow and reproduce and when N is sub-optimal, growth is reduced (Haque *et al*., 2001). Some proteins act as structural units in plant cells while others act as enzymes, making possible many of the biochemical reactions on which life is based.

Nitrogen is a component of energy-transfer compounds, such as adenosine triphosphate (ATP) which allows cells to conserve and use the energy released in metabolism. It is a necessary component of several vitamins, e.g., biotin, thiamine, niacin and riboflavin. The nutrient is a vital constituent of protein and protoplasm and therefore necessary for biomass increase and reproduction in plants. A good supply of N stimulates root growth and development, as well as the uptake of other nutrients. The nutrient N mediates the utilization of phosphorus (P), potassium (K) and other elements in plants (Brady and Weil, 2002). The optimal amounts of P and K elements in the soil cannot be utilized efficiently if N is deficient in plants. It occurs in all enzymes necessary for proper plant

functions (Sanginga and Woomer, 2009). Therefore N deficiency or excess can result in reduced crop yields. Thus N availability in sufficient quantity throughout the growing season is essential for optimum crop growth.

2.2 Sources of Soil Nitrogen

Soil N exists in two general forms, which are organic and inorganic compounds (Muhammad *et al.*, 2010). Organic N constitutes between 95 to 99% of the potentially available N in the soil is in organic forms, either in plant and animal residues, in the relatively stable soil organic matter (SOM) or in living soil organisms, mainly microbes such as bacteria. The organic form of N is not directly available to plants, but some can be converted to available forms by microorganisms and vice versa through biological decomposition of organic matter (OM). Organic inputs of N in the soil are through organic materials, including farmyard manure, compost manure, green manure and plant residues. The amount of N added to the soil by these organic inputs depends on the quality and quantity of N that the material contains (Kalumuna, 2005). Most of the plant-available N is in inorganic (sometimes called mineral N) NH_4^+ and NO_3^- forms. Ammonium ions bind to the soil's negatively-charged cation exchange complex and behave much like other cations in the soil. The inorganic N accounts for only 1 to 5% of the soil's N content (Brady and Weil, 2002); and it is contained in soluble organic compounds on soil exchange sites in the form that can be taken up and utilized by plants (Gioseffi *et al*., 2012).

Nitrogen can be supplemented in the soil from external sources through organic inputs, biological N_2 fixation (BNF), industrial fertilizers and atmospheric N deposition (Brady and Weil, 2002). The use of cover crop residues and agroforestry are among the

technologies that generate high plant biomass, thereby increasing soil N contents through BNF at relatively lower labour cost (Kalumuna, 2005).

2.3 Biological N_2 Fixation by Legumes

According to Brady and Weil (2002) N is the nutrient that is most commonly deficient, contributing to reduced agricultural yields throughout the world. Molecular N or di-nitrogen (N_2) makes up four-fifths of the atmosphere, but is metabolically unavailable directly to higher plants. It is available to some microorganisms through BNF in which atmospheric N_2 is converted to ammonia by mediation of the enzyme nitrogenase.

Legumes depend on soil mineral N and biologically fixed atmospheric N_2 in meeting their N requirements for growth and production (Buresh *et al*., 1997). Leguminous plants fix atmospheric N_2 by working symbiotically with special bacteria, *Rhizobium*, which live in the root nodules. Legume–*Rhizobium* symbiotic system is the most important biological N_2 fixation (BNF) system in nature (Peoples *et al*., 1995a), providing about 65% of the biosphere's available N (Lodwig *et al.,* 2003) for use in agricultural system. The process of BNF offers an economically attractive and ecologically sound means of reducing external N input and improving the quality and quantity of internal resources (Saikia and Jain, 2007).

2.4 Factors Affecting BNF

The quantities of N_2 fixed vary with legume species and environmental conditions. The most important factors influencing the quantity of N_2 fixed by Rhizobia are soil characteristics, photosynthetic activity, climate and legume management (Tisdale *et al.,* 1993; Hungria and Vergas, 2000).

2.4.1 Soil characteristics

2.4.1.1 Soil chemical properties

Soil acidity

Soil acidity can restrict the survival and growth of Rhizobia (Tisdale *et al.,* 1999). Soils which are acid contain aluminum (Al^{3+}), manganese (Mn^{2+}) and hydrogen ions (H^{+}) which injure Rhizobia and legume roots (Tisdale *et al.,* 1999; Shoko *et al*., 2007). The optimal soil pH for effective BNF is 6 – 7 and anything outside this range (less than 5 or greater than 8) is detrimental to root hair infection, hence limiting nodule development.

2.4.1.2 Soil physical properties

Soil moisture

Soil water influences the growth of soil micro-organisms through processes of diffusion, mass flow, and nutrient concentration. Soil water is related to soil pore space, and soils containing larger pore spaces retain less water. Thus, soil aggregates having smaller internal pore spaces are more favorable environments for the growth of Rhizobia and most soil microbes (Turco and Sadowsky, 1995). Soil-water content also directly influences the growth of rhizosphere micro-organisms, like Rhizobia, by decreasing water activity below critical tolerance limits and indirectly by altering plant growth, root architecture, and exudations (Mohammadi *et al*., 2012). It has been reported by Silveira *et al*. (2001), that water stress has a significant effect on the growth and biological N fixation of the crop. The effect of drought on biological N_2 fixation has been widely reported and is considered to be by far the most important environmental factor resulting in crop yield losses (Marino *et al*., 2007). Hsiao and Xu (2000) reported that a decrease in soil water potential can markedly affect root hair and retard nodule growth and N_2 fixation.

Also environmental stresses are important for LCC growth, nodulation and the activity of the nodules. Literature shows that moisture stress had a profound effect on N_2 fixation of cover crops affecting nodule initiation, growth and activity (Kikafunda *et al*., 2001). Pimratch *et al*. (2010) reported reduction in N_2 fixation by peanut under water stress ranged from 13.0 to 63.9 % between field capacity and 2/3 of the available water. Furthermore, Zahran (2010) found that the dry weight of soybean was not affected by water stress between 50 and 30% of field capacity, although the number and weight of nodules and N_2 fixation were reduced.

Soil Temperature

Soil temperature affects the growth and activities of both N fixing legume plants and bacterial. Legume species show varying tolerance to high temperature in their nodulating abilities. Most of the N fixing bacterial can grow well at temperatures between 25 to 40 ^{o}C (Michiels *et al*., 1994; Zahran, 1999). Higher or lower temperatures inhibit N_2 fixation (Giller, 2001).

2.4.1.3 Soil biological properties

Plant and microorganism interactions in rhizosphere region are very important for plant growth. In the rhizosphere region, Rhizobial activities occur as reciprocal and compulsory interactions (symbiosis) of plant-microorganism (Altieri, 2000; Garcia and Altieri, 2005). One of the important activities related to soil qualities is beneficial microorganism activities. The most important of these activities is a root nodule bacterium which provides to biological N_2-fixation (Ferreira *et al*., 2000). These organisms are important parts of the nature as they reproduce and function properly thus are considerably affected by the environmental conditions (Dogan *et al*., 2007).

2.4.2 Photosynthetic activity

Nitrogen fixation along with photosynthesis as the energy supplier, is the basis of the soil environment under a constant state of change and, as such, can be relatively stressful for both macro and micro-organisms (Mohammadi *et al*., 2012). A high rate of photosynthetic production is strongly related to increased N fixation by Rhizobia (Poppi and Norton, 1995). Climatic factors that reduce the rate of photosynthesis will reduce N fixation. These factors include reduced light intensity, moisture stress and low temperature (Tisdale *et al*., 1999).

2.4.3 Climatic conditions

2.4.3.1 Temperature

Several environmental conditions are limiting factors to the growth and activity of the N_2-fixing plants. Atmospheric temperature influence rate of BNF. Studies carried out in Sweden to investigate the interactive effect of atmospheric temperature and light on BNF found that the efficiency of the N_2-fixing enzyme nitrogenase reaches its maximum near 25 ^{o}C (Vitousek *et al*., 2002; Houlton *et al*., 2008; Gundale *et al*., 2012), and therefore increased mean annual temperatures have a direct positive effect on N_2-fixation rates (Houlton *et al*., 2008).

2.4.3.2 Moisture

Environmental water stresses are also important for Rhizobia growth, nodulation and the activity of the nodules. It has been reported by Silveira *et al.* (2001) that water stress has a significant effect on the growth and BNF of the crop. The effect of drought on biological N_2 fixation has been widely reported and is considered to be by far the most important environmental factor resulting in crop yield losses (Marino *et al.,* 2007). Hsiao and Xu (2000) reported that a decrease in soil water potential can markedly affect root hair and

retard nodule growth and N_2 fixation. Peoples and Herridge (1990) observed that moisture stress had a profound effect on N_2 fixation of soybeans because nodule initiation, growth and activity were more sensitive to water stress than the general root and shoot metabolism; on the other hand water logging in pigeon pea significantly reduced root activity, nodulation, and nitrogenase activity. Typical environmental stresses faced by the legume nodules and their symbiotic partner (*Rhizobium*) may include photosynthate deprivation, water stress, salinity, soil nitrate, temperature, heavy metals, and biocides (Walsh, 1995). For such constraints to be controlled, cover crops can contribute (or fix) substantial quantities of N_2 into the soil. Therefore, a competitive and persistent rhizobial strain is not expected to express its full capacity for N_2 fixation if limiting factors (e.g., salinity, unfavorable soil pH, nutrient deficiency, mineral toxicity, temperature extremes, insufficient or excessive soil moisture, inadequate photosynthesis, plant diseases, and grazing) inhibit on the vigor of the host legume (Peoples *et al.*, 1995b).

2.4.4 Legume management

The amount of N_2 actually fixed by a legume depends also on agricultural practices. Management practices such as the intensity of tillage or intercropping practices alters the edaphic, chemical and biophysical factors and therefore influence BNF indirectly (Montanez, 2000).

2.4.5 Tillage practices

Soil tillage methods have complex effects on the physical, chemical and biological properties of soil. Tillage methods affect directly related with soil microbial activities such as organic matter, soil humidity, temperature and ventilation as well as the degrees of interaction between soil mineral and organic matter. As a result of these effects, significant differences were observed in the population of microbial activities in soil

(Kladivko, 2001; Saggar *et al*., 2001). Dogan and his colleague (2011) when evaluating tillage methods reported that the effect of six different soil tillage methods on some parameters related with N_2 fixation have been investigated. According to the findings of research under no-tillage with direct seeding (NTDS) plots, root weights (6.9 g plant^{-1}), number of nodules (96 number plant^{-1}), weight of nodules (0.318 g plant^{-1}) and root N_2 content (0.71%) were found to be statistically ($p = 0.05$) higher than with the other tillage methods. In the reduced tillage with rotary tiller (RTR) plots, the values of up-root dry weight (51.3 g plant^{-1}), mean nodule weight (3.91 mg nodule^{-1}), root N content (2.38%), are found higher on the lands than in NTDS plots (Dogan *et al.*, 2011).

The results of the study have showed that, parameters of N Rhizobial fixation has been affected negatively by the conventional tillage methods in which 3-5 tillage operations are applied and soil is disturbed. There were differences among the tillage methods and these differences were found to be statistically significant. In general, the best results related with Rhizobial activity have been obtained with NTDS and No-Tillage with Heavy Disking (NTHD). However, other soil tillage methods decreased the N_2 fixation (Dogan *et al.*, 2011). Similar studies have also indicated that zero and reduced soil tillage methods have increased the soil microbial activity and population (Ferreira *et al*., 2000; Alvarez *et al*., 1995).

2.4.6 Fertilization practices

Among other common agricultural practices, fertilization with P and N has an important effect on N_2 fixation. The yield advantages of maize-legume systems over the continuous maize without N fertilizer were from 0 to 135%. In Ethiopia (Jimma) and Tanzania (Tanga), high productivity was obtained from maize following sole legumes. The continuous sole maize yields were 1.95 and 1.48 t ha^{-1} for Jimma and Tanga, respectively.

The fertilizer value of total legume N was estimated to exceed 50 and 69 kg N ha^{-1} that can replace the current need for mineral N fertilizer at Tanga and Jimma, respectively (Bogale *et al*., 2001). Studies on effect of mineral N on N_2 fixation conducted on soybean observed that plots where no N fertilizer was added, the maximum amount of N_2 fixation reached 337 kg ha^{-1} (Salvagiotti *et al*., 2008a, Mohammadi *et al*., 2012).

The amount of N fixed by grain legume such as soybean is affected by colonization of soil Rhizobia (Mabood *et al.,* 2006), and by their interaction with other biological, physical and chemical properties of soil (Goss and de Varennes, 2002; Giller and Cadesch, 1995; Rebafka *et al.,* 1993). These are highly influenced by management practices such as tillage and crop residue application as well as by the spatial-temporal arrangement of the crop components.

2.4.7 Crop residue application

Literature shows that yield responses to incorporated residues were equivalent to those obtained by application of inorganic fertilizer N at a rate equal to two-thirds of the N yield of incorporated crop residue. Likewise, the incorporated residues of alfalfa and red clover were reported to contribute 65 to 71% of their total N content to succeeding maize, an equivalent of 90 to 125 kg N ha^{-1} from inorganic fertilizer. Incorporation of cowpea grown for 60 days as green manure at two weeks before sowing of maize substituted 75 kg ha^{-1} of fertilizer-N requirements for grain maize production (Bogale *et al*., 2001).

2.5 Importance of Cover Crops

Cover crops play a multitude of roles in modern crop management systems. They have direct and indirect effects on soil properties as they promote an increased biodiversity in the agro-ecosystem. They help in building up soil fertility through litter fall, which will be

returned to the soil during decomposition and fixation of atmospheric N_2 (Rao and Suresh, 1999). This potential is achieved through N_2 fixation; nutrient recycling and organic matter build up in the soil. The amounts of N_2 fixed vary between cover crops, different genotypes and different environments in which they are grown (Giller and Wilson, 1993). The ability of LCC to soil N addition is a major benefit, particularly in areas where fertilizer is scarce and expensive. The LCC offer considerable benefits because of their ability to ameliorate soil fertility decline through fixation of atmospheric N_2 and improve the yield of the subsequent crops (Giller *et al*., 1997; Shoko *et al*., 2007). Further, Shoko and Tagwira (2005) noted that cover crops being legumes have the potential to improve soil pH and the availability of OM, exchangeable bases and some trace elements such as Zn and Cu.

Ledgard and Giller (1995) reported that nutrient benefits of integrating legumes into cropping systems (simultaneous intercropping, relay intercropping, rotations and improved fallows), accrue more to subsequent crops after root and nodule senescence and decomposition of fallen leaves. In regions where smaller amounts of biomass are produced like in the dry areas and eroded soils, cover crops are beneficial as they protect the soil during fallow periods, mobilize and recycle nutrients, improve the soil structure and break compacted layers and hard pans, permit a rotation in a monoculture and can be used to control weeds and pests. The LCC assist in controlling pest and pathogen populations, and preserve biodiversity in agro-ecosystems (Lu *et al.,* 2000). For example, Striga population and other weeds were reduced during the legume crop presences. Striga weed population in the subsequent cereal crop indicated that plots previously planted with LCC had low population counts (Onyango *et al*., 2002). The cover crops are also grown to prevent soil erosion by wind and water (Sullivan, 2003). Moreover, they serve as sinks for plant nutrients that might otherwise be lost by volatilization or leaching. The crops

provide weed control through competition and allelopathy. They are also planted to improve water infiltration and sometimes produce food and feed. The LCC when grown in rotation with cereals have the capacity to provide high quality organic inputs to meet N demands of subsequent crops (Carsky *et al*., 1999; Tian *et al*., 1999; Ojiem *et al*., 2000). Hence the crops make up a fundamental component of the stability of the agriculture production system.

2.6 Effect of LCC on Soil Properties

2.6.1 Effect of LCC on physical properties

Cover crops improve soil quality by increasing soil organic matter (SOM) levels through the input of cover crop biomass over time. The SOM plays a central role in mediating the transformation and cycling of nutrients essential to plant growth. It encompasses living microorganisms as well as plant and animal tissues in various stages of decomposition (Craswell and Lefroy, 2001). There are several mechanisms through which SOM regulates nutrient solubility and plant uptake. First, SOM influences the composition, size, and activity of the soil microbial population, which in turn determines the rates at which materials are decomposed and nutrients from those materials are mineralized, or made available for plant uptake (Craswell and Lefroy, 2001). Cover crop biomass acts as a physical barrier between rainfall and the soil surface. The foliage of cover crops reduces the impact of raindrops before they hit the soil surface preventing soil from splashing. This prevents slaking of soil aggregates and sealing of the soil surface. The roots of the cover crops bind soil particles together, improving soil structure and water penetration, while preventing the soil particles from moving (McGourty, 2004). Cover crops break soil hardpans resulting in high infiltration of rain and irrigation water (Deborah, 2001). They prevent erosion as a soil cover while also controlling weeds in cropping systems such as intercropping where bare soil would otherwise be present (Carsky *et al*., 2001).

The addition of OM when legumes are incorporated also improves water infiltration, aggregate stability and moisture retention in soil (Wilson, 2001). McGourty (2004) reported that roots of LCC help aggregate soils as fine roots penetrate the soil profile (especially grasses). The LCC with large tap roots such as *Tephrosia vogelii* help to create macropores when the plants die, and a void is left from the decomposing roots. These macropores greatly assist the movement of air and water into the soil profile. Soil organisms using the decomposing LCC as a food source create waxes and other sticky substances that hold the fine particles into aggregates, lowering bulk density and improving soil tilth. As organic matter increases in the soil, so does the soil's ability to hold water.

2.6.2 Effect of LCC on chemical properties

Besides increasing soil N, decomposed LCC increase the soil cation exchange capacity. Therefore, the ability of a soil to hold and exchange nutrients increases. Additionally, nutrients are often chelated into organic complexes, and are more readily exchanged from these substrates than from inorganic clay minerals. Since many organic growers also use compost, this also adds to the fertility of vineyard soils (McGourty, 2004).

2.6.3 Effect of LCC on biological properties

The living organisms in the agricultural field system play a critical role in its resilience and productivity. They fill ecological niches that sustain the field system. The soil biota are key drivers of biological processes that mediate nutrient cycling, efficiency of plants' water use, and the impact of pests such as insects and disease. Organic matter is a food source for macro and micro-organisms. Many of these organisms assist in recycling cover crops into the soil, while improving soil physical qualities in the process. Particularly noteworthy are increases in earthworm populations; they are a good indicator of soil

health and improved physical conditions. Increased biological activity occurs in the soil after the incorporation of organic matter from LCC. Soil macro and microbial populations mediate the cycling of N in a field system. As living organisms die and return to the soil, microorganisms break down these materials into their components, including organic N. Organic N in the soil is further processed by other species of soil microbes and converted to ammonium, a process called mineralization. In this form, N may be consumed by soil microbes, immobilized but stored in the soil for future use; taken up by plants; or converted to nitrate, which can also be utilized by both microbes and plants. Studies show that these organisms can reduce damage from root pathogens by inhibiting their growth and development (McGourty, 2004).

Cover crops can provide habitat and food for beneficial insects at different stages of their life cycle. They also provide habitat for prey, such as aphids, mites, caterpillars, and other creatures. Research entomologists have a difficult time understanding the dynamics of pest and prey relationships in the cover crop, and their effects on grapevine canopies. Regardless, growers report experiences of reduced leafhopper and mite problems when cover crops are planted in lieu of conventional insecticide applications (McGourty, 2004).

2.7 Contribution of Cover Crops on Soil Nitrogen

The value of legumes in crop systems has long been recognized for their potential to supply a large amount of N to succeeding crops. For example, estimates of the fertilizer-N value of alfalfa to subsequent maize were reported to be as high as 180 kg N ha^{-1} (Bogale *et al*., 2001). Studies on integrated soil management with cover crops (sunnhemp, lablab, and velvet) conducted in Nigeria indicated that the N fertilizer replacement value of legume rotations varied between 6 and 14 kg N ha^{-1} (Carsky *et al*., 1999). Without N application to the test crop, grain yields following legume fallow were 235–265 kg ha^{-1}

higher than after natural fallow. The benefits of a legume fallow to subsequent crops were mostly related to above-ground N of the previous legume (Sanginga, 2003). Growing maize after soybean improves grain yield by 1.2 to 2.3 fold.

Furthermore, combining cowpea or soybean residue with 45 kg N ha^{-1} urea provides maize yields similar to the recommended rate of 90 kg urea-N ha^{-1} on even the poorest fields (Sanginga *et al*., 2001). Further studies when evaluating different winter legumes when used as cover crops reduced N-fertilizer requirements of the following maize, sorghum and cotton crops by 50 to 90 kg N ha^{-1} (Bogale *et al*., 2001). Work at one station in Nigeria indicated that the proportion and amount of N_2 fixed by velvet bean and *Lablab* depended on the cropping systems (live-mulching or *in situ* mulching) and field practices (inoculation with Rhizobia or N fertilizer application). The quantity of N fixed by velvet bean in the N fertilized and Rhizobia inoculated plots ranged from 133 kg to 188 kg N ha^{-1}. In un-inoculated (*Lablab*) plots, the quantity ranged from 146 to 157 kg N ha^{-1}. This represents 64–75% of the plant total N for velvet bean and 62–70% for *Lablab*. Live-mulching increased the proportion of N_2 fixed by 14% (velvet bean) and 20% (*Lablab*). Nevertheless, the amounts of N_2 fixed by both legumes were significantly higher *in situ* than in the live-mulched systems (Sanginga, 2003). The amount of N_2 fixed varied between 76 and 242 kg ha^{-1} depending on the legume species (Sanginga, 2003). Dakora and Keya (1997) suggest that grain legumes fix between 15 - 210 kg N ha^{-1} and that "crop rotation involving legume and cereal monocultures is by far more sustainable than intercropping, the most dominant cultural practice in the continent". Studies conducted in West Africa reported that soybean was able to fix between 44 and 103 kg N ha^{-1} and had a positive N balance of 43 kg N ha^{-1}. In Ghana Ennin-Kwabiah and Osei-Bonsu (1993) reported cowpea fixed between 30 – 125 kg N ha^{-1}.

2.8 Contribution of LCC on Yield of Subsequent Crop

The cover crop root system has the ability to explore a larger volume of the soil profile and is more likely to provide nutrients which cannot be reached and supplied to a subsequent crop. Studies conducted in the northern zone of Tanzania on relay and intercropping of maize and LCC reported significant improvement of maize grain yields in maize-*D. lablab* intercrop compared to the rest of the treatments 4.6 vs 4.3, 4.1 and 2.1 t ha^{-1} for maize- jackbean, maize-velvet bean and maize monocrop, respectively (Tuaeli *et al.*, 2003).

2.9 Cover Crop Decomposition

Cover crop decomposition refers to breaking down of the OM from complex to a simpler form, mainly through the action of fungi and bacteria, or be broken down into smaller or simpler parts. Decomposition also refers to rotting or decaying (Encarta, 2009).

The type of cover crop to grow is influenced by the quantity and quality of mulch it provides (IIRR and ACT, 2005). Broad-leaved cover crops accumulate minerals at high concentrations in their tissue and when they are laid down as no-till mulch, the plant nutrients become slowly available during decay of the mulch (Sullivan, 2003). Rotting of cover crops is mainly determined by its chemical composition carbon to nitrogen (C:N) ratio of the material and on climatic conditions. Determining the ratio of carbon to N in the cover crop biomass is the most common way to estimate how quickly biomass N was mineralized to release nutrients for use by the succeeding crop. As a general rule, cover crop residues with C:N ratios lower than 25:1 will release N quickly. Values exceeding 30 parts carbon to one part N (C:N ratio of 30:1) are generally expected to immobilize N during the early stages of the decomposition process. Legume cover crops such as hairy vetch and crimson clover, when killed at flowering immediately before maize planting;

generally give C:N ratios of 10:1 to 20:1 (Ranells and Wagger, 1992). During the decomposition process some materials will decay fairly fast losing about 50% of their dry matter in 4 – 6 weeks (Wangari and Msumali, 2000). Residues with C:N ratios greater than 25:1 rot more slowly and their N is more slowly released.

2.10 Factors Affecting Decomposition

Residue decomposition is one of the most important processes in the biosphere as it regulates the release of nutrients for plant growth as well as the CO_2 emissions into the atmosphere (Silver and Miya, 2001; Austin and Vivanco, 2006). The rates at which the decomposing legume residues release N has been linked to their structural and chemical characteristics or ‘‘residue quality’’, to the soil physical-chemical and biological activities and to environmental factors such as temperature and moisture (Giller and Cadisch, 1995; Palm *et al*., 2001; Van Veen and Kuikman, 1990).

2.10.1 Residue quality

Under suitable soil moisture and temperature conditions, decomposition process proceeds at a rate dependent upon the quality and quantity of the residues (Myers *et al*., 1994). Quality refers to characteristics of the litter (chemistry and physical attributes) that influence the susceptibility of litter to decomposition (Karberg *et al*., 2008). Litter containing high concentrations of labile compounds (e.g. sugars, amino acids) tends to decompose rapidly because these compounds can be readily metabolized by soil microorganisms or leached. For example, labile structural compounds such as cellulose are quickly cleaved by exoenzymes into sugar sub-units, which again are readily metabolized by microbial organisms. In contrast, recalcitrant structural compounds such as lignin and chitin are too large to pass through cell membranes, and are instead slowly decomposed by aid of extracellular enzymes. Non-systematic chemical structure and

complicated bonding make these compounds difficult for enzymes to attack, providing a slow release of N and P for continued microbial growth (Karberg *et al*., 2008). The quality of an organic material refers to its organic constituents and nutrient content (Mafongoya *et al*., 1998; Cadisch and Giller, 1997). Organic constituents are important because the energy available to decomposer organisms depends on the proportion of soluble C, cellulose and hemicelluloses, and lignin. Soluble C includes metabolic and storage C, and is primarily responsible for promoting microbial growth and activity (Nair *et al*., 1999). Green foliage usually contains 20 to 30% soluble C. Cellulose and hemicelluloses, which constitute 30 to 70% of plant C are structural polysaccharides of intermediate quality; they are attacked by the decomposer microbes after soluble carbohydrates have been depleted (Nair *et al*., 1999).

These specific residue characteristics affecting quality vary by species and even plant part and age. Residue quality indices include ratio of C to N, polyphenol to N, and polyphenols + lignin to N (Mafongoya and Nair, 1997). All these are valid indicators, but each has its own advantages and disadvantages (Mafongoya *et al*., 1997).

2.10.2 Soil physical characteristics

Unfavourable soil moisture conditions such as saturation or inadequate moisture to levels of desiccation can be harmful to some microorganisms, leading to retarded decomposition. Soil moisture governs decomposition and N mineralization by influencing microbial activities involved in this process. Low soil moisture restricts the activities of bacteria involved in nitrification, consequently slowing down the rate of N mineralization. The rate of nitrification increases with adequate soil moisture. The first rains in the season results into a sharp increase in soil NO_3^- levels referred to as nitrate flush (Warren *et al.,* 1997). Under excess soil moisture conditions, when water fills the pore space,

mineralization process ceases and nitrification process dominate, resulting to conversion of NO_3^- and NO_2^- to nitrogenous gases (NO, N_2O and N_2). These gases eventually escape into the atmosphere. This condition normally occurs when the field is water logged, but may also occur after heavy rains due to temporal anaerobic soil conditions (Warren *et al.,* 1997; Brady and Weil, 2002). Increasing temperature from 20 to 60 ^oC will accelerate decomposition because microorganisms are activated. At higher temperatures, actenomycetes out-number bacteria and fungi. At temperatures below 20 ^oC decomposition is slowed. The optimum temperatures are 26 and 50 ^oC for nitrification and ammonification, respectively (Azam *et al.,* 1993).

Adequate supply of oxygen (O_2) is important for respiration of soil microorganisms (decomposers) and for oxidizing NH_4^+ to NO_3^- in the process of nitrification. Inadequate O_2 supply limits N mineralization and favors denitrification. Water stress depresses O_2 uptake and reduces the supply of metabolites required in legume nodules for N_2 fixation, leading to low N accumulation. The condition of inadequate O_2 supply occurs when the soil is water logged and when there is high microbial population (Warren *et al.,* 1997).

2.10.3 Soil chemical characteristics

Soil pH affects N mineralization indirectly as it controls the activities of bacteria responsible in N mineralization processes. A pH range of 5.5 to 7.5 seems to be quite favorable for optimum decomposition rate. As soil pH increases, H^+ ions in solution are reduced by converting more NH_4^+ to NH_3, thus reducing the concentration of NH_4^+. Reduction in concentration of NH_4^+, leads to converting NO_3^- to NH_4^+, hence retarding the process of ammonification and nitrification and favoring denitrification (Brady and Weil, 2002).

2.10.4 Soil biological and environmental characteristics

Legumes contribute to an increased diversity of soil flora and fauna lending a greater stability to the total life of the soil. Faunal community structure is the major factor determining the rate of decomposition (Bohlen *et al*., 1997, Dechaine *et al*., 2005). Where substrate is available, soil microbial activity increases exponentially with soil temperature, with microbial activity often doubling with a 10°C increase in temperature (Kirschbaum, 1995). Soil microbes use the increased N from legumes to break down carbon-rich residues of crops like wheat or maize. Microorganisms can also be limited by soil moisture. As temperatures increase, soil moisture assumes an increasingly important role for maintaining high rates of microbial activity (Peterjohn *et al*., 1994). As a result, rates of litter decomposition increase with both increasing temperature and moisture (Meentemeyer, 1978).

2.11 Some Cover Crops commonly used in SHT and their Potential to Improve Soil Nitrogen

Agricultural Research Institute (ARI) Uyole in the Southern Highlands (SH) of Tanzania has been evaluating the agronomic performance of different cover crops for conservation farming and fertility improvement in the area since 2000. Studies on conservation agriculture by Mkomwa *et al*. (2007) reported that three soil-enriching cover crops, *Mucuna*, lablab and *Canavalia*, contributed to a significant decrease in fertilizer use. However, quantification of the amount of N fixed by particular legume cover crop has yet been done. The research therefore intends to evaluate five leguminous cover crops which include Jack-bean (*Canavalia ensiformis,* L.), Velvet bean (*Mucuna pruriens,* L.), Cowpea (*Vigna unguiculata,* L.), Lablab (*Dolichos lablab,* L.) and soybean (*Glycine max,* L.) for their potentiality in contributing to fixed N_2 in the zone.

2.11.1 Jack bean (*Canavalia ensiformis* L.)

Botanical characteristics

The jackbean is an annual plant, shrub, erect or climbing, 1 to 2 m height and its leaves have a length of 6 to 12 cm, oval - elliptical, white hair with regular density. The plant produces an average of 7 pods linear, slightly curved, 25 to 30 cm long by 3.5 wide capsules. Its seed weight is about 1.5 g which are white and shiny, and measures about 21-22 x 14-15 x 8- 10 mm (Sauer, 1964; Pugalenthi *et al.,* 2010). The flowers are pink-purple in colour. It has deep roots, which makes it drought resistant and can be grown on degraded tropical soils where other legumes will not grow (Akinlade *et al*., 2007).

Agricultural importance

Jackbean grows in poor soils and in areas of low rainfall. However, jackbean produces less biomass than velvet bean and it is not a good weed suppressor. It can yield 5 t ha^{-1} dry matter in 6 months. Agronomic studies in Cuba reported that jack bean produced a total biomass of 5.3 t ha^{-1} (Acosta, 2009). Jackbean is toxic (it contains canavelin) and is used by some communities to control moles (Gachene and Kimuru, 2003).

The cover crop has proven to be a useful species in tropical soil reclamation efforts because its deeply penetrating root system contributes to drought tolerance (Price and Berkelaar, 2005). Studies conducted in Nicaragua by Douxchamps (2010) showed that farmers were attracted to the performance of jackbean due to its vigorous growth, good soil cover and outstanding level of adaptation to drought stress based on green forage yield. Moreover, jackbean is also adapted to a wide range of other stress factors, including low fertility soils (CIAT, 2004; Schmidt *et al*., 2005). Due to its tolerance to shade, jack bean is used in Honduras as a cover crop in association with coffee. It has been reported to fix more than 200 kg ha^{-1} of N $year^{-1}$ (Acosta, 2009).

2.11.2 Velvet bean (M*ucuna pruriens* L.)

Botanical characteristics

Velvet bean is an annual plant with long vines that can reach over 15 m in length. When the plant is young, it is almost completely covered with fuzzy hairs, but when older, it is almost completely free of hairs (Dhawan *et al.,* 2011). The leaves are tri-pinnate and ovate shaped. The sides of the leaves are often heavily grooved and the tips are pointy. The plant bears white or purple flowers, its seed pods are about 10 cm long and are covered in loose orange hairs that cause a severe itch if they come in contact with skin due to protein chemical compounds known as mucunain.

Agricultural importance

Velvet bean grows well in diverse environments, usually producing the highest biomass among cover crops tested (Carsky *et al*., 2001). The crop tolerates low soil fertility, acidic soils, and drought conditions (Weber, 1996), properties which indicates its potential for surviving and producing biomass during the drier part of the year. In Brazil (Burle *et al*., 1992), when velvet bean was grown at the end of the rainy season, it survived a dry season of 4 months (with 10 mm mean monthly rainfall). Velvet bean produced an average of 2.4 t DM ha^{-1}, and continued growing when the rains started. Studies conducted in Uganda by Kaizzi (2006) and his colleagues reported that during 22 week, velvet bean produced 2.6–7.9 t ha^{-1} of dry matter, accumulating 80–200 kg N ha^{-1}, and derived approximately 34–108 kg N ha^{-1} from the atmosphere. Ibewiro *et al.* (2000) in Nigeria reported that velvet bean fixed between 65% and 69% of its N, amounting to 7 to 10 kg N ha^{-1} within 13 weeks in the roots.

Farmers in the northern coast of Honduras use velvet bean with excellent results, producing maize (*Zea mays* L.) yields of about 3,000 kg ha^{-1} more than double their

national average. Sanginga *et al*. (1996) reported that when velvet bean was fertilized with P in West Africa, it accumulated about 166 kg N to 310 kg N ha^{-1} in 12 weeks. They also indicated that velvet bean derived 70% of its N from atmospheric N, representing 167 kg N ha^{-1} 12 $week^{-1}$ in the field. In West Africa, the ability of velvet bean to control a local weed, cotton wool grass (*Imperata cylindrica*), seemed to have a major influence on its adoption (Versteeg *et al*., 1998), indicating that farmer adoption of cover crop technology may not only be based on agronomic yield, but also on other important uses (Becker *et al*., 1995).

Velvet bean has been effective in fixing and recycling N, preventing nutrient loss to the environment (Capo-chichi *et al*., 2002). The velvet bean has been reported to fix up to 150 kg N ha^{-1} as well as produce 35 tons of organic matter per year and, when integrated with maize, can increase grain yields up to 2500 kg ha^{-1} (Bunch, 1990).

When used as a cover crop, velvet bean has a nematocidal effect (McSorley *et al*., 1994) as well as the ability to smother weeds (Fujii *et al*., 1992; Becker and Johnson, 1998; Versteeg *et al*., 1998), particularly broad leaf weeds (Hepperly *et al*., 1992).

2.11.3 Cowpea (*Vigna unguiculata* L.)

Botanical characteristics

Cowpea is an annual legume with trifoliate leaves. There are many cultivars, bred for diverse ecological niches, and they vary greatly in growth habit. Some are short, upright bush types, and others are tall and vine-like. Cowpea grows rapidly, reaching a height of 48–61 cm when grown under favorable conditions. Most root growth usually occurs within the topsoil layer, but in times of drought cowpea can grow a taproot as long as 2.0 m to reach moisture deeper in the soil profile (Valenzuela and Smith, 2002).

Agricultural importance

Cowpea is a legume of African origin that is useful as a rotational cover crop to help meet a cash crop's N needs, to control erosion, and to improve soil properties. Cowpea has a unique ability to fix even in poor soils (pH range 4.5 – 9.0, organic matter less than 0.2% and a sand content of more than 85%. It is also shade-tolerant and therefore, compatible as an intercrop with a number of cereals and root crops, as well as sugarcane and several plantation crops. Used as a cover crop, cowpea also suppresses weeds and can encourage populations of beneficial insects to defend cash crops from insect pests. Its drought tolerance makes it valuable in rainfed agriculture or in unirrigated fallow fields. In soils low in phosphorus, the roots of cowpea develop effective mycorrhizal associations, improving the soil's available P content. Some new cowpea cultivars have been bred especially for the ability to take up soil P, so that it can be made available for following crops (Valenzuela and Smith, 2002).

Its quick growth and rapid ground cover have made cowpea an essential component of sustainable subsistence agriculture in marginal land and drier regions of the tropics, where rainfall is scanty and soils are sandy with little organic matter. At the same time, if early-maturing erect/semi-erect varieties are grown as a pure stand crop with required inputs, cowpea has the potential of yielding as high as cereals on productivity per day basis (Singh *et al*., 1997).

2.11.4 Lablab (*Dolichos lablab* L.)

Botanical characteristics

Lablab is a climbing or erect perennial herbaceous crop often grown as an annual. It grows up to 1 m tall, with long stems in climbing types extending as much as 6 m from the base of the plant. The leaves are trifoliate, and the flowers are purple or white. It has a

strong taproot with many lateral and adventitious roots. It grows rapidly in fertile soil. Both determinate (bush) and indeterminate (vining) varieties exist. It has an approximate growing cycle of 60 days. The fruit is a flat, broad pod, with wavy margins 10 – 12 cm long. When immature, the pods and their nutritious seeds can be eaten (Valenzuela and Smith, 2002).

Agricultural importance

Lablab is a tropical legume that has many uses including human consumption of grain, green manure, and as cover crop. It is mainly grown for food as it is palatable to both animals and humans and is drought tolerant. Over 200 genotypes of lablab are recognized but most of them remain unnamed (Hill *et al*., 2006). In South and Central America, East and West Indies, Asia, China, and India, lablab grain provides a source of protein in the human diet, and the herbage is used as green manure for erosion control and to improve soil fertility for following crops (Hill *et al*., 2006). The beans are edible when green or dry. It produces as much biomass as velvet bean. In the vegetative stages, lablab has 3.0 - 5.8% N in the fresh leaves. It produces 8 t ha^{-1} dry matter in 3.5 months.

It is also popular as a N-fixing plant contributing to soil N and improve soil quality. The level of N fixation from effectively nodulated legumes depends upon the growth rate of the legume and upon soil conditions; usually 15-40 kg N is fixed for each 1000 kg dry mater of shoots grown (Humphreys, 1995). Lablab is a popular choice as a cover crop on infertile, acidic soils, and it is drought tolerant once established. Lablab is fairly drought resistant and re-grows well even in the early part of the dry season following an earlier cut (Weber, 1996). Lablab grows well at altitudes between 0 and 1800 m.a.s.l. Its main disadvantage is its susceptibility to pests and diseases (Gachene and Kimuru, 2003) and is susceptible to root-knot nematode infection (Valenzuela and Smith, 2002).

2.11.5 Soybeans (*Glycine max* L. Merril)

Botanical characteristics

Soybean varies in growth and habit. The height of the plant varies from less than 0.2 to 2.0 m. The pods, stems, and leaves are covered with fine brown or gray hairs. The leaves are trifoliate, having three to four leaflets per leaf, and the leaflets are 6–15 cm long and 2–7 cm broad. The leaves fall before the seeds are mature. The inconspicuous, self-fertile flowers are borne in the axils of the leaf and are white, pink or purple. The fruit is a hairy pod that grows in clusters of three to five, each pod is 3–8 cm long and usually contains two to four (rarely more) seeds 5–11 mm in diameter (Bailey *et al*., 1976).

Agricultural importance

Soybeans are unique among legumes with contents of 40% protein and 21% oil as well as isoflavones. Thus, soybean is the most widely grown protein and oilseed crop in the world (Coskan and Dogan, 2011). Furthermore, soybean improves soil fertility and fixes N in the soil for the succeeding crop. Soybeans have the ability to fix N using the *Bradyrhizobium japonicum* bacteria. The plant can fix about 24 - 168 kg N ha^{-1} (Sanginga and Woomer, 2009). When grown in rotation with maize, it serves as a catch crop in controlling *Striga hermonthica*, a parasitic weed that attacks maize, by causing suicidal germination of *Striga* (Dugje *et al*., 2009). Soybean itself represents 77% of the N fixed by the crop legumes by fixing 16.4 t N annually, fixation by soybean in the U. S., Brazil and Argentina is calculated at 5.7, 4.6 and 3.4 t, respectively (Herridge *et al*., 2008).

CHAPTER THREE

3.0 MATERIALS AND METHODS

The study was carried out in two phases under field conditions. The first phase aimed at the determination of BNF of the 5 legume cover crops (LCC). While the second phase was on decomposition rate and pattern of N release from the 5 LCC.

3.1 Field Experiment

3.1.1 Experimental sites

The study was conducted on-station at ARI-Uyole experimental field and on-farm at Mwandobela sub location in Maramba village Mbarali district. The ARI-Uyole is located in Mbeya region at latitude 08^{o} 56' S, longitude 033^{o} 06 E and 1795 meters above sea level (m.a.s.l.). Mwandobela is located at latitude 08.83586 S, longitude 033.60957 E and 1398 m.a.s.l. Both locations experience a mono/unimodal rainfall pattern between Novembers to May ranging from 650 to 2200 mm with an annual average of 1500 mm. Temperature ranges from 15 – 18 ^{o}C and 22 – 28 ^{o}C for ARI-Uyole and Mwandobela, respectively. Soils at Mwandobela are brownish loams (Haplic Andosol) while at ARI Uyole they are deep brown sandy clay loam (Mollic, Andosol. Vitric Haplic). Natural vegetation is savannah tropical wooded grasslands and tropical forests and mountainous grasslands- most cleared for agriculture at Mwandobela and ARI-Uyole respectively (Mussei *et al*., 2013).

3.1.2 Weather

Weather data were recorded at ARI –Uyole meteorological station including rainfall (mm), maximum, minimum and grass temperature (^{o}C), relative humidity (RH %) and

radiation ($MJm^{-2}day^{-1}$) under field experiment. While at Mwandobela only rainfall (mm) data was recorded.

3.1.3 Soil sampling

Soil samples were collected at three stages; first stage was done before setting the experiment, second at 80% flowering of LCC and third was after decomposition for different soil properties as described below.

3.1.3.1 Soil sampling for site characterization

Composite soil sample for site characterization was collected in December 2011from the experimental sites two weeks before setting the experiment. Twenty five and thirty samples were collected from ARI-Uyole and Mwandobela, respectively at 0 - 20 cm depth in a zig zag way as described by Pleysier (1995). The samples were air dried ground and passed through a 2 mm sieve before analysis. Soil chemical and physical properties were determined at ARI-Uyole soil laboratory using analytical methods presented in Table 1.

Table 1: Soil physical and chemical properties analytical methods

Properties	Character	Unit	Method	Source
Physical	Clay, Sand and Silt	%	hydrometer	Anderson and Ingram (1993).
Chemical	pH S:W of 1:2.5		pH meter	McLean, 1982
	OC	%	Walkley and Black	Nelson and Sommers 1982
	Total N	%	Micro-Kjeldahl digestion-distillation	Bremner and Mulvaney, 1982
	Extractable P	mg kg^{-1}	Bray 1	Olsen and Somners 1982

3.1.3.2 Soil sampling at 80% flowering

Soil mineral N and pH were determined in the soil sampled from LCC plots at harvest. Samples were collected from 0 – 5 cm depth. Three points each from six plots were diagonally sampled from the net plot areas and mixed to one sample per legume specie. The samples were packed in polythene bags and subsequently taken for laboratory analysis.

3.1.3.3 Soil sampling after decomposition

Soil samples from decomposition experiment were collected from 0 – 2.0 cm depth below each litter bag at each sampling time (3 weeks incubation). The samples were packed in polythene bags and subsequently taken to the laboratory for soil N determination.

3.1.4 Experimental materials

Five LCC namely jack bean, velvet bean, cowpea, lablab and soy bean var. Bossier seeds were obtained from ARI-Uyole. The selection of cover crops was based on their performance at ARI-Uyole (ARI, 2002). Maize variety UH 615 was used as a non – biological N fixing crop and triple super phosphate (TSP 46% P_2O_5).

3.1.5 Experimental methods

Experimental design, treatments and treatment allocation

To increase precision at the site the field experimental design was a Latin square (LSD) applying six treatments laid out with six rows and six columns (Clewer and Scarisbrick, 2001). The treatments included (i) reference crop that was pure stand of maize, while other treatments were (ii) velvet bean, (iii) jackbean, (iv) lablab, (v) cowpea and (vi) soya bean. Treatment allocation was done using randomization process described by Gomez and Gomez, (1984).

3.1.6 Agronomic practices

3.1.6.1 Land preparation

Tillage was done 7 days before planting using a power tiller and animal drawn plough at ARI-Uyole and Mwandobela, respectively.

3.1.6.2 Planting

Planting was done on 24 December 2011 at ARI-Uyole and on 30 December 2011 at Mwandobela village. The plot size used was 4.5 x 3.75 m. Cowpea, lablab, velvet bean, Jackbean and maize were sown at a spacing of 0.75 x 0.3 m whereas Soybean was planted at spacing of 0.5 x 0.1 m. Three seeds of cowpea were sown per hill; whereas two seeds of lablab, velvet bean, jackbean, soybean and the reference crop were sown per hill. Triple superphosphate (TSP 46% P_2O_5) fertilizer was applied by banding at planting at the rate of 60 kg P per hectare (Mkoga *et al.*, 2010) for cover crops and maize.

3.1.6.3 Thinning

All plots were thinned to one plant per hill two weeks after seedling emergence.

3.1.6.4 Weeding

Plots were weeded twice during the season; the first weeding at 21 DAP and then 43 DAP using hand hoe between rows and uprooting by hand within the rows to ensure all plots are free of weeds.

3.1.6.5 Insect and disease control

Insect control was done regularly depending on the occurrence using Selecron (Profenofos) 720 g l^{-1} at the rate of 25 ml in 15 l of water. Diseases were controlled twice by applying Rido Super 72 WP (Mencozeb 64 + Metalaxyl 8%WP) at the rate of 25 - 30

g 10 l^{-1} of water (Kanyeka *et al*., 2007). The application of insecticide and fungicide was done using a knapsack sprayer.

3.1.7 Data collection

3.1.7.1 Crop growth variables

Data collected for cover crops included plant stand at emergence, plant height (cm), ground coverage (%), days to 80% flowering, dry matter yield and nodulation. Data collected for maize crop was dry matter for N determination. All the variables were assessed at 80% flowering of the cover crops except for percent emergence.

3.1.7.2 Plant stand at emergence (%)

This was done by counting emerged seedlings from the three central rows and calculated its percentage from the total expected plants. For cover crops records was collected at first true leaf (VE) as described by Lafitte, 1993.

3.1.7.3 Plant height (cm)

Plant height (cm) was determined by measuring the height from the soil surface to the tip of the shoot using a 5 meter steel tape measure and mean value from five plants determined.

3.1.7.4 Ground coverage (%)

Ground coverage of all cover crops was determined using 0.5 x 0.5 m wooden quadrant per plot as described by Chikoye (1999). A quadrant graduated by nylon string into 25 squares each with 10 x 10 cm was thrown randomly three times per plot. The square covered by the respective cover crop species was counted and calculated to obtain % ground coverage.

3.1.7.5 Days to 80% flowering of cover crops

Days to 80% flowering of cover crops was determined by counting the number of days from planting to when the cover crop plants had flowered at about 80% of the population.

3.1.7.6 Dry matter yield (t ha^{-1})

Dry matter yield for cover crops was collected using a 0.5 x 0.5 m quadrant by harvesting the above ground parts by randomly throwing three times per plot. All the plant parts in the quadrant were harvested sorted to remove unwanted materials and sent to the laboratory for DM determination as described by Peoples *et al*. (1989). After drying the samples at 65 ^{O}C for 48 h the materials were weighed using AND Balance model EK-12KA®. The cover crop materials were then taken for decomposition experiment.

Three randomly selected maize plants from middle rows from each plot were harvested by cutting 2-3 cm above ground parts to ground level at the time corresponding to 80% flowering of the respective cover crop to determine N content. The samples were brought to laboratory, dried to constant weight at 65 ^{O}C for 48 h and weighed. The total N content was determined using the micro Kjeldahl method after the dried samples being powdered using Wiley mill and sieved with 1 mm sieve.

3.1.7.7 Nodule assessment

Four randomly selected plants from each plot of cover crop were dug out for nodule analysis. The analysis included nodule count, effective nodule, nodule score and nodule weight. The process involved watering before loosening the soil around the plants to a reasonable depth using a hand hoe and a sharpened peg making sure their roots were not disturbed. The plants were then pulled out gently and washed by soaking in a half filled bucket. The nodules were removed and those that fell off during the process of washing

were added and counted. Nodule score was assessed using the scale described by Corbin *et al*. (1977) and Peoples *et al*. (1989) and their effectiveness were carried out qualitatively by visual observation of cross sections of the nodules. A pinkish or red color was used to indicate the effective nodules as described by Corbin *et al*. (1977) and Peoples *et al*. (1989). Nodule weight per plant was assessed by putting the nodules in the paper bags and oven-dried at 65 ^{o}C for 48 h after which they were weighed.

3.1.8 Laboratory nitrogen analysis

After sample grinding, 0.3 g of plant material and 1 g for soil each were mixed with 20 ml concentrated sulfuric acid (H_2SO_4) and mixed with catalyst (salt mixture of K_2SO_4, Cu_2SO_4•$5H_2O$, Se; at the ratio of 1:0.1:0.01 for soil while for plant Se is omitted), and digested in a block digester (model Gerhardt Kjeldatherm) for two hours. During digestion the temperature used ranged from 280 – 320 ^{O}C and 320 – 420 ^{O}C for plant and soil samples, respectively. After cooling, the mixture was distilled using the Kjeltic Auto Distillation unit (Gerhardt Vapodest) and catalyst (NaOH), 15ml mixture of 4% boric acid, methyl red and bromocresol green were used to trap ammonia. The quantity of ammonia was determined by titration with standard 0.05 N H_2SO_4 and the concentration of total N in the sample were calculated as shown below and described by Bremner and Mulvaney (1982).

N % = 14/1000 * 0.05 * Volume of acid used/ Sample weight.

3.1.9 Estimation of N fixation by nitrogen difference method (NDM)

Dried plant shoots (of each plant sample) were ground and the total N content was determined by the micro Kjeldahl method. Determination of N_2 fixation (kg ha^{-1}) by individual leguminous cover crops (N-fixing) at flowering stage and of maize (non-N-

fixing) as reference crop was estimated using the steps as described by Peoples *et al.* (1989).

%N from N_2-fixation = 100 x [(Ntfp – Ntnp)/Ntfp])…….(1)

This method is based on the assumption that the N_2-fixing crop and the non-N fixing crop assimilate identical amounts of soil N.

Where:

Ntfp = is total N in the N_2-fixing legume plant

Ntnp = is total N in the non-N_2-fixing reference plant

Therefore, Ntnp: mean N yield of maize was recorded during harvesting of each cover crop *spp*. Quantities of N_2-fixed was calculated using %N from N_2-fixing as:

N fixed ($kgha^{-1}$) = {(%N from N_2 fixation) /100} x weight of legume biomass……...(2)

Recent studies have indicated that nodulated roots of legume plants contain substantial amount of fixed N and that the proportion varies with species (Unkovich and Pate, 2000). In this study, no attempt was made to estimate the fixed N in roots of the studied legumes.

3.1.10 Data analysis

Data analysis was done using the following linear statistical model as described by Snedecor and Cochran (1984) at $P < 0.05$.

$y_{ij} = \mu + pi + yj + \tau_k + eij$ ……...(3)

Where:

y_{ij} = is the observation on the experimental unit in the i^{th} row and j^{th} colum of the design

μ = experimental mean

pi = row effect

yj = colum effect

τ_k = is the effect of k^{th} treatment

eij = random error

Means were compared using DMRT at 5% level of probability and GenStat (2007) Forth Edition statistical software was used to assist the analysis.

3.2 Decomposition Experiment

3.2.1 Site preparation and experimental materials

Within an experimental site an area was set aside for incubation process. The dried shoot materials of LCC from field experiment were used for incubation.

3.2.2 Experimental methods

Experimental design, treatments and treatment allocation

The experiment was conducted as a split - split plot (RCBD) with three replications. The main-plot factor were aboveground and underground incubation position; while the five LCC as sub-plot factor and the six sampling periods (retrieval) at an interval of three weeks as sub–subplot factor. Six samples in litter bag (3 from above ground and 3 underground main-plots) from each species were randomly drawn at three weeks intervals and analyzed for N content. Also samples of soil below each litter bag were collected for N analysis.

Twenty grams of dried shoot materials were filled into a 20 x 20 cm litterbag as described by Karberg *et al*. (2008). The samples were incubated on the soil surface (aboveground) and below the soil surface (underground) at sample distance of 20 cm and the depth of 0-15 cm. The distance separating one type of cover crop biomass to another in the decomposition experiment was 40 cm. A total of 360 samples (6 sampling times x 6 samples per cover crop x 5 cover crops x 2 sites) were incubated. Irrigation was done twice a week using a watering can. Samples in litter bag were drawn at 3, 6, 9, 12, 15 and 18 weeks after incubation. The collected samples were packed into paper bags and sent to the laboratory for N analysis as described by Pandey and Ray (2007).

3.2.3 Data collected

The collected data included N content from five LCC tissues at each sampling time and soil N (%).

3.2.4 Data analysis

The general linear equation used for analysis as described by Clewer and Scarisbrick (2001) was as follows;

$$Y_{ijkm} = \mu + \beta_i + A_j + \delta_{ij} + B_k + AB_{ik} + \omega_{ijk} + C_m + AC_{im} + BC_{km} + ABC_{jkm} + \varepsilon_{ijkm} \ldots\ldots\ldots (4)$$

Where:

Y_{ijkm} =Response level

μ =General effect

β_i =Block effect

A_j = Main plot effect

δ_{ij} = The main plot random error (Error a)

B_k =Sub-plot effect

AB_{ik} = Interaction effect between the main-plot and the subject

ω_{ijk} = Subject error (Error b)

C_{m} =Sub-sub-plot effect

AC_{im} =Interaction effect between main-plot and the sub-sub-plot

BC_{km} = Interaction effect between sub-plot and the sub-sub-plot

ABC_{jkm} = the three way (Factor A*B*C =Interaction effect between main-plot, sub-plot and the sub-sub-plot)

ε_{ijkm} = Sub-sub-plot random error effect (error c)

Means were compared using DMRT at 5%.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Field Experiment

4.1.1 Weather

The amount of rainfall received during the study was unevenly distributed at both sites. At ARI-Uyole rainfall amount was 338.3 and 26.8 mm in December 2011 and April 2012, respectively. At Mwandobela rainfall amount was 138.9 and 16.7 mm in February and May 2012, respectively. During the cropping season the frost occurred once at ARI-Uyole and at Mwandobela ice rain occurred twice. At ARI-Uyole monthly maximum air temperature was 25.3 and 21.2 ^{O}C in October 2011 and July 2012, respectively, while minimum air temperature was 14.3 and 6.2 ^{O}C in January and July 2012, respectively. Mean ground temperature was 13.0 and -3.5 ^{O}C (frost) in January and July 2012, respectively. The mean relative humidity was lowest in October and November (30%); and highest in January (62%). The Radiation was lowest (14.7 $MJm^{-2}day^{-}1$) in January and highest in June (19.0 $MJm^{-2}day^{-1}$) as shown in Fig. 1 and 2.

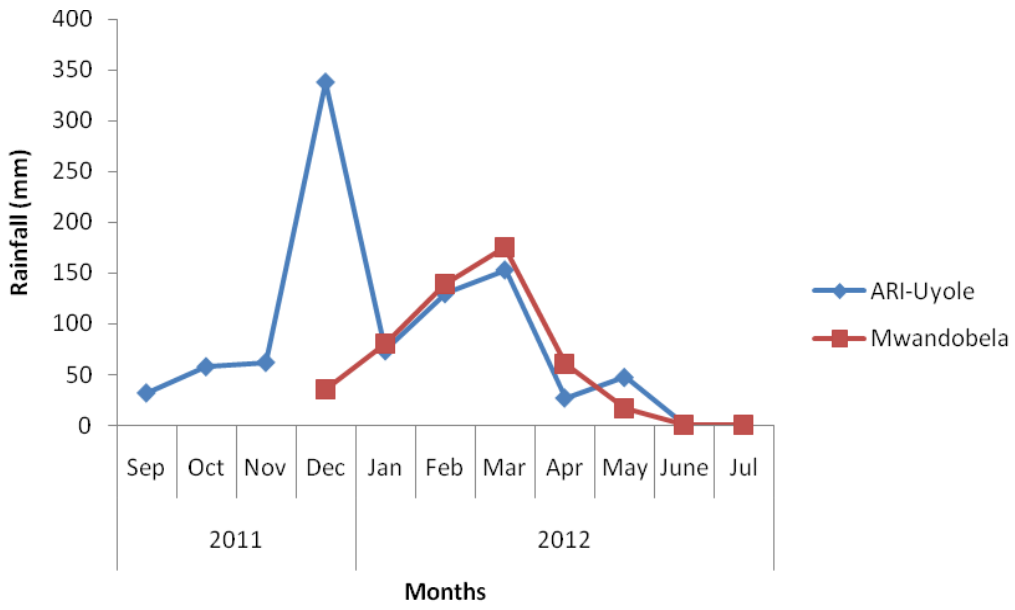

Figure 1: Rainfall at ARI-Uyole and Mwandobela for season 2011/2012

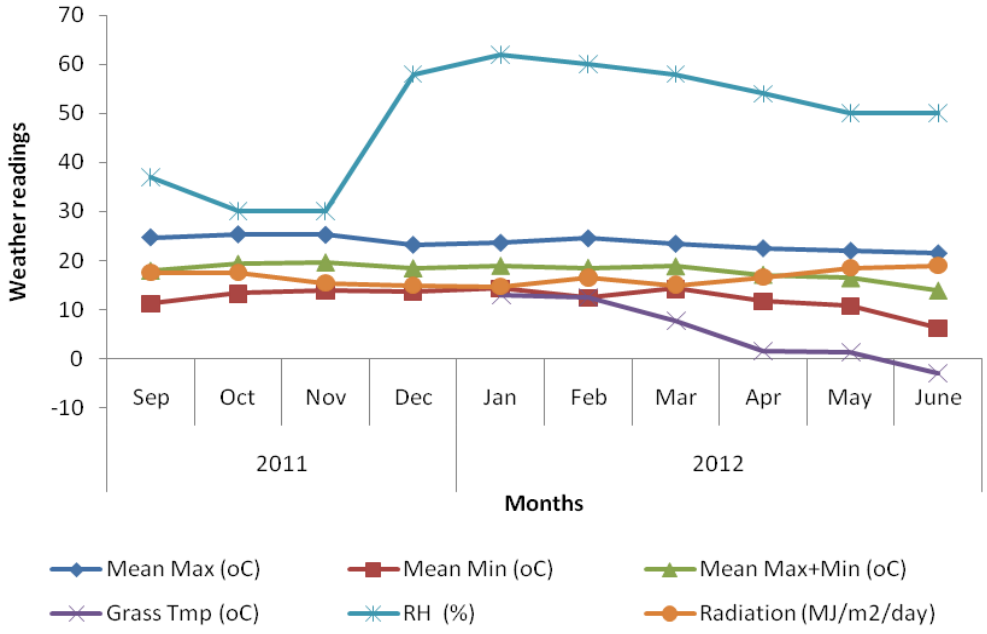

Figure 2: Weather trends at ARI-Uyole for 2011/2012 season

4.1.2 Soil analytical results

4.1.2.1 Site characterization

The soil analytical results were interpreted based on Landon (1991) descriptions. Soil characteristics of the experimental sites before planting the LCC are shown in Table 2. Particle distribution of the soil at 0 – 20 cm depth was 30.8% clay, 44 % sand and 25.2% silt; and 20.08% sand, 49.6% clay and 30.32% silt for ARI-Uyole and Mwandobela, respectively. The soils were classified as sandy loam and sandy clay loam for ARI-Uyole and Mwandobela, respectively. The sites had medium pH (water) and cation exchange capacity; and very low N and organic C for both sites. ARI-Uyole had moderate extractable P while Mwandobela had low P.

Table 2: Soil characteristics before planting of LCC at ARI-Uyole and Mwandobela

Parameter	Unit	ARI-Uyole		Mwandobela	
		Value	Rating	Value	Rating
Physical properties					
Clay	%	30.8		20.1	
Sand	%	44.0	sandy loam	49.6	sandy clay loam
Silt	%	25.2		30.3	
Chemical properties					
Soil pH (1:25) H_2O	pH	6.51	Medium	6.02	Medium
Total N	%	0.04	Very low	0.02	Very low
Organic Carbon	%	0.18	Very low	1.28	Very low
Extractable P	$mgkg^{-1}$	17.04	Moderate	11.97	Low
CEC	($cmol_c$ (+) kg^{-1}	10.31	Medium	13.63	Medium

4.1.2.2 Soil analytical results at 80% flowering

Table 3 shows soil N and pH before planting and at 80% flowering of LCC at the study areas. Results show that there was an improvement in % N from 0.04 to a range of 0.08 (100 %) to 0.1 (150 %) at ARI-Uyole and from 0.02 to 0.08 (300 %) at Mwandobela. There was a drop in soil pH from 6.51 to a range of 5.7 to 5.9 at ARI-Uyole and from 6.02 to a range of 5.6 to 5.9 at Mwandobela as a result of planting LCC.

Table 3: Soil pH and N before planting and at 80% flowering of LCC at ARI-Uyole and Mwandobela

	Cover crop	ARI-Uyole			Mwandobela		
		pH	% N	% N increment	pH	% N	% N Increment
Before planting		6.51	0.04		6.02	0.02	
At 80% flowering	Jackbean	5.8	0.08	100	5.9	0.08	300
	Velvet bean	5.7	0.09	125	5.6	0.08	300
	Cowpea	5.9	0.09	125	5.7	0.08	300
	Lablab	5.9	0.09	125	5.7	0.08	300
	Soybean	5.9	0.10	150	5.8	0.08	300

4.1.3 Growth parameters of the different cover crops

4.1.3.1 Crop emergence (%)

Table 4 indicates the comparison between cover crops on crop emergence, plant height, ground coverage and at 80% flowering. Significant effect ($p \leq 0.05$) of LCC at both sites as indicated in Table 4. At ARI-Uyole there were significant differences ($p<0.05$) among plants at emergence. The highest emergence (93.5 %) was recorded on plots with cowpea followed by lablab (92.8%), velvet bean (89.7 %), soybean (85.7%) and lastly was jackbean (68.8 %).

Table 4: Effect of LCC on emergence, plant height, ground coverage and days to 80% flowering for LCC at ARI-Uyole and Mwandobela

Cover crop	ARI-Uyole				Mwandobela			
	Emergence (%)	Plant height (cm)	Ground coverage (%)	Days to 80% flowering	Emergence (%)	Plant height (cm)	Ground coverage (%)	Days to 80% flowering
Jackbean	68.8 b	58.4 b	62.3 c	101	77.5 c	62.1 b	78.4 b	80
Velvet bean	89.7 a	70.3 a	100.0 a	137	85.8 b	70.5 a	100.0 a	126
Cowpeas	93.5 a	49.8 c	87.4 b	131	95.8 a	39.3 c	99.5 a	112
Lablab	92.8 a	57.9 b	97.7 a	88	95.3 a	59.1 b	99.7 a	76
Soybean	85.7 b	45.9 d	80.0 b	76	75.2 c	42.1 c	71.2 b	59
Grand mean	**87**	**78.7**	**82.6**	**106.6**	**82**	**70.07**	**82.9**	**90.6**
CV (%)	9.1	11.2	7	1.01	7.4	12.1	9.5	18.9

Means in the same column followed by the same letter are not statistically different ($p<0.05$) by Duncan's New Multiple Range Test.

At Mwandobela there were significant differences ($p<0.05$) among plants at emergence. Cowpea recorded the highest with 95.8 and lablab with 95.3%. The emerged plants were followed by plots with velvet bean (85.8 %), jackbean (77.5%), and soybean (75.2%).

4.1.3.2 Plant height (cm)

The tallest plants were recorded in plots with velvet crop having 70.3 and 70.5 cm at ARI-Uyole and Mwandobela sites, respectively. At ARI-Uyole soybean recorded the shortest (45.9 cm) while at Mwandobela soybean and cowpea had plant height of 42.12 and 39.29 cm, respectively. Plant height variation was attributed mainly to differences in plant species.

4.1.3.3 Ground coverage (%)

Results show significant differences ($p \leq 0.05$) among LCC on ground coverage. Velvet bean and lablab had the highest ground coverage of 100.0 and 97.7% at ARI-Uyole, respectively; whereas jackbean had the lowest ground cover of 62.3%. At Mwandobela the highest ground cover was recorded by velvet bean (100%), lablab (99.7%) and cowpea (99.5%) whereas jackbean (78.4%) and soybean (71.2 %) recorded the lowest ground cover. These results agree with the findings by Carsky *et al*. (2001) who reported that ground coverage development increased with time of cover crops in the field and velvet bean species recorded the highest 100% ground cover in 60-90 days after planting in West Africa. Furthermore, Carsky *et al*. (2001) found out that velvet bean physically protected soil from raindrop impact and prevented surface soil compaction, thus reducing rain water runoff and soil erosion.

Table 5: Effect of LCC on nodule assessment, N content, dry matter and fixed N at ARI-Uyole and Mwandobela

Cover crop	ARI						Mwandobela					
	Nodule number	Effective nodule	Nodule score	N content (%)	Dry matter (t ha $^{-1}$)	Fixed N (kg ha $^{-1}$)	Nodule number	Effective nodule	Nodule score	N content (%)	Dry matter (t ha $^{-1}$)	Fixed N (kg ha $^{-1}$)
Jackbean	0.6 c	0.2 b	0.1 b	4.7 b	5.7 c	27.0 c	1.1 a	0.1 b	0.1 b	4.8 c	6.1 c	29.5 c
Velvet bean	10.9 a	5.1 a	1.7 a	5.1 a	21.4 a	108.0 a	14.1 a	5.3 a	1.0 b	5.5 a	17.7 a	95.9 a
Cowpea	8.2 a	3.0 a	1.0 a	4.5 c	11.6 b	52.2 b	17.5 a	5.7 a	1.8 a	5.1 b	9.5 b	48.4 b
Lablab	3.8 b	0.1 b	0.3 b	4.7 b	6.6 c	30.7 c	5.4 a	1.8 b	0.7 b	4.3 d	8.2 b	34.9 c
Soybean	3.4 b	0.3 b	0.2 b	3.9 d	4.7 d	18.5 c	21.3 a	5.5 a	1.6 a	4.6 c	5.2 c	24.0 d
Grand mean	**5.38**	**1.74**	**0.66**	**4.58**	**10.0**	**47.28**	**11.88**	**3.68**	**1.04**	**4.86**	**9.34**	**46.5**
CV (%)	19.1	12.9	10.8	10.2	12.2	18.4	19.3	16.0	14.7	4.2	13.2	6.2

Means in the same column followed by the same letter are not statistically different ($p<0.05$) by Duncan's New Multiple Range Test.

4.1.3.4 Days to 80% flowering of cover crops

Number of Days to 80% flowering of cover crops did not show significant differences ($p < 0.05$) between sites. Velvet bean took 137 days to 80% flowering at ARI-Uyole and 126 days at Mwandobela while soybeans took 76 days at ARI-Uyole and 59 days at Mwandobela. The non significant effect observed on number of days to 80 % flowering of LCC could be attributed to the difference in altitude between the two sites. Since ARI-Uyole is at higher altitude (1795 m.a.s.l) it experienced cooler temperature (17 ^{O}C), which increased the number of days the LCC to flower (106 days). On the other hand, Mwandobela located at medium altitude (1398 m.a.s.l) experienced relatively warmer temperature (26 ^{O}C) resulting the cover crops to attain 80% flowering relatively much earlier (90.6 days).

4.1.3.5 Nodule assessment

4.1.3.5.1 Nodule number

At ARI-Uyole, velvet bean recorded the highest number of nodules and the differences were significant ($p \leq 0.05$) compared with the rest of LCC except cowpeas. On the other hand jack bean significantly produced the lowest number of nodules compared with all the other LCC. At Mwandobela, there were no significance differences among the LCC in number of nodules.

4.1.3.5.2 Effective nodule

At both sites, there were significant differences among LCC in effective number of nodules. At ARI-Uyole the highest number of effective nodules was observed in plots with velvet bean (5.1) followed by cowpea (3.0), soybean (0.3) and lablab (0.2). The least number (0.1) was observed with jackbean. At Mwandobela, the highest numbers of effective nodule was observed in plots with cowpea (5.7), followed by soybean (5.5),

velvet bean (5.3) and lablab (1.8). The least number was observed on plots with jackbean having 0.1 and differences were significant ($p \leq 0.05$) when it was compared with the other LCC except Lablab.

4.1.3.5.3 Nodule score

The highest nodule score at ARI-Uyole was recorded on plots with velvet bean (1.7) followed by cowpea (1.0), lablab (0.3) and soybean (0.2). The least was jackbean which recorded 0.1. At Mwandobela site the highest were observed on plots with cowpea (1.8) followed by soybean (1.6), velvet bean (1.0) and lablab (0.7). The last reading was recorded on plots with jackbean at 0.1.

Cowpea resulted in higher (2.8) nodule score in both sites followed by velvet bean (2.7). Jackbean recorded the lowest (0.2) nodule score at both sites. Similar fidings were reported by Kikafunda *et al*. (2001), in which the author observed few effective nodules on jackbean. The results from this study indicate that soybean produced high number of effective nodules at Mwandobela and lowest at ARI-Uyole. The findings at Mwandobela are in agreement with observations made by Ojiem *et al.* (2007).

4.1.3.6 Nitrogen content (%)

Significant difference ($p<0.05$) among LCC studied was observed for N content. The results from ARI-Uyole showed that highest N concentration was recorded in plots with velvet bean (5.1%) followed by jackbean (4.7%), lablab (4.7%) and cowpea (4.5%). The least N content was recorded from soybean at 3.9%. However, at Mwandobela the highest were recorded in plots with velvet bean (5.5%) followed by cowpea (5.1%), jackbean (4.8%) and soybean (4.6%). The least reading was observed on plots with lablab at 4.3%.

The percentage N content from plant materials is associated with dry matter production and subsequently total amount of N fixed by the LCC.

4.1.3.7 Dry matter

Highly significant effects ($p \leq 0.001$) among LCC in dry matter accumulation were observed at both sites and velvet bean produced the highest biomass. The dry matter yield of legume at ARI-Uyole was found to be higher on plots with velvet bean (21.35 t ha^{-1}), followed by cowpea (11.57 t ha^{-1}), lablab (6.57 t ha^{-1}) and jackbean (5.71 t ha^{-1}). A similar trend was observed at Mwandobela Table 5. At both sites, soybean produced the lowest dry matter accumulation. High dry matter production observed in velvet bean materials was also associated with long time spent by the crop in the field before attaining 80% flowering. Eilitta *et al*. (2002) reported that velvet bean has the capacity to establish ground cover rapidly, produce large amount of above ground biomass and accumulate nutrients with consequent beneficial impacts on main crop yield in various environments.

4.1.3.8 Fixed nitrogen

The quantities of N_2 fixed by the LCC are presented in Table 5. At ARI-Uyole the highest amount of fixed N was observed on plots with velvet bean followed by cowpea, lablab and jackbean at 108.04, 52.24, 30.78 and 27.02 kg N ha^{-1}, respectively. The least fixed N was observed on plots with soybean at 18.45 kg N ha^{-1}. At Mwandobela site the highest reading was recorded with velvet bean followed by cowpea, lablab and jackbean at 95.85, 48.39, 34.93 and 29.53 kg N ha^{-1}, respectively. The lowest fixer was soybean fixing 24.01 kg N ha^{-1}.

4.1.3.9 Performance of LCC on N content, dry matter and fixed N_2 across location

Results on studied LCC across location showed that velvet bean had high N content (5.3%), high dry matter (19.5 t ha^{-1}) and accumulated high fixed N (101.9 kg N ha^{-1}) followed by cowpeas, lablab, jackbean and lowest was soybeans (Figures 3-5). The results obtained conquer with findings by Mullen (1999) who reported that well-nodulated LCC can fix around 20 to 140 kg residual N ha^{-1} in the soil which is equivalent to 50–300 kg urea fertilizer ha^{-1}. Velvet bean accumulated high dry matter followed by cowpea and least was soyabean. The N content was almost similar for all studied LCC Fig. 3. The fixed N_2 in velvet bean is dependent on biomass levels. The results are similar to the findings by Buckles *et al.* (1998). The results show significant differences ($p \leq 0.05$) among LCC in the amount of N fixed. Similar results were reported by Dakora and Keya (1997) who found that legumes can fix between 15 and 581 kg N ha^{-1}. Velvet bean produced the highest amount whereas soybean produced the lowest amount of fixed N from both sites. These findings are contrary to results reported by Salvagiotti and colleagues (2008b). The authors found the amount of N_2 fixed by soya averaged 61–152 kg N ha^{-1}. Similarly, results from this study on N fixed by jackbean contradict findings by Bayorbor *et al.* (2006) in Ghana who found that jack bean fixed 187.24 kg N ha^{-1} when evaluating some herbaceous legumes for use in rice.

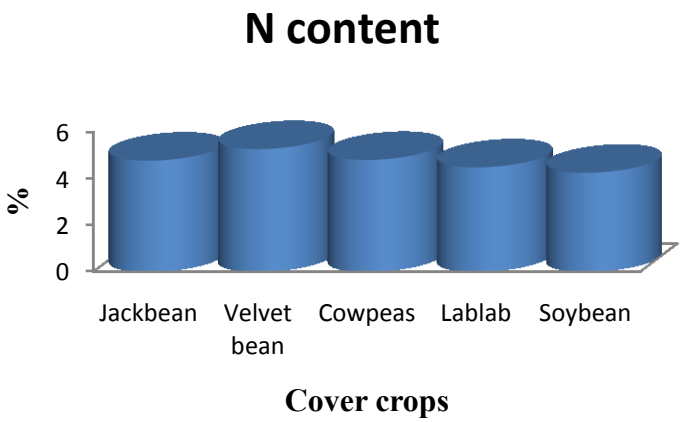

Figure 3: Performance of LCC on N content (%)

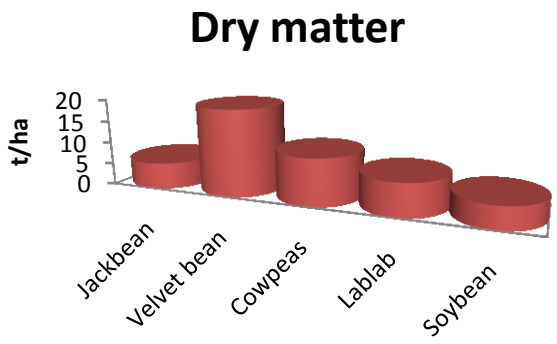

Figure 4: Performance of LCC on dry matter accumulation (t ha^{-1})

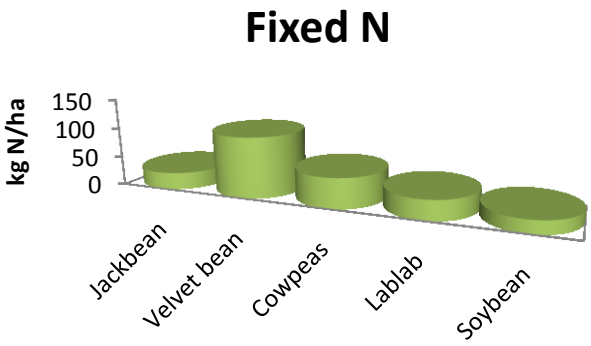

Figure 5: Performance of LCC on fixed N across all locations

4.2 Decomposition Experiment

4.2.1 Decomposition rate and pattern of N content in the soil and LCC leaves

The patterns of N content in the soil and of decomposed leaves of LCC are presented in Figure 6-25. Generally, there was a decreasing trend of N content in LCC leaves placed above and underground position throughout the decomposing period at ARI-Uyole. The graphs show a bit faster decrease at 9 - 12 weeks for velvet bean when placed underground. Similarly faster decrease was observed at 3 - 6 weeks for cowpeas when placed aboveground. The results show that there was an increasing trend of soil N with time of decomposition in all LCC under study. However, faster rates were observed at 12-15 weeks of decomposition for jack bean, velvet bean and cowpea when placed both above and underground position. Lablab and soybean show slight decreasing trend throughout the decomposition period when placed both above and underground position.

Results for decomposition of LCC leaves at Mwandobela show a similar trend throughout the time. There was a slight decreasing trend of N content in leaves and a slightly increasing trend of N content in soil when placed above and underground position.

4.2.2 Combined effect of N content on location and position

Table 6 presents the combined effect on location, position, cover crops and time on N content. No significant difference was observed on N content when combined on both locations and positions at ARI-Uyole and Mwandobela areas. However, Mwandobela area was slightly higher in N content when compared to ARI-Uyole area.

4.2.3 Combined effect of LCC and incubation time on N content

The effect of LCC and incubation time on N content show highly significant difference ($p<0.001$). Plots with lablab legume showed to have higher nitrogen content followed by soya, cowpea, velvet and lastly by jackbean legume. Means for the effect of retrieval time

on nitrogen content gave highly significant difference between retrieval periods. The amount of nitrogen obtained within 6 weeks retrieval time was higher followed by 18, 12, 9, 3 and 15 weeks retrieval time periods.

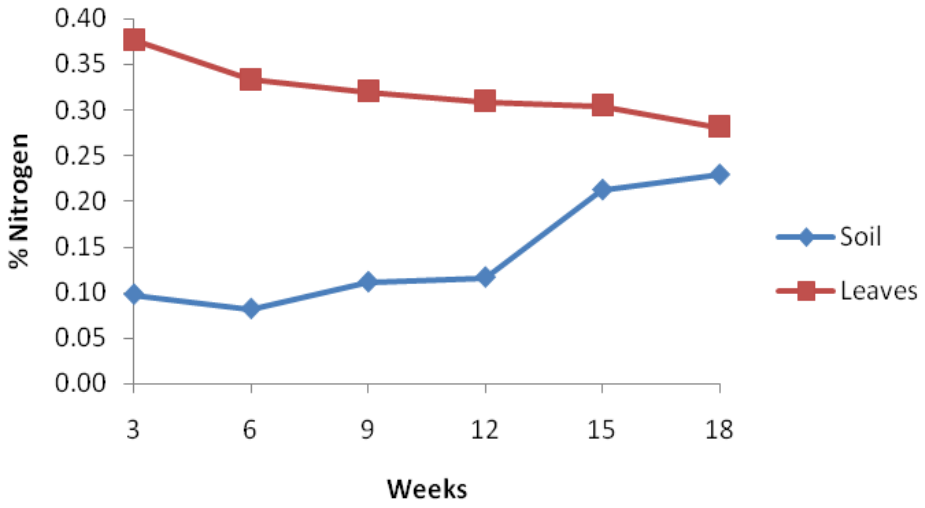

Figure 6: The N content for soil and leaves of jack bean placed aboveground by time after decomposition at ARI-Uyole

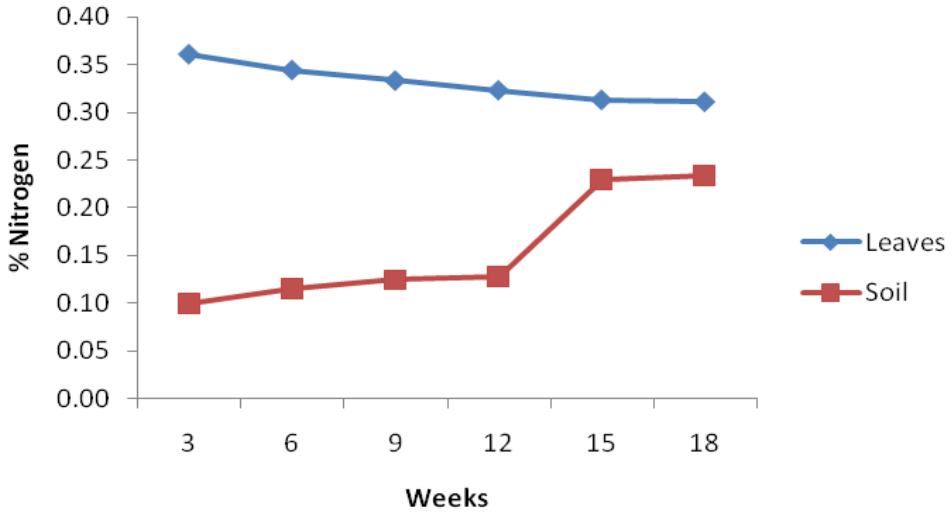

Figure 7: The N content for soil and leaves of jack bean placed underground by time after decomposition at ARI-Uyole

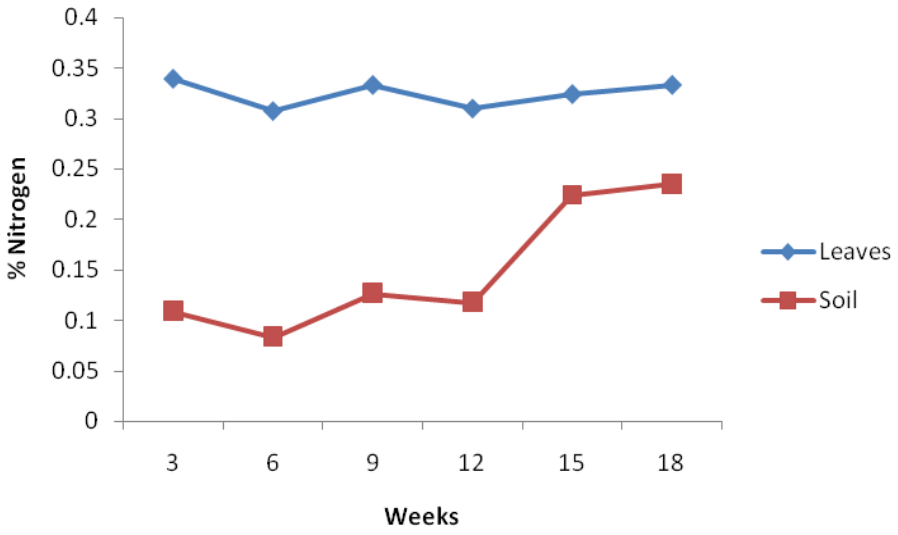

Figure 8: The N content for soil and leaves of velvet bean placed aboveground by time after decomposition at ARI-Uyole

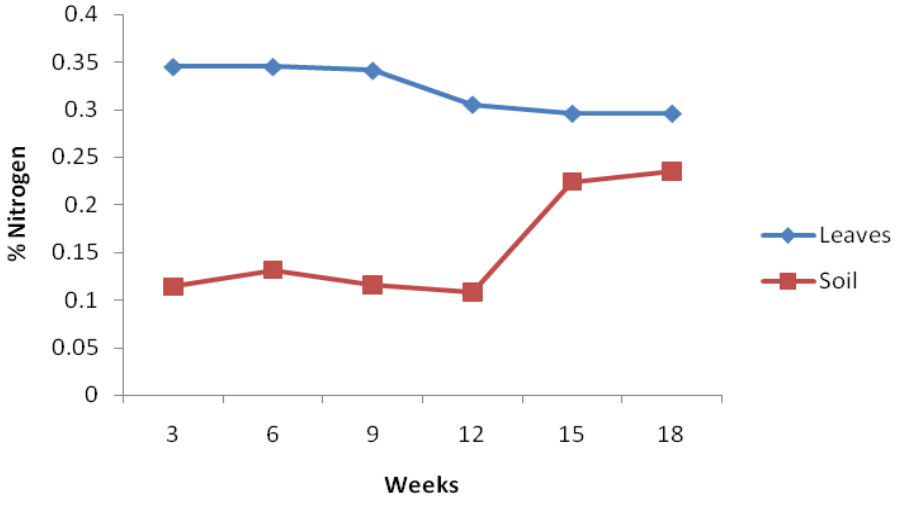

Figure 9: The N content for soil and leaves of velvet bean placed underground after decomposition by time at ARI-Uyole

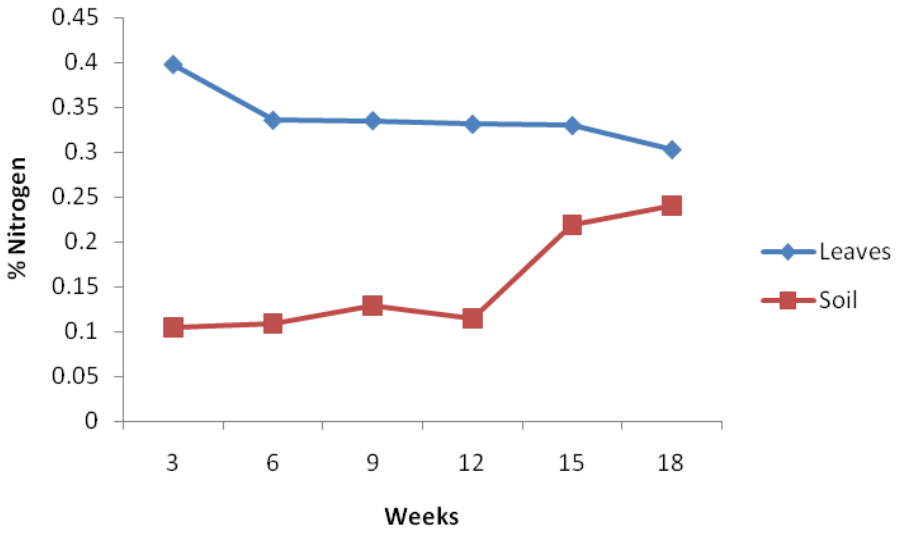

Figure 10: The N content for soil and leaves of cowpea placed aboveground after decomposition by time at ARI-Uyole

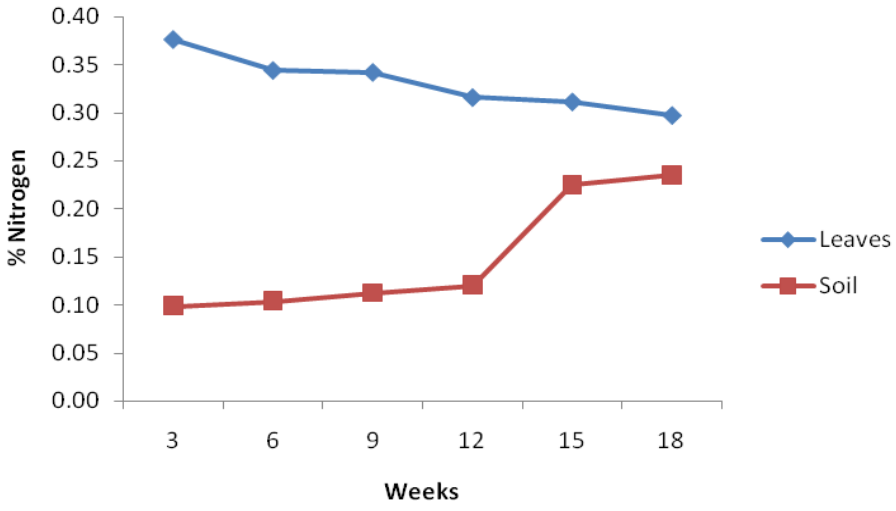

Figure 11: The N content for soil and leaves of cowpea placed underground after decomposition by time at ARI-Uyole

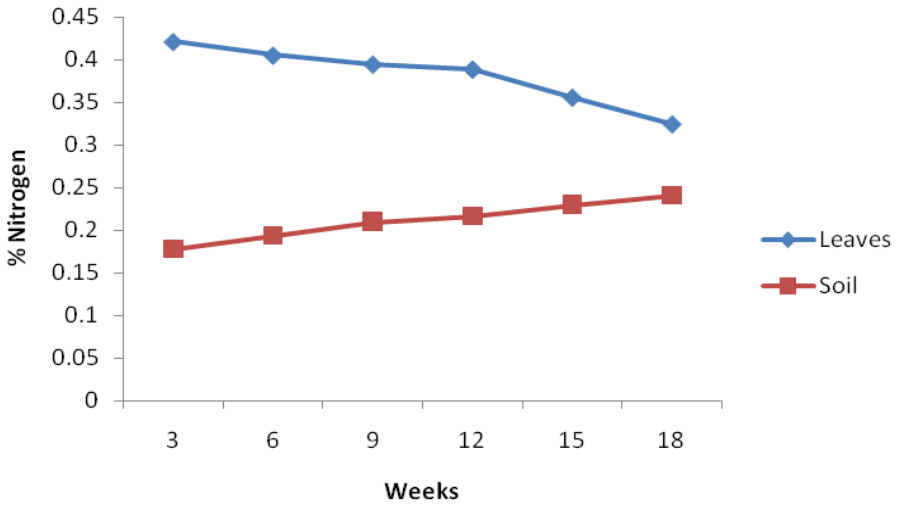

Figure 12: The N content for soil and leaves of lablab placed aboveground after decomposition by time at ARI-Uyole

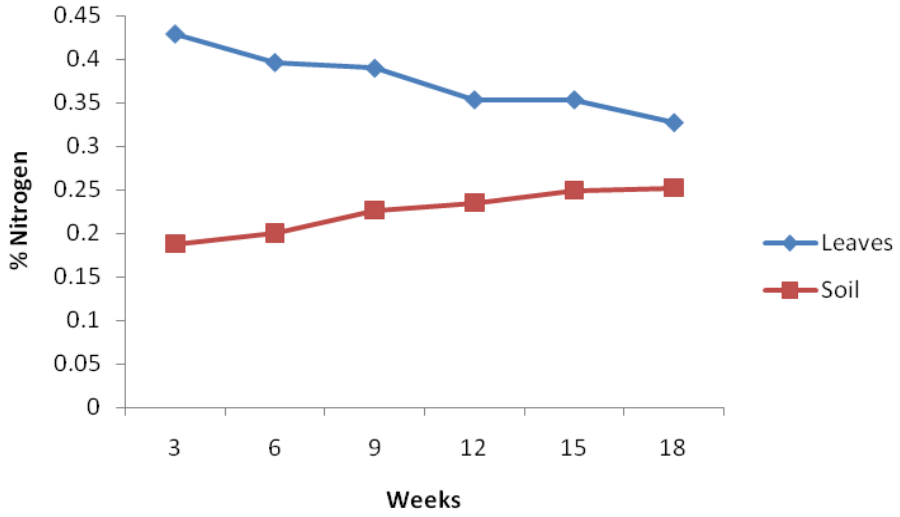

Figure 13: The N content of lablab placed underground for soil and leaves after decomposition by time at ARI-Uyole

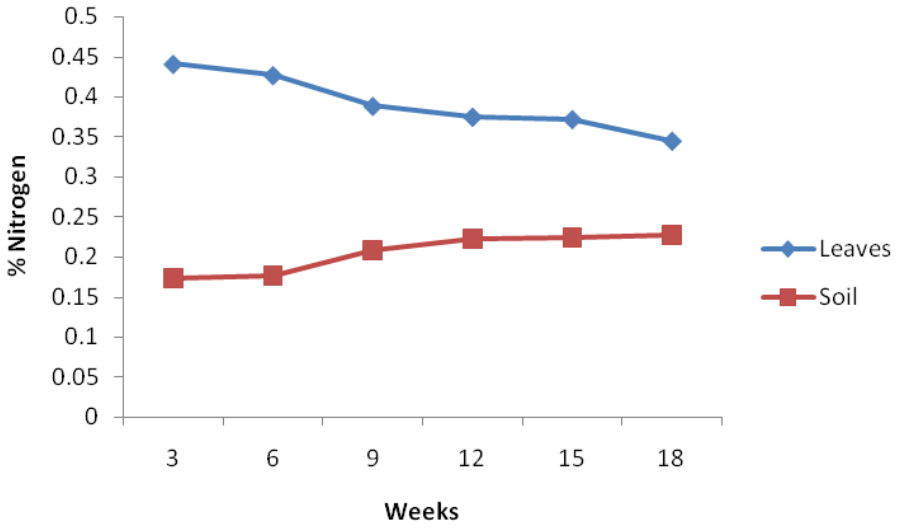

Figure 14: The N content for soil and leaves of soybean placed aboveground after decomposition by time at ARI-Uyole

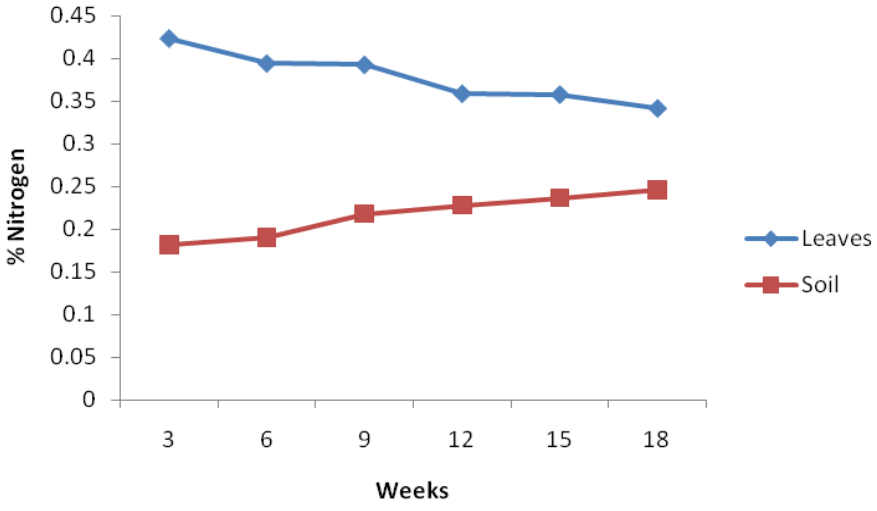

Figure 15: The N content for soil and leaves of soybean placed underground after decomposition by time at ARI-Uyole

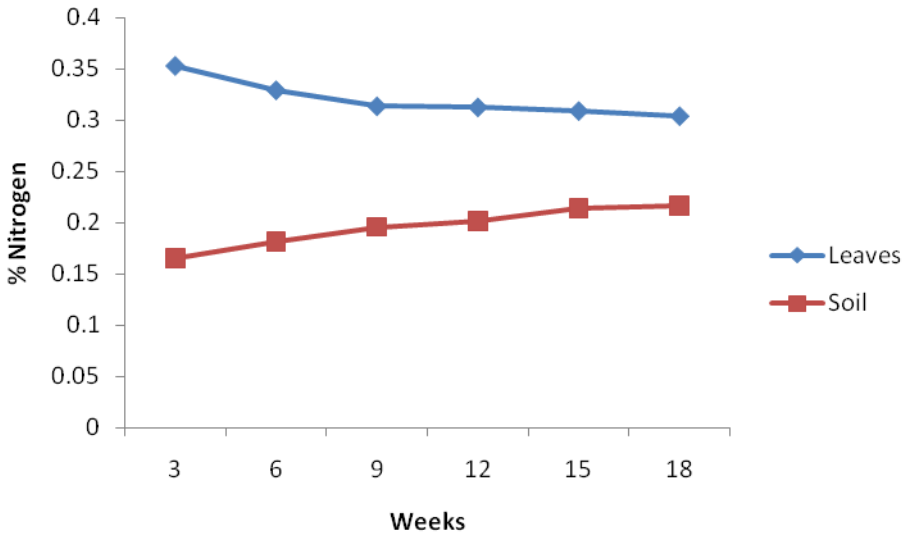

Figure 16: The N content for soil and leaves of jackbean placed aboveground after decomposition by time at Mwandobela

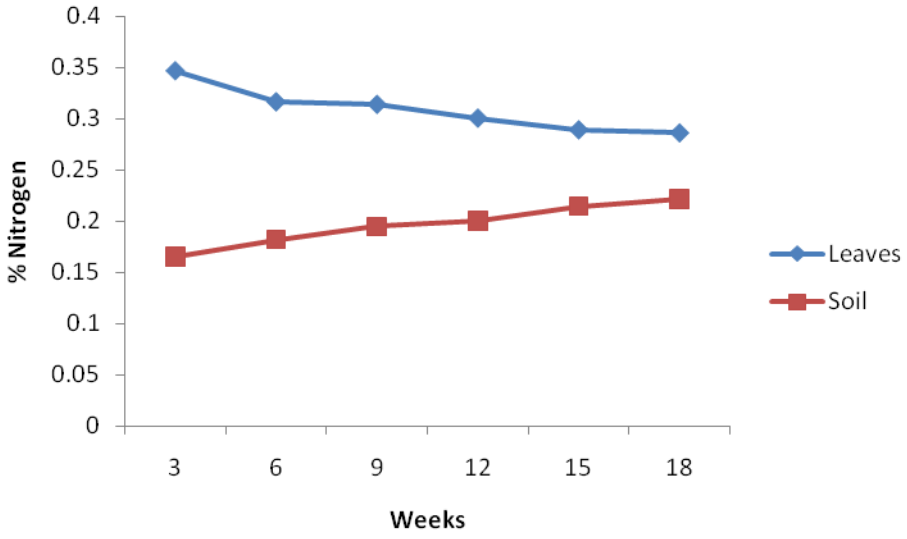

Figure 17: The N content for soil and leaves of jackbean placed underground after decomposition by time at Mwandobela

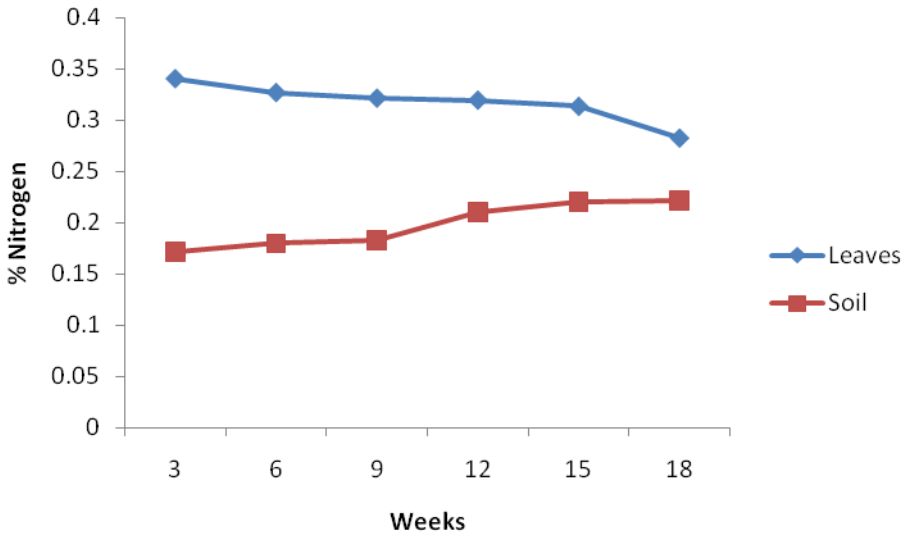

Figure 18: The N for soil and leaves content of velvet bean placed aboveground after decomposition by time at Mwandobela

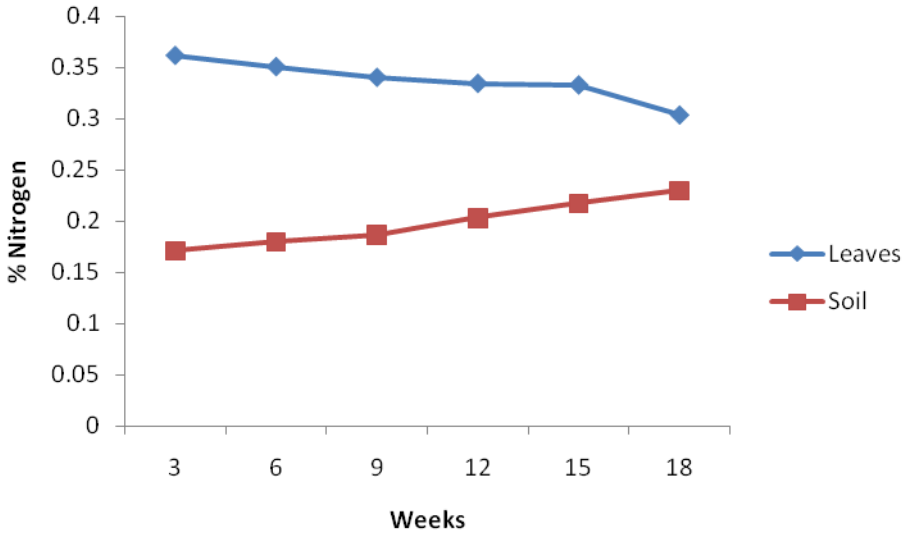

Figure 19: The N for soil and leaves content of velvet bean placed underground after decomposition by time at Mwandobela

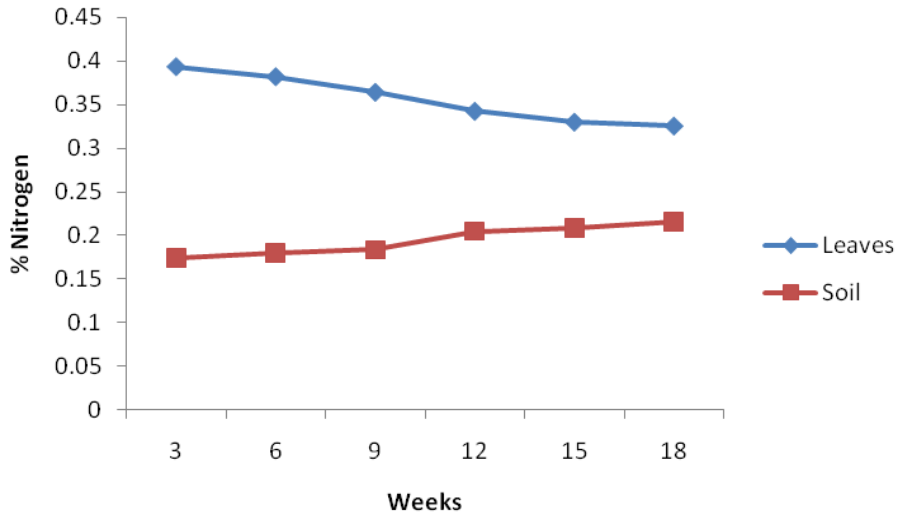

Figure 20: The N content for soil and leaves of cowpea placed aboveground after decomposition by time at Mwandobela

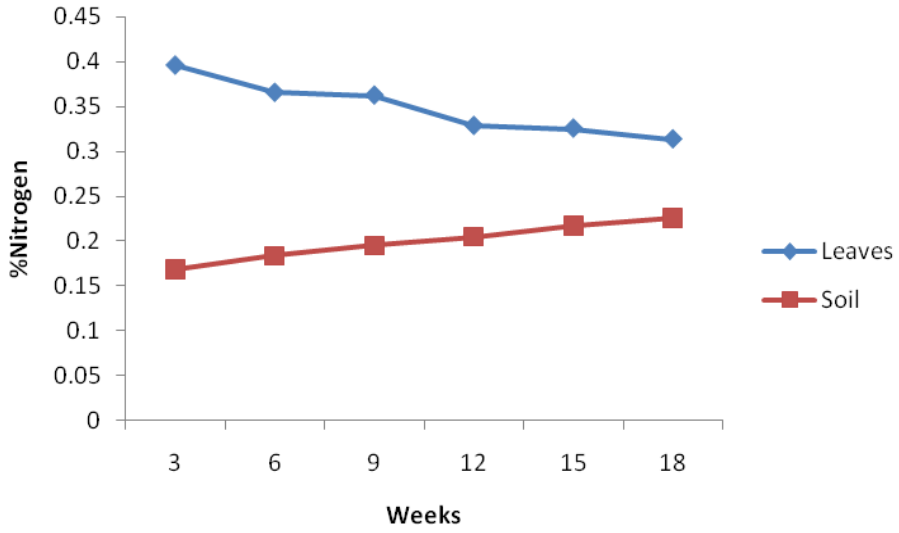

Figure 21: The N content for soil and leaves of cowpea placed underground after decomposition by time at Mwandobela

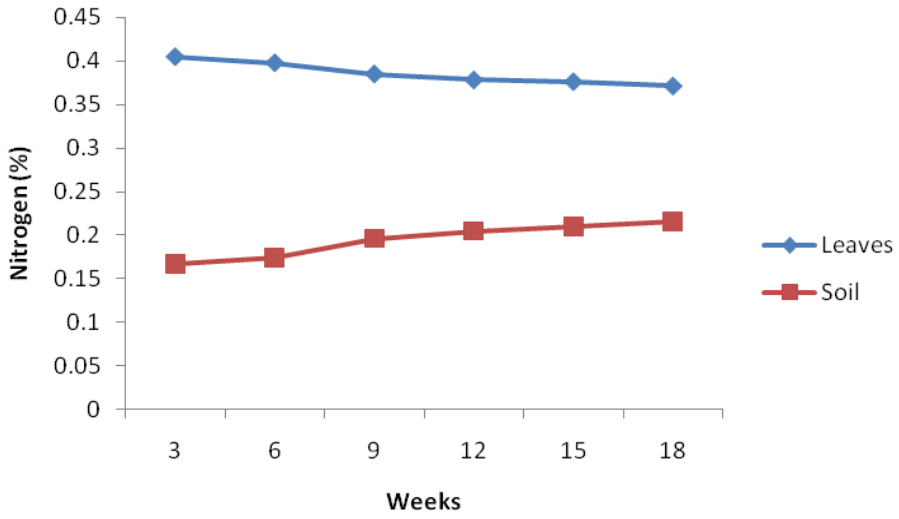

Figure 22: The N content for soil and leaves of lablab placed aboveground after decomposition by time at Mwandobela

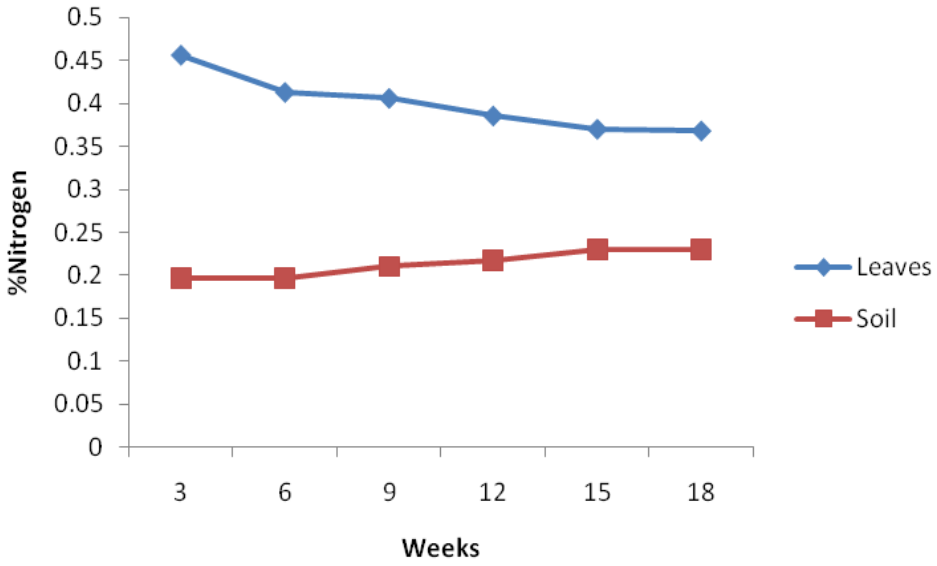

Figure 23: The N content for soil and leaves of lablab placed underground after decomposition by time at Mwandobela

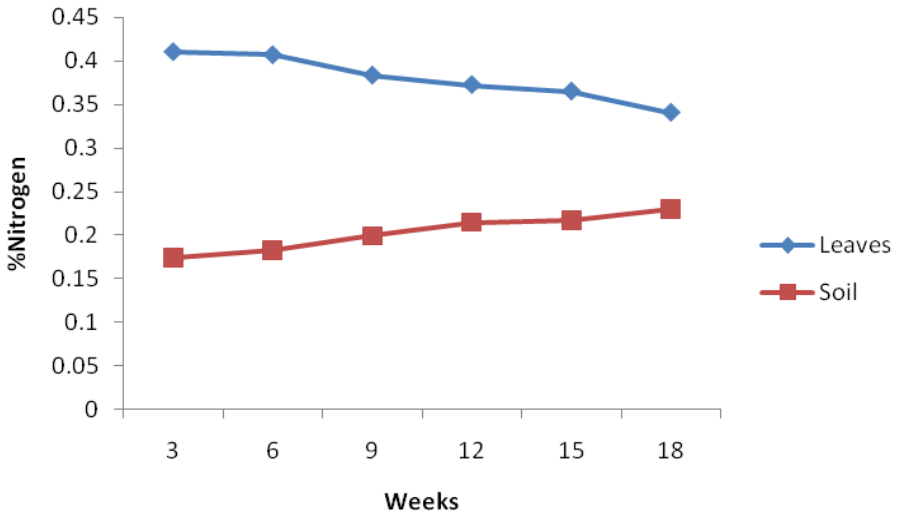

Figure 24: The N content for soil and leaves of soybean placed aboveground after decomposition by time at Mwandobela

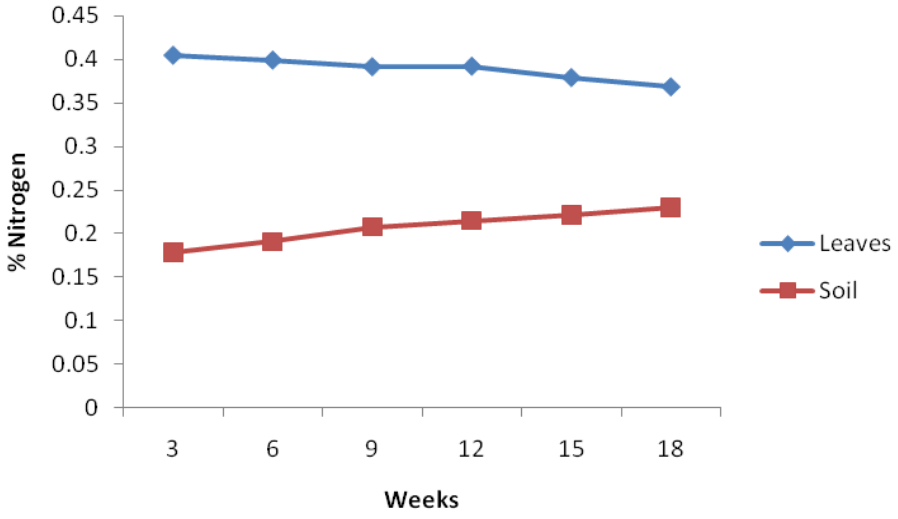

Figure 25: The N content of soybean placed underground for soil and leaves after decomposition by time at Mwandobela

Table 6: Combined effect of location, position, cover crops and time on N content

Variable		%Nitrogen content
Location	ARI-Uyole	0.349 a
	Mwandobela	0.354 a
Position	Aboveground	0.353 a
	Underground	0.352 a
LCC	Jackbean	0.320 c
	Cowpea	0.344 b
	Lablab	0.385 a
	Velvet	0.325 c
	Soya	0.384 a
Time (weeks)	3	0.352 bc
	6	0.360 a
	9	0.352 bc
	12	0.354 b
	15	0.335 c
	18	0.357 b

Means in the same column followed by the same letter is not statistically different ($p<0.05$) by Duncan's New Multiple Range Test.

Generally, the N content of decomposed LCC in leaves was decreased with time and it did not show a stable state for both sites and positions. Thonnissen *et al*. (2000) when evaluating legume decomposition and nitrogen release when applied as green manures to tropical vegetable reported similar results. Furthermore, the study show that N content in the soil was increasing with time of decomposing LCC tissues and it did not attain its peak during the study period. In Kenya similar results were reported by Odhiambo (2010) when evaluating cover crops decomposition and N release on different soils.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Generally the study observed that different LCC species have different potential of fixing N_2 and accumulating dry matter. Among the studied LCC across locations, velvet bean had high N_2 fixing potential (101.9 kg N ha^{-1}) followed by cowpea (50.3 kg N ha^{-1}). Furthermore, velvet bean had high N_2 fixing potential (101.9 kg N ha^{-1}) and accumulated high dry matter (19.5 t ha^{-1}) followed by cowpea (50.3 kg N ha^{-1} and 10.5 t ha^{-1}).

There was an increasing trend of soil N with time of decomposition. However, faster rates of increasing soil N were observed at 12-15 weeks of decomposition for jack bean (0.09 - 0.13 % N), velvet bean (0.08 – 0.12 % N) and cowpea (0.11 – 0.12 % N) when placed both above and underground position.

5.2 Recommendations

From the results of these studies, the following are recommended:

i. Velvet bean and cowpea to be incorporated in cropping systems so as to improve crop productivity and soil fertility for resource poor farmers.

ii. Evaluation of LCC together with synchronizing N release by residues and uptake by the subsequent crop should be done for wider adaptability.

iii. The results of this study were obtained from only one season. In order to validate the findings, it is recommended that the study be conducted in different agro-ecological environments and seasons.

REFERENCES

Acosta, S. I. C. (2009). Promoting the use of tropical legumes as cover crops in Puerto Rico. Dissertation for Award of MSc Degree at University of Puerto Rico, Mayagüez, Campus, 67pp.

Akinlade, J. A., Farinu, G. O., Taiwo, A. A., Aderinola, O. A., Adebayo, T. A., Ojebiyi, O. O. and Olaniran, O. A. (2007). Agronomic and nutritive evaluation of Jack bean (*Canavalia ensiformis*) for fodder in the Derived Savannah Zone of Nigeria. *International Journal of Research* 2(12): 1059 – 1063.

Altieri, M. A. (2000). The ecological impacts of transgenic crops on agroecosystem health. *Ecosystem Health* 6: 13 – 23.

Alvarez, R., Dõaz, R. A., Barbero, N., Santanatoglia, O. J., Blotta, L. (1995). Soil organic C, microbial biomass and CO_2-C production from three tillage systems. *Soil Tillage Research* 33: 17 – 28.

Anderson, J. M. (1993). *Tropical Soil Biology and Fertility.* (Edited by Ingram, J. S. I.), Commonwealth of Agriculture Bureau International, Wallingford. London. 221pp.

ARI-Uyole (2002). *Annual Agricultural Engineering Research Progress Report.* Uyole - Agricultural Research Institute, Mbeya, Tanzania. 241pp.

Austin, A. T. and Vivanco, L. (2006). Plant litter decomposition in a semi-arid ecosystem controlled by photodegradation. *Nature* 442: 555 – 558.

Azam, F., Simmons, F. W. and Mulvaney, R. L. (1993). Mineralization of N from plant residues and its interaction with native soil N. *Soil Biology and Biochemistry* 25: 1787 – 1792.

BACAS/SADC (2008). *Land and Water Management Research Programme.* Integrated soil fertility management. Sokoine University of Agriculture Morogoro, Tanzania. 138pp.

Bailey, L. H., Bailey, E. Z. and Hortatorium, L. H. B. (1976). *Hortus Third: A Concise Dictionary of Plants Cultivated in the United States and Canada*. Macmillan Publishers, New York. 1061pp.

Bationo, A., Ntare, B. R., Tarawali, S. and Tabo, R. (2003). Soil fertility management and cowpea production in the Semi-Arid Tropics of West Africa. In: Fatokun, C. A., Tarawali, S. A., Singh, B. B., Kormawa, P. M. and Tamo, M. (Eds.). Challenges and opportunities for enhancing sustainable cowpea production. Cowpea as a key factor for a new approach to integrated crop-livestock systems research in the dry savannas of West Africa. *Proceedings of the Workshop, International Institute for Tropical Agriculture,* 4 – 7 September 2000, Ibadan, Nigeria. pp. 301 – 318.

Bationo, A., Wani, S. P., Bielders, C. L., Vlek, P. L. G. and Mokwunye, U. (2000). Crop residue and fertilizer management to improve soil organic carbon content, soil quality, and productivity in the desert margins of West Africa. In: *Global Climate Change and Tropical Ecosystems Advances in Soil Science*. (Editors by Lal, R., Kimble, J. M. and Stewart, B. A. (Eds.), CRC Press, Washington DC, USA. pp. 117 – 145.

Bayorbor, T. B., Addai, I. K., Lawson, I. Y. D., Dogbe, W. and Djabletey, D. (2006). Evaluation of some herbaceous legumes for use as green manure crops in the rainfed rice based cropping system in Northern Ghana. *Journal of Agronomy* 5(1): 137 – 141.

Becker, M. and Johnson, D. E. (1998). Legumes as dry season fallow in upland rice-based cropping systems of West Africa. *Soil Biology and Fertility* 27: 358 – 367.

Becker, M., Ladha, J. K. and Ali, M. (1995). Green manure technology: Potential, usage, and limitations. A case study for lowland rice. *Plant and Soil* 174: 181 – 194.

Bogale, T., Assenga, R. H., Mmbaga, T. E., Friesen, D. K., Kikafunda, J. and Ransom, J. K. (2001). Legume fallows for maize-based systems in Eastern Africa: Contribution of legumes to enhanced maize productivity and reduced nitrogen requirements. *Seventh Eastern and Southern Africa Regional Maize Conference held* from 11 – 15 February 2001. pp. 324 – 329.

Bohlen, P. J., Parmalee, R. W., McCartney, D. A. and Edwards, C. A. (1997). Earthworm effects on carbon and nitrogen dynamics of surface litter in corn agroecosystems. *Ecological Applications* 7(4): 1341 – 1349.

Brady, N. C. and Weil, R. R. (2002). *The Nature and Properties of Soils.* (13th Ed.) Prentice Hall, Upper Saddle River, New Jersey. 960pp.

Bremner, J. M. and Mulvaney, C. S. (1982). *Total Nitrogen*. *In: Methods of Soil Analysis Part 2.* (Edited by Page, A. L.), American Society of Agronomy, Madison, Wisconsin. 616pp.

Buckles, D., Triomphe, B. and Sain, G. (1998). *Cover Crops in Hillside Agriculture, Farmer Innovation with Mucuna.* International Development Research Centre Ottawa, Canada. 218pp.

Bunch, R. (1990). *Low-input Soil Restoration in Honduras: the Cantarranas Farmer-to-Farmer Extension Project*. Sustainable Agriculture Gatekeeper Series No. 23. International Institute for Environment and Development, London. 12pp.

Buresh, R. J., Sanchez, P. A. and Calhoun, F. (1997). Soil fertility replenishment takes off in east and Southern Africa. In: *Integrated Plant Nutrient Management In Sub-Saharan Africa: From Concept To Practice***.** (Editors by Vanlauwe, B., Diels, J., Sanginga, N. and Merckx, R.), Commonwealth of Agriculture Bureau International, Wallingford, UK. 45pp.

Burle, M. L., Suhet, A. R., Pereira, J., Resck, D. V. S., Peres, J. R. R., Cravo, M. S., Bowen, W., Bouldin, D. R. and Lathwell, D. J. (1992). *Legume Green Manures: Dry Season Survival and the Effect on Succeeding Maize Crops.* Soil Management Bulletin No. 4. Soil Management Collaborative Research Support Program, Raleigh, North Carolina. 35pp.

Cadisch, G. and Giller, K. E. (Eds.) (1997). *Driven by Nature: Plant Residue Quality and Decomposition.* Commonwealth of Agriculture Bureau International, Wallingford, UK. 409pp.

Capo-chichi, L. J. A., Weaver, D. B. and Morton, C. M. (2002). *Agronomic and Genetic Attributes of Velvetbean (Mucuna sp.): An Excellent Legume Cover Crop for Use in Sustainable Agriculture. Making Conservation Tillage Conventional: Building a Future on 25 years of Research*. Special Report No. 1. Alabama Agricultural Experiment Station and Auburn University, Alabama. 319pp.

Carsky, R. J., Oyewole, B. and Tian, G. (1999). Integrated soil management for the savanna zone of West Africa: Legume rotation and fertilization. *Nutrient Cyclinge in Agroecosystems* 55: 95 – 105.

Carsky, R. J., Oyewole, B. and Tian, G. (2001). Effect of phosphorus application in legume cover crop rotation on subsequent maize in the savanna zone of West Africa. *Nutrient Cyclinge in Agroecosystems* 59: 151 – 159.

Chapman, H. D. (1965). *Cation Exchange Capacity. In: Methods of Soil Analysis*. (Edited by Black, C. A.), Agronomy No. 9. American Society of Agronomy, Madison, Wisconsin. 901pp.

Chikoye, D. (1999). *Methods of Assessing Ground Cover by Herbaceous Cover Crops.* CIEPA Newsletter Issue No. 4. November 1999. 6pp.

Chilagane, A. (1990). *Crotalaria in Peasant Agriculture, Research and Training Newsletter*. Ministry of Agriculture, Livestock Development and Co-operatives, Dar es Salaam, Tanzania. 24pp.

Chivenge, P., Vanlauwe, B. and Six, J. (2011). Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. *Plant and Soil* 242: 1 – 30.

CIAT (2003). *Farmers' Evaluations and Innovations with Legume Cover Crops*. Highlights in Africa Series No. 6. International Center for Tropical Agriculture, Colombia. 2pp.

CIAT (2004). *Annual Report, Tropical Grasses and Legumes. Optimizing Genetic Diversity for Multipurpose Use.* International Center for Tropical Agriculture, Cali, Colombia. 217pp.

Clewer, A. G. and Scarisbrick, D. H. (2001). *Practical Statistics and Experimental Design for Plant and Crop Science*. John Wiley and Sons Publisher, New York. 332pp.

Corbin, E. J., Brokwell, J. and Gault, R. R. (1977). Nodulation studies on chickpea (*Cicer arientiunum*). *Australian Journal of Experimental Agriculture and Animal Husbandry* 17: 126 – 134.

Coskan, A. and Dogan, K. (2011). Symbiotic nitrogen fixation in soybean. *Soybean Physiology and Biochemistry* 307: 167 – 182.

Craswell, E. T. and Lefroy, R. D. B. (2001). The role and function of organic matter in tropical soils. *Nutrient Cycling in Agroecosystems* 61: 7 – 18.

Dakora, F. D. and Keya, S. O. (1997). Contribution of legume nitrogen fixation to sustainable agriculture in Sub-Saharan Africa. *Soil Biology and Biochemistry* 29: 809 – 817.

Deborah, J. (2001). *Water Harvesting and Soil Moisture Retention. A Study Guide for Farmer Field School.* The farm Level Applied Research Methods for east and Southern Africa, Nairobi, Kenya. 19pp.

Dechaine, J., Ruan, H., Sanchez de Leon, Y. and Zou, X. (2005). Correlation between earthworms and plant litter decomposition in a tropical wet forest of Puerto Rico. *Pedobiologia* 49(6): 601 – 607.

Dhawan, S. S., Rai1, G. K., Darokar, M. P., Lal, R. K., Misra, H .O. and Khanuja, S. P. S. (2011). Comparative genetic analysis of trichome-less and normal pod genotypes of *Mucuna pruriens* (Fabaceae). *Genetic and Molecular Research* 10(3): 2049 – 2056.

Dogan, K., Celik, I., Gok, M. and Coskan, A. (2011). Effect of different soil tillage methods on *Rhizobial* nodulation, biyomas and nitrogen content of second crop soybean. *African Journal of Microbiology* 5(20): 3186 – 3194.

Dogan, K., Gok, M. and Coskan, A. (2007). Effects of bacteria inoculation and iron application on nodulation and N-fixation in peanut as a 2nd crop. *Journal of Suleyman Demirel* 22(3): 43 – 52.

Douxchamps, S., Humbert, F. L., van der Hoek, R., Mena, M., Bernasconi, S. M., Schmidt, A., Rao, I., Frossard, E. and Oberson, A. (2010). Nitrogen balances in farmers fields under alternative uses of a cover crop legume: A case study from Nicaragua. *Nutrient Cycling in Agroecosystems Cycle Agroecosystem* 88: 447 – 462.

Dugje, I. Y., Omoigui, L. O., Ekeleme, F., Bandyopadhyay, R., Lava Kumar, P. and Kamara, A. Y. (2009). *Farmers' Guide to Soybean Production in Northern Nigeria*. International Institute of Tropical Agriculture, Ibadan, Nigeria. 21pp.

Eilitta, M., Sollenberger, L. E., Lintell, R. C. and Harrington, L. W. (2002). On-farm experiments with maize-mucuna systems in the Los Tuxtlas region of Veracruz, Mexico. 1. Mucuna biomass and maize grain yield. *Experimental Agriculture* 39: 5 – 17.

Encarta (2009). Microsoft Encarta dictionaries. Microsoft Corporation in the United States.[http://microsoftcooperation.encarta.msn.com] site visited on 22/3/2011.

Ennin-Kwabiah, S. and Osei-Bonsu, P. (1993). *Management of Cowpea, Soybean and Groundnut in Tropical Cropping Systems*. Crop Management Guide No. 36. Crop Research Institute, Nigeria. 34pp.

Ferreira, M. C., Andrade, D. S., Maria, L., Chueire, O., Takemura, S. M., Hungria, M. (2000). Tillage method and crop rotation effects on the population sizes and diversity of bradyrhizobia nodulating soybean. *Soil Biology and Biochemistry* 32: 627 – 637.

Fujii, Y., Shibuya, T. and Yasuda, T. (1992). Allellopathy of mucuna: Its discrimination of L-DOPA as a candidate of allellopathic substances. *Japan Agriculture Research* 25: 238 – 247.

Gachene, C. K. K. and Kimaru, G. (Eds.) (2003). *Soil Fertility and Land Productivity: A Guide for Extension Workers in the Eastern Africa Region.* Technical Handbook Series No. 30. Regional Land Management Unit, Nairobi, Kenya. 146pp.

Garcia, A. G. and Altieri, M. A. (2005). Transgenic Crops: Implications for biodiversity and sustainable agriculture. *Bulletin of Science, Technology and Society* 25(4): 335 – 353.

GenStat (2003). *GenStat for Windows. Release 4.23DE Discovery*. (4th Edition). VSN International Ltd., Hemel Hempstead, UK. 120pp.

Giller, K. E. (2001). *Nitrogen Fixation in Tropical Cropping Systems.* Commonwealth of Agriculture Bureau International, Wallingford, UK. 423pp.

Giller, K. E. and Cadisch, G. (1995). Future benefits from biological nitrogen fixation: An ecological approach to agriculture. *Plant and Soil* 174: 255 – 277.

Giller, K. E. and Wilson, K. J. (1993). *Nitrogen Fixation in Tropical Cropping Systems*. Commonwealth of Agriculture Bureau International, Wallingford, UK. 313pp.

Giller, K. E., Cadisch, 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. pp. 193 – 218.

Giller, K. E., McDonagh, J. F. and Cadish, G. (1994). Can biological nitrogen fixation sustain agriculture in the tropics? In: *Soil Science and Sustainable Land Management in the Tropics.* (Editors by Syers, J. K. and Rimmer, D. L.), Commonwealth of Agriculture Bureau International, Wallingford, UK. pp. 173 – 191.

Gioseffi, E., de Neergaard, A. and Schjoerring, J. K. (2012). Interactions between uptake of amino acids and inorganic nitrogen in wheat plants. *Biogeosciences* 9: 1509 – 1518.

Gomez, K. A. and Gomez, A. A. (1984*). Statistical Procedures for Agricultural Research*. (2nd Ed.), John Willey and Sons Publishers, New York. 680pp.

Goss, M. J. and de Varennes, A. (2002). A soil disturbance reduces the efficiency of myccorhizal associations for early soybean growth on N_2 fixation. *Soil Biochemistry* 34: 1167 – 1173.

Gundale, M. J., Nilsson, M., Bansal, S. and Jaderlund, A. (2012). The interactive effects of temperature and light on biological nitrogen fixation in boreal forests. *New Phytologist* 194(2): 453 – 463.

Haque, M. M., Hamid, A. and Bhuiyan, N. I. (2001). Nutrient uptake and productivity as affected by nitrogen and potassium application levels on maize/sweet potato intercropping system. *Korean Journal of Crop Science* 46(1): 1 – 5.

Hepperly, P., Aguilar-Erazo, H., Perez, R., Diaz, M. and Reyes, C. (1992). Pigeon Pea and Velvet Bean Allelopathy. In: *Allelopathy Basic and Applied Aspects.* (Editors by Rizvi, S. J. H. and Rizvi, V. (Eds.), Chapman and Hall, London, UK. pp. 357 – 370.

Herridge, D. F., Peoples, M. B. and Boddey, R. M. (2008). Global inputs of biological nitrogen fixation in agricultural systems. *Plant and Soil* 311: 1 – 18.

Hill, J. O., Robertson, M. J., Pengelly, B. C., Whitbread, A. M. and Hall, C. A. (2006). Simulation modelling of lablab (*Lablab purpureus*) pastures in northern Australia. *Australian Journal of Agricultural Research* 57: 389 – 401.

Houlton, B. Z., Wang, Y. P., Vitousek, P. M. and Field, C. B. (2008). A unifying framework for dinitrogen fixation in the terrestrial biosphere. *Nature* 454: 327 – 330.

Hsiao, T. C. and Xu, L. K. (2000). Sensitivity of growth of roots versus leaves to water stress: Biophysical analysis and relation to water transport. *Journal of Experimental Botany* 51**:** 1595 – 1616.

Hubbell, D. H. and Kidder, G. (2003). *Biological Nitrogen Fixation. Institute of Food and Agricultural Sciences.* Extension Series No. 16. University of Florida, Gainesville. 4pp.

Hudgens, R. E. (2000). Sustaining soil fertility in Africa: The potential for legume green manures. *Proceedings of the 15th Conference of the Soil Science Society of East Africa.* pp. 63 – 78.

Humphreys, L. R. (1995). Diversity of productivity of tropical legumes. In: *Tropical Legumes in Animal Nutrition*. (Editors by D'Mello, J., P. F. and Devendra, C. (Eds.), Commonwealth of Agriculture Bureau International, Wallingford, UK. 21pp.

Hungria, M. and Vargas, M. A. T. (2000). Environmental factors affecting N2 fixation in grain legumes in the tropics, with an emphasis on Brazil. *Field Crops Research* 65: 151 – 164.

Ibewiro, B., Sanginga, N., Vanlauwe, B. and Merckx, R. (2000). Nitrogen contributions from decomposing cover crop residues to maize in a tropical derived savanna. *Nutrient Cycling in Agroecosystems* 57(2): 131–140.

IIRR and ACT (2005). *Conservation Agriculture: A Manual for Farmers and Extension Workers in Africa*. International Institute of Rural Reconstruction, Nairobi, Kenya. 251pp.

Kaizzi, C. K., Ssali, H. and Vlek, P. L. G. (2006). Differential use and benefits of Velvet bean (*Mucuna pruriens* var. *utilis*) and N fertilizers in maize production in contrasting agro-ecological zones of E. Uganda. *Agricultural Systems* 88(1): 44 – 60.

Kalumuna, M. C. (2005). Influence of cover crops on nitrogen availability, moisture content and maize yield under sub-humid climate of Morogoro, Tanzania. Thesis for Award of PhD Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 207pp.

Kanyeka, E., Kamala, R. and Kasuga, R. (2007). *Improved Agricultural Technologies Recommended in Tanzania*. First Edition. Department of Research and Training. Ministry of Agriculture Food Security and Cooperatives, Dar es Salaam, Tanzania. 144pp.

Karberg, N. J., Scott, N. A. and Giardina, C. P. (2008). Methods for Estimating Litter Decomposition. In: *Field Measurements for Forest Carbon Monitoring.* (Edited by Hoover, C. M.), Springer Science and Business Media. 111pp.

Kikafunda, J., Bogale, T. T., Mmbaga, T. E. and Assenga, R. H. (2001). Legume fallows for maize-based cropping systems in East Africa: Screening legumes for adaptability, biomass and nitrogen production. *Paper Presented During the Seventh Eastern and Southern Africa Regional Maize Conference* held on 11 – 15 February 2001. pp. 319 – 323.

Kirschbaum, M. U. F. (1995). The temperature dependence of soil organic matter decomposition and the effect of global warming on soil organic C storage. *Soil Biology and Biochemistry* 27: 753 – 760.

Kladivko, J. K. (2001). Tillage systems and soil ecology. *Soil and Tillage Research* 61(2): 61 – 76.

Lafitte, H. R. (1993). *Identifying Production Problems in Tropical Maize:* A Field Guide. CIMMYT, Mexico. 122pp.

Landon, J. R. (Ed.) (1991). *Booker Tropical Soil Manual*. Longman Group Ltd., Harlow, United Kingdom. 156pp.

Ledgard, S. J. and Giller, K. E. (1995). Atmospheric N_2-fixation as an alternative nitrogen source. In: *Nitrogen Fertilization and Environment.* (Edited by Bacon, P.), Marcel Dekker, New York. 486pp.

Lodwig, E. M., Hosie, A. H. F., Bourdès, A., Findlay, K., Allaway, D., Karunakaran, R., Downie, J. A. and Poole, P. S. (2003). Amino-acid cycling drives N fixation in the legume–Rhizobium symbiosis. *Nature* 422: 722 – 726.

Lu, Y. C., Watkins, K. B., Teasdale, J. R. and Abdul-Baki, A. A. (2000). Cover crops in sustainable food production. *Food Reviews International* 16: 121 – 157.

Mabood, F., Zhou, X. and Smith, D. (2006). *Bradyrhizobium japonicum* preincubated with methyl Jasmonate increases soybean nodulation and nitrogen fixation. *Agronomy Journal* 98: 289 – 294.

Mafongoya, P. L., Giller, K. E. and Palm, C. A. (1997). Decomposition and nutrient release pattern of prunings and litter of agroforestry trees. *Agroforestry Systems* 38: 77 – 97.

Mafongoya, P. L., Giller, K. E. and Palm, C. A. (1998). Decomposition and nitrogen release patterns of tree prunings and litter. *Agroforestry Systems* 38: 77 – 97.

Malley, Z. J., Ndimbo, M., Mmari, W., Mzimbiri, M., Mwalukasa, N., Mwanga, A. and Majaliwa, L. (2012). *Improving Soil Productivity in Smallholder Maize-based Production System through Integration of Soybeans and Groundnuts in The Southern Highlands of Tanzania*. Alliance for a Green Revolution in Africa Peramiho Publishers, Songea, Tanzania. 13pp.

Marandu, A. E. T., Mbogoni, J. D. J. and Ley, G. J. (Eds) (2014). *Revised Fertilizer Recommendations For Maize And Rice In The Eastern, Southern Highlands And Lake Zones Of Tanzania.* Ministry of Agriculture, Food Security and Cooperatives, Dar es Salaam, Tanzania. 40pp.

Marino, D., Frendo, P., Gonzalez, E. M., Puppo, A. and Arrese, C. (2007). NADPA recycling systems in oxidative stressed nodules: A key role for the NADP + dependent isocitrate dehydrogenase. *Planta* 225**:** 413 – 421.

Mary, A. L. and Majule, A. E. (2009). Impacts of climate change, variability and adaptation strategies on agriculture in semi arid areas of Tanzania: The case of Manyoni District in Singida Region, Tanzania. *African Journal of Environmental Science and Technology* 3 (8): 206 – 218.

McGourty, G. (2004). Cover cropping systems for organically farmed vineyards. [http://www.practicalwinery.com/septoct04/septoct04p22.htm] site visited on 22/3/2011.

McLean, E. O. (1982). *Soil pH and Lime Requirement, American Society of Agronomy*, *Branch of Agriculture Dealing with Various Physical and Biological Factors*. In: Methods of Soil Analysis. Madison, Wisconsin. 224pp.

McSorley, R., Dickson, D. W. and Brito, J. A. (1994). Host status of selected tropical rotation crops to four populations of root-knot nematodes. *Nematropica* 24: 45 – 53.

Meentemeyer, V. (1978). Macroclimate and lignin control of litter decomposition rates. *Ecology* 59: 465 – 472.

Michiels, J., Verreth, C. and Vanderleyden, J. (1994). Effects of temperature stress on bean nodulating Rhizobium strains. *Applied and Environmental Microbiology* 60: 1206 – 1212.

Mkoga, Z. J., Tumbo, S. D., Kihupi, N. and Semoka, J. (2010). Extrapolating effects of conservation tillage on yield, soil moisture and dry spell mitigation using simulation modelling. *Journal of Physics and Chemistry of the Earth* 35: 686 – 698.

Mkomwa, S., Mussei, A., Mwakimbwala, R., Mulengera, N. and Kiranga,. E. (2007). Mbeya district case study. In: (Editors by Shetto, R. and Owenya, M.), Conservation Agriculture as Practised in Tanzania: *Three Case Studies. Nairobi. African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement,* Food and Agriculture Organization, Rome, Italy. 147pp.

Mnkeni, P. N. S., Semoka, J. M. R. and Mwanga, S. N. (1992). Dissolution of some Tanzanian phosphate rocks of igneous and sedimentary origin. *Zimbabwe Journal of Agriculture Research* 30 (1): 67 – 76.

Mohammadi, K., Sohrabi, Y., Heidari, G., Khalesro, S. and Majidi, M. (2012). Effective factors on biological nitrogen fixation. *African Journal of Agricultural Research* 7(12): 1782 – 1788.

Montanez, A. (2000). *Overview And Case Study On Biological Nitrogen Fixation: Perspectives And Limitations. Case Study B2*. Food and Agriculture Organization, Rome, Italy. 11pp.

Muhammad, A. R., Asghar, A., Muhammad, A. M. and Mumtaz, H. (2010). Effect of fertilizer levels and plant densities on yield and protein contents of autumn planted maize. *Pakistan Journal of Agricultural Science* 47(3): 201 – 208.

Mullen, C. (1999). Summer legume forage crops: cowpeas, lablab, soybeans. [http://www.dpi.nsw.gov.au/agriculture/field/field-crops/foragefodder/crops/summer-leg ume-forage] site visited 21/6/2012.

Mussei, A., Mwakimbwala, R., Ngailo, J.A., Kihupi, J., Murro, J. and Mghogho, R. (2013). *Basic Data Collection and Updating of the Existing Farming Systems in The Southern Highlands of Tanzania. In: Book of Results of the Southern Highlands*. Zone Agricultural Research and Development Fund, Mbeya, Tanzania. 198pp.

Myaka, F. A., Chibunda, R. T., Kidunda, R. S. and Rwamugira, W. (2003). Factors limiting crops and livestock productivity and their effect on household food security and incomes. In: Towards food security. *Proceedings of the Third Collaborative Research Workshop and Food Security* held on 28-30 May 2003, Morogoro, Tanzania. pp. 1 – 20.

Myers, R. J. K., Palm, C. A., Cuevas, E., Gunatilleke, I. U. N. and Bros-sard. (1994). The synchronization of nutrient mineralization and plant nutrient demand. In: *The Biological Management of Tropical Soil Fertility.* (Editors by Woomer, P. L. and Swift, M. J.), Wiley Sayce Publication, Chichester, UK. pp. 81 – 116.

Nair, P. K. R., Buresh, R. J., Mugendi, D. N. and Latt, C. R. (1999). Nutrient cycling in tropical agroforestry systems, myth and science. In: *Agroforestry in Sustainable Agricultural Systems.* (Editors by Buck, L. E., Lassoie, J. P. and Fernandes, E. C. M.), CRC Press, Washington DC. 31pp.

Odhiambo, J. J. O. (2010). Decomposition and nitrogen release by green manure legume residues in different soil types. *African Journal of Agricultural Research* 5(1): 90 – 96.

Ojiem, J. O., Mureithi, J. G. Maobe, S. N., Okwuosa, E. A. and Nekesa, C. (2000). Effect of phosphorus on nodulation and dry matter yield of legume green manure *species* in the humid highlands of Kenya. In: Mureithi, J. G., Macharia, P. N., Gichuru, M., Mburu, M., Mugendi, D. N. and Gachene, C. K. K. (Eds). *Soil Science Society of East Africa Proceedings of the 18th Conference and End of the Millennium Celebrations*, Mombasa Kenya, 4 - 8 December 2000. pp. 183 – 188.

Ojiem, J. O., Vanlauwe, B., de Ridder, N. and Giller, K. E. (2007). Niche based assessment of contributions of legumes to the nitrogen economy of Western Kenya smallholder farms. *Plant and Soil* 292: 119 – 135.

Olsen, S. R. and Sommers, L. E. (1982). *Phosphorus In: Methods of Soil Analysis*. (Edited by Page, A. L.), American Society of Agronomy, Madison, Wisconsin. 430pp.

Onim, J. F. M., Mathura, M., Otieno, K. and Fitzbugh, H. A. (1990). Soil fertility changes and response of maize and beans to green manures of leucaena, sesbania and pigeon pea. *Agroforestry Systems* 12: 197 – 215.

Onyango, C., Oduwo, A., Okoko, N., Kidula, N. and Mureithi, J. G. (2002). *Green Manuring to Improve Soil Fertility and Reduce Striga Weed Infestation in Smallholder Farms*. South Nyanza, Kenya. 176pp.

Palm, C. A., Gachengo, C. N., Delve, R. J., Cadisch, G. and Giller, K. E. (2001). Organic inputs for soil fertility management in the tropical agro-ecosystems: application of an organic resource database. *Agricultural Ecosystems and Environment* 83: 27–42.

Pandey, C. B. and Rai, R. B. (2007). Nitrogen cycling in gliricidia (*Gliricidia sepium*) alley cropping in humid tropics. *International Society for Tropical Ecology* 48(1): 87 – 97.

Peoples, M. B. and Herridge, D. F. (1990). Nitrogen fixation by legumes in tropical and subtropical agriculture. *Advanced Agronomy* 44: 153 – 223.

Peoples, M. B., Brockwell, J., Herridge, D. F., Rochester, I. J., Alves, B. L. R., Urquiaga, S., Boddey, R. M., Dakora, F. D., Bhattarai, S., Maskey, S. L., Sampet, C., Rerkasem, B., Khans, D. F., Hauggaard-Nielsen, H. and Jensen, B. S. (2009). The contributions of N-fixing crop legumes to the productivity of agricultural systems. *Symbiosis* 48: 1 – 17.

Peoples, M. B., Faizah, A. W., Rerkasem, B. and Herridge, D. F. (1989). Methods for evaluating N fixation by nodulated legumes in the field. Australian Centre for International Agricultural Research Canberra. *Monograph* 11: 7 – 76.

Peoples, M. B., Herridge, D. F. and Ladha, J. K. (1995a). Biological Nitrogen fixation: An efficient source of nitrogen for sustainable Agricultural production? *Plant and Soil* 174: 3 – 28.

Peoples, M. B., Landha, J. K. and Herridge, D. F. (1995b). Enhancing legume N_2 fixation through plant and soil management. *Plant and Soil* 174: 83 – 101.

Peterjohn, W. T., Melillo, J. M., Steudler, P. A., Newhrk, K. M., Bowles, F. P., Aber, J. D. (1994). Responses of trace gas fluxes and N availability to experimentally elevated soil temperatures. *Ecological Applications* 4: 617 – 625.

Pimratch, S., Jogloy, S., Vorasoot, N., Toomsan, B., Kesmala, T., Patanothai, A. and Holbrook, C. C. (2010). Effects of drought on characters related to nitrogen fixation in peanut. *Asian Journal of Plant Sciences* 9: 402 – 413.

Pleysier, L. J. (1995). Soil sampling and sample preparation. International Institute of Tropical Agriculture, Lagos, Nigeria. 38pp.

Poppi, D. P. and Norton, B. W. (1995). Intake of tropical legumes. In: *Tropical Legumes in Animal Nutrition.* (Editors by D'Mello, J. F. P. and Devendra, C.), Commonwealth of Agriculture Bureau International, Wallingford, UK. 47pp.

Price, J. G. and Berkelaar, D. (2005). Traditional techniques for improving soils leguminous ground covers and green manures. Educational concerns for hunger organization. [http://www.echotech.org/mambo/index.html] site visited on 20/6/2013.

Pugalenthi, M., Doss, A., Rajendrakumaran, D. and Vadivel, V. (2010). Antibacterial activity of *Canavalia ensiformis* L. DC seeds due to solvent extract and fraction method. *Indian Journal of Science and Technology* 3(1): 94 – 95.

Ranells, N. N. and Wagger, M. G. (1992). Nitrogen release from crimson clover in relation to plant growth stage and composition. *Agronomy Journal* 84: 424 – 430.

Rao, J. V. and Suresh, G. (1999). The influence of nitrogen fixing trees and fertilizer levels on the growth, yield and N_2 uptake of cowpea on a rainfed alfisol. *Experimentapl. Agriculture* 36: 41 – 50.

Rebafka, F. P., Mndunguru, B. J. and Marschner, H. (1993). Crop residue application increases nitrogen fixation and dry matter production in groundnut (Arachis hypogea L.) growth on an acid sandy soil in Nigeria, West Africa. *Plant and Soil* 150: 213 – 222.

Robertson, M. J., Sakala, W., Benson, T. and Shamudzarira, Z. (2005). Simulating response of maize to previous velvet bean (*Mucuna pruriens*) crop and nitrogen fertiliser in Malawi. *Field Crops Research* 91: 91 – 105.

Saggar, S., Yeates, G. W., Shepherd, T. G. (2001). Cultivation effects on soil biological properties, microfauna and organic matter dynamics in Eutric Gleysol and Gleyic Luvisol soils in New Zealand. *Soil and Tillage Research* 58: 55 – 68.

Saikia, S. P. and Jain, V. (2007). Biological nitrogen fixation with non- legumes: An achievable target or a dogma? Review article. *Current Science* 92(3): 317 – 322.

Salvagiotti, F., Cassman, K. G., Specht, J. E., Walters, D. T. and Weiss, A. (2008a). Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review. *Field and Crops Research* 108(1): 1 – 13.

Salvagiotti, F., Cassman, K. G., Specht, J. E., Walters, D. T., Weiss, A. and Dobermann, A. R. (2008b). Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review. *Field Crops Research* 133: 1 – 13.

Sanginga, N. (2003). Role of biological N fixation in legume based cropping systems; a case study of West Africa farming systems. *Plant and Soil* 252: 25 – 39.

Sanginga, N. and Woomer, P. L. (Eds.) (2009). *Integrated Soil Fertility Management in Africa: Principles, Practices and Developmental Process*. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture, Nairobi, Kenya. 263pp.

Sanginga, N., Okogum J. A., Akobundu, I. D. and Kang, B. T., (1996). Phosphorus Requirement and nodulation of herbaceous and shrub legumes in low P soils of a Guinean Savanna in Nigeria. *Applied Soil Ecology* 3: 247 – 255.

Sanginga, N., Okogun, J. A., Vanlauwe, B., Diels, J. and Dashiell, K. (2001). *Contribution of Nitrogen Fixation to the Maintenance of Soil Fertility With Emphasis on Promiscuous Soybean- Based Cropping Systems in the Moist Savanna of West Africa*. In: Tian, G., Ishida, F. and Keatinge, J. D. H. (Eds.), Sustaining Soil Fertility in West Africa. SSSA Special Publication No. 58. Soil Science Society of America. Madison, USA. pp. 157 – 178.

Sauer, J. (1964). Revision of *Canavalia ensiformis* L.DC. *Brettonia* 16: 106 – 181.

Schmidt, A., Peters, M., Franco, L. H. and Schultze-Kraft, R. (2005). *Canavalia brasiliensis* a multipurpose legume for the sub-humid tropics. In: *International Grassland Congress*. (Mara, F. P. O., Wilkins, R. J.,'t Mannetje, L., Lovett, D. K. and Boland, T. M. (Eds.), Wageningen Academic Publishers, Wageningen. 382pp.

Shoko, M. D. and Tagwira, F. (2005). Assessment of the potential of vegetable and grain soybeans as breakcrops in sugarcane production systems in Zimbabwe. *African Crop Science Society* 7: 59 – 65.

Shoko, M. D., Tagwira, F. and Zhou, M. (2007). The potential of reducing nitrogen fertilizers in a soybean-sugarcane production system in Zimbabwe. *African Journal Agricultural Research* 2: 16 – 26.

Silveira, J. A. G., Costa, R. C. L. and Oliveira, J. T. A. (2001). Drought-induced effects and recovery of nitrate assimilation and nodule activity in cowpea plants inoculated with bradyrhizobium spp. under moderate nitrate level. *Brazilian Journal of Microbiology* 32: 187 – 194.

Silver, W. L. and Miya, R. K. (2001). Global patterns in root decomposition: comparisons of climate and litter quality effects. *Oecologia* 129: 407 – 419.

Singh, B. B., Chambliss, O. L. and Sharma, B. (1997). Advances in cowpea breeding. In: Singh, B. B., Mohan Raj, D. R., Dashiell, K. E., Jackai, L. E. N. (Eds.), *Proceedings, Advance Cowpea Research,* Devon, UK. pp. 30 – 49.

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. Soil Science Society of America*. (Editors by Buresh, R. J., Sanchez, P. A. and Calhoun, F.), Special Publication No. 51. Madison, Wisconsin. pp. 49 – 52.

Snedecor, G. W. and Cochran, W. G. (1989). *Statistical Methods*. Eighth Edition. Iowa State University Press, Ames. 503pp.

Sullivan, P. (2003). Overview of cover crops and green manures. Fundamentals of Sustainable Agriculture. [http://attra.ncat.org/attra-pub/PDF/covercrop.pdf] site visited on 12/6/2011.

Thonnissen, C., Midmore, D. J., Ladha, J. K., Olk, D. C. and Schmidhalter, U. (2000). Legume decomposition and nitrogen release when applied as green manures to tropical vegetable production systems. *Agronomy Journal* 92: 253 – 260.

Tian, G., Kolawole, G. O., Salako, F. K. and Kang, B. T. (1999). An improved cover crop-fallow system for sustainable management of low activity clay soils of the tropics. *Soil Science* 164(9): 671 – 682.

Tisdale, S. L., Havlin, J. L., Beaton, D. B. and Werner, L. N. (1999). *Soil Fertility and Fertilizers. An Introduction to Nutrient Management*. (6^{th} Ed.), Prentice Hall, New Jersey. 4pp.

Tisdale, S. L., Beaton, J. D., Nelson, W. L. and Havlin, J. L. (1993). *Soil Fertility and Fertilizers*. (5^{th} Ed.), Macmillan Publishing Company, New York. 355pp.

Tuaeli, E., Mbaga, M. and Friesen, D. (2003). Adoptable maize/legume systems for improved maize production in northern Tanzania. *African Crop Science* 6: 649 – 654.

Turco, R. F. and Sadowsky, M. J. (1995). Understanding the microflora of bioremediation. In: Skipper, H. D. and Turco, R. F. (Eds.), Bioremediation: Science and Applications. *Proceeding of Soil Science Society of America,* Madison. pp. 87 – 103.

Unkovich, M. J. and Pate, J. S. (2000). An appraisal of recent field measurements of symbiotic N_2 fixation by annual legumes. *Field Crop Research* 65: 211 – 228.

URT (2000). *Tanzania Soil Fertility Initiative:* Concept Paper Report No. 81. Food and Agriculture Organization, Rome, Italy. 129pp.

Valenzuela, H and Smith, J. (2002). Cowpea: Sustainable agriculture green manure crops. [http://www.ctahr.hawaii.edu/oc/freepubs/pdf/greenManureCrops/cowpea.pdf] site visited on 12/6/2012.

Van Veen, J. A. and Kuikman, P. J. (1990). Soil structural aspects of decomposition of organic matter. *Biogeochemistry* 11: 213 – 233.

Versteeg, M. N., Amadji, F., Eteka, A., Gogan, A. and Koudokpon, V. (1998). Farmers' adoptability of Mucuna fallowing and agroforestry technologies in the coastal savanna of Benin. *Agriculture Systems* 56(3): 269 – 287.

Vitousek, P. M., Cassman, K., Cleveland, C., Crews, T., Field, C. B., Grimm, N. B., Howarth, R. W., Marino, R., Martinelli, L. and Rastetter, E. B. (2002). Towards an ecological understanding of biological nitrogen fixation. *Biogeochemistry* 57: 1 – 45.

Walsh, K. B. (1995). Physiology of the legume nodule and its response to stress. *Soil Biology and Biochemistry* 27: 637 – 655.

Wangari, N. and Msumali, G. P. (2000). *Decomposition of Sesbania Seban and Lantana Camara Green Manures: Effect of the Type of Green Manure and Rate of Application.* In: Soil Technologies for Sustainable Smallholder Farming Systems in East Africa. Soil Science Society of East Africa. Signal Press, Nairobi. Kenya. 20pp.

Warren, G. P., Muthamia, J. and Irungu, J. W. (1997). Soil fertility improvements under manuring in semi-arid Lower Embu and Tharaka-Nithi. In: *Focus on Agricultural Research for Sustainable Development in a Changing Economic Environment. Proceedings of the 5th KARI Scientific Conference,* 14 - 16 October 1996, Nairobi, Kenya. pp. 151 – 163.

Weber, G. (1996). Legume based technologies for African savannas: Challenges for research and development. *Biology of Agricultural Horticulture* 13: 309 – 333.

Wilson, M. E. (2001). Organic Matter Dynamics in Willow and Eucalypt Lined Central Victorian Streams. Unpublished PhD thesis, University of Ballarat, Ballarat, 170 pp.

Zahran, H. H. (1999). *Rhizobium*-Legume Symbiosis and N Fixation under Severe Conditions and in an Arid Climate. *Microbiology and Molecular Biology Reviews* 63: 968 – 989.

Zahran, H. H. (2010). Legumes–microbes interactions under stressed environments. In: *Microbes for Legume Improvement*. (Edited by Khan, M. S.), Springer-Verlag, Berlin, Heidelberg, pp. 353 – 387.

Zhu, Z. L. (2000). Loss of fertilizer N from plants-soil system and the strategies and techniques for its reduction. *Soil and Environmental Science* 9: 1 – 6.

Zhu, Z. L. and Chen, D. L. (2002). Nitrogen fertilizer use in China-contributions to food production, impacts on the environment and best management strategies. *Nutrient Cyclinge Agroecosystems* 63: 117 – 127.

APPENDICES

Appendix 1: Summary of analysis of variance (ANOVA) of studied variables at ARI-Uyole

Variable	Column	Row	Treatment
Emergence (%)	ns	ns	***
Plant height (cm)	ns	ns	***
Ground coverage (%)	ns	ns	***
Flowering (80%)	ns	ns	***
Nodule number	ns	ns	***
Effective nodule (no)	ns	ns	***
Nodule score	ns	ns	***
Dry matter (t/ha)	ns	ns	***
Nitrogen content (%)	ns	ns	***
Fixed nitrogen (kg/ha)	ns	ns	***

ns = not significant

* = significant at P<0.05

**= significant at P<0.01

***= significant at P<0.001

Appendix 2: Summary of analysis of variance (ANOVA) for Mwandobela

Variable	Column	Row	Treatment
Emergence (%)	ns	ns	***
Plant height (cm)	ns	ns	***
Ground coverage (%)	ns	ns	***
Flowering (80%)	ns	ns	***
Nodule number	ns	ns	***
Effective nodule (no)	ns	ns	***
Nodule score	ns	ns	***
Dry matter (t/ha)	ns	ns	***
Nitrogen content (%)	ns	ns	***
Fixed nitrogen (kg/ha)	ns	ns	***

ns = not significant

* = significant at P<0.05

**= significant at P<0.01

***= significant at P<0.001

Appendix 3: Summary of combined analysis of variance (A NOVA) for the studied variables

Variable	Location	Column	Row	Treatment	Location x Treatment	Location x Column	Treatment x Colum
Emergence (%)	**	ns	ns	***	***	ns	ns
Plant height (cm)	**	ns	ns	***	***	ns	ns
Ground coverage (%)	ns	ns	ns	***	***	ns	*
Flowering (80%)	***	ns	ns	***	***	ns	*
Nodule number	***	*	ns	***	***	ns	ns
Effective nodule (no)	***	ns	ns	***	***	ns	ns
Nodule score	***	ns	ns	***	***	ns	ns
Dry matter (t/ha)	**	ns	ns	***	***	ns	ns
Nitrogen content (%)	ns	ns	ns	ns	ns	ns	ns
Fixed nitrogen (kg/ha)	*	ns	ns	*	*	ns	ns

ns = not significant

* = significant at P<0.05

**= significant at P<0.01

***= significant at P<0.001

Appendix 4: Summary of combined analysis of variance (ANOVA) for the N content after decomposition

Variable	Location	Position	Treatment	Time	Interaction
Nitrogen content (%)	ns	ns	***	***	***

ns = not significant

* = significant at P<0.05

**= significant at P<0.01

***= significant at P<0.001