EFFECT OF MAIZE AND COMMON BEAN INTERCROPPING PATTERNS ON SOIL FERTILITY, CROP GROWTH AND YIELD

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A DISSERTATION SUBMMITED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE.

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ABSTRACT

A study was conducted to establish the effect of intercropping patterns using improved maize and common bean varieties recommended for low attitude areas (Morogoro) on soil fertility, growth and yield. The experiment was conducted in the Crop Museum at the main campus of Sokoine University of Agriculture in Morogoro, Tanzania. The site is located between latitude 06^{o}50'S and longitude 37^{o}39'E at 526 meter above sea level. The experiment was laid out in a randomized complete block design with three replications. The treatments included; Sole maize, sole common bean, conventional 1maize-1common bean, improved 1maize-2common bean and 2maize-2common bean intercropping patterns. Improved maize variety, *Meru HB 513* and common bean variety, *Pesa* were used. Fertilizers TSP and MOP at 27kg P/ha and 20kg K/ha, respectively, were used at planting. Growth parameters, nodulation and N_2-fixation of common bean, nutrients uptake, yield and yield components were recorded. The results showed that common bean in the improved (1:2) intercrop pattern recorded significantly ($p<0.008$) the highest value (11.67 kg/ha) of N_2-fixed than other treatments. Maize crop growth, leaf area index and total dry matter were significantly ($p<0.001$, $p<0.015$ and $p<0.001$, respectively) reduced by intercropping patterns. Similarly, common bean crop growth, leaf area index and total dry matter were highly significantly ($p<0.001$, $p<0.001$ and $p<0.001$, respectively) reduced. Intercropping patterns had no significant effect on maize yield and yield components. However, pod number and yield of common bean were significantly ($p<0.001$, $p<0.001$, respectively) reduced. The improved 1:2 intercrop pattern is the most beneficial in terms of the amount of N-fixed, land equivalent ratio (LER) and land saved as it produced highest fixed N (11.67 kg/ha), LER (1.59) and land saved (37.1%). On the bases of these results, farmers are advised to apply the improved (1:2) intercrop pattern.

However, validation of these findings is recommended for two to three seasons to come up with appropriate deduction.

DECLARATION

I, Ayubu Mushemado hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work done within the period of my registration and has not been submitted in any other institution.

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The above declaration is confirmed by;

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(Second supervisor)

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DEDICATION

This work is dedicated to my daughter Noreen and Norah so that this study will be a source of motivation for their education foundation. Also it is dedicated to my sister Julieth Sabinus Mushema for her prayers, encouragement and support throughout this study.

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LIST OF ABREVIATION AND SYMBOLS

%	Percent
/	Per
<	Greater than
<	Less than
ANOVA	Analysis of variance
ATP	Adenosine Triphosphate
BCR	Benefit cost ratio
BNF	Biological nitrogen fixation
CEC	Cation exchange capacity
CGR	Crop growth rate
cm	Centimetre
cmolc (+) kg^{-1}	Centimole (+) per kilogram
CV	Coefficient of variation
DAP	Days after planting
DM	Dry matter
EC	Exchangeable concentration
EURS	Efficiency Use In Rhizobia Symbiosis
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Statistics
Fig.	Figure
g	Gram
g/cm^{3}	Gram per cubic centimeter
ha	Hectare
ha^{-1}	Per hectare

HB	Hybrid
K	Potassium
K_2O	Potassium oxide
kg	Kilogram
LA	Leaf area
LAI	Lear area index
lb	Pound
LER	Land equivalent ratio
LSD	Least significant difference
m^2	Meter square
m^{-2}	Per meter square
MAI	Monetary advantage index
MBILI	Two
mg kg^{-1}	Milligram per kilogram
mg	Milligram
ml	Milliliter
mm	Millimeter
MOP	Muriate of potash
MPN	Most probable number
MSc	Master of science
N	Nitrogen
N_2	Dinitrogen
NaCL	Sodium chloride
NaOH	Sodium hydroxide
Ndfa	Nitrogen derived from the atmosphere
ns	Not significant

^{o}C	Degree Celsius
OC	Organic carbon
P	Phosphorus/ Probability
P_2O_5	phosphorus pentioxide
pH	Negative logarithm of hydrogen ion concentration
$Plant^{-1}$	Per plant
RGR	Relative growth rate
SNF	Symbiotic nitrogen fixation
SSA	Sub-Saharan Africa
SUA	Sokoine University of Agriculture
$t\ ha^{-1}$	Tones per hectare
TMA	Tanzania meteorological agency
TN	Total nitrogen
TSP	Triple supper phosphate
USA	United State of America
USDA	United State Department of Agriculture

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Maize (*Zea mays L.*) also known as corn in USA and *mahindi* in Swahili is the third cereal after rice and wheat across the globe (Dwivedi *et al*., 2015). It is the major cereal crop grown and consumed in almost every region in Tanzania (Cochrane and D’Souza, 2015). Maize accounts for 31% of the total food production and constitutes more than 75% of the cereal consumption in the country. It is estimated that the annual per capita consumption of maize is around 128 kg. According to Peter *et al.* (2013) and Lyimo *et al.* (2014), nearly 400 grams of maize are consumed per day per person in Tanzania; average national consumption is estimated to be over three million metric tones per year (FAOSTAT, 2014). Maize contributes about 34 – 36 % of the average daily calorie intake (BEFS, 2013). It has been identified as a key crop to enhance income, poverty alleviation and food security (Homann-Kee *et al*., 2013).

More than half of cultivated land in Tanzania (around 45% or over 4.9 hectares) is used for maize production (Pauw and Thurbw, 2011), with average potential yield between 1.0 and 1.5 t ha^{-1}, compared with the estimated potential yields of 4-5 t ha^{-1} (Barreiro-Hurle, 2012). About 85 % of maize in Tanzania is produced by small-scale farmers with minimum utilization of inputs production technologies and practices. Soil fertility and use of unimproved seed are among the major limitations in maize production in Tanzania (Msaky *et al*., 2010). There are different old maize varieties in Tanzania such as *Kilima-ST*, *Kito-ST*, *Katumani-ST*, *Stuka* (1 and 2), *Staha*, *TMV* (1 and 2) as indicated by Lyimo *et al*., (2014) and as listed by TOSCI (2016), but since then there are new improved varieties such as *Selian H215*, *WE* (*4102, 4110, 4114, 4115 and 4112*), T104, *Meru Lishe* (503 and

511), *Meru HB 513* and *Meru HB 515*. However, farmers in the country do not use improved seed probably due to low adoption of recommended agronomic practices and improved varieties (Lyimo *et al*., 2014). Therefore, in this study improved *Meru HB 513* and *Pesa*, maize and common bean varieties were used to develop knowledge and agronomic practices that will help farmers to adopt the use of improved varieties.

Common bean (*Phaseolus vulgaris L.*) is also food-secure and nutritious crop, especially in Sub-Saharan Africa (SSA). It plays a dietary role in supplying proteins, carbohydrates, essential mineral elements and vitamins to people all ages to both rural and urban households. It is estimated that the crop meets more than 50% of dietary protein requirements of households in SSA (Broughton *et al*., 2004). The annual per capita consumption of common bean is higher among low income people who cannot afford to buy nutritious food stuff, such meat and fish (Beebe *et al*., 2013). In East Africa, Tanzania is a major common bean producing country where it is estimated that over 75% of rural households depend on common bean for home consumption as well as cash crop income(Hillocks *et al*., 2006). In addition to the dietary value, legume such as common bean have the ability to develop root nodules in symbiosis with rhizobia to fix freely available atmospheric dinitrogen gas (N_2) and converting it to a biologically useful, combined form of N – ammonia, for use by the host plant or by associated or subsequent crop (Graham and Vance, 2003). Thus, beans are important crop that needs to be assessed for its capacity to fix N_2 as source of N for improving soil fertility and increase its yields.

In Tanzania, maize is commonly grown as a sole crop and as an intercrop with legumes such as common bean, cowpeas, pigeon peas and bambara nuts (Mekuria *et al.,* 2004). Intercropping is a type of mixed cropping and defined as the agricultural practice of cultivating two or more crops in the same space at the same time (Andrew and Kassam, 1976). Intercropping of maize with legumes is an alternative to maize monocropping and has a number of advantages compared to monocropping systems (Carruthers *et al*., 2000). One of these is the well known advantage of biological nitrogen fixation (BNF) in cropping systems, which is known to contribute to soil fertility improvement (Bloem *et al*., 2009). Legumes such as common bean have ability to form a symbiotic relationship with soil bacteria capable of trapping nitrogen gas (N_2) from the atmosphere and converting it into ammonia, which can be used by the plant for development and seed production. Atmospheric nitrogen is converted to ammonia by the nitrogenase enzyme in a process known as biological nitrogen fixation (BNF) (Brady and Weil, 2008).

The process of BNF contributes to the increase of nitrogen in the soil and improves soil fertility. Estimate indicates that crop legumes can fix between 30 and 150 kg of nitrogen per crop per hectare (Unkovich *et al*., 2008). Ojiem *et al*. (2007) and Nyemba and Dakora (2010) reported a range BNF from 33 to 124 kg N ha^{-1} by groundnuts, whereas Egbe *et al.* (2007) and Njira *et al*. (2012) reported a BNF range from 20 to 124 kg N ha^{-1} by pigeon pea from studies done in sub-Saharan Africa. FAO (1984) cited by Silva and Uchida (2000) worldwide reported BNF range from 40 to 70 kg N ha^{-1} by common bean, however, values for common bean biological N-fixation in Tanzania are very scant (Rweyemamu, C.L. personal communication, 2017). Benefits of legume N_2 fixation include soil fertility improvement (mainly through legume plant residues left after harvesting), savings on fertilizer costs and extra cash income from sale of crop surpluses and improved protein nutrition (Sanginga and Woomer, 2009). Nitrogen-fixing legumes work symbiotically with special bacteria, *rhizobia*, which live in the root nodules. Legume-rhizobium symbiosis system is the most important biological nitrogen fixation (BNF) system in nature, providing about 65% of the available nitrogen in the biosphere (Peoples *et al*., 1995). However, many studies of cereal-legume intercropping have shown that the quantity of N fixed by the legume depends on such factors as the morphology, density, competitive ability of intercropping, presence of effective rhizobia strains, available nitrogen, availability of various essential plant nutrients, temperature and moisture (Mohammadi *et al*., 2012).

1.2 Justification

Although intercropping has been used traditionally for thousands of years and is widespread in many parts of the world including Tanzania, to date it is poorly understood from an agronomic perspective (Hailu, 2015). Available evidence indicates that improved intercropping systems with integration of legumes would influence improved soil fertility, crop yields and consequently householder income (Sanginga and Woomer, 2009). However, small scale farmers in Tanzania lack information and knowledge on optimum cropping patterns. Not much has been done to evaluate performance and productivity in terms of soil properties, crop growth and yields under the improved intercropping systems, involving improved cereal and legume varieties, and agronomic information on improved varieties is scant. Further, knowledge on the effect of fertilizer application on intercrop productivity is generally lacking in Tanzania, despite the wide variability in soil fertility status in farmers' fields. The fertilizer requirement (phosphorus and potassium) for maize and common bean had been worked out (Kanyeka *et al*., 2007; Marandu *et al*., 2013), but when these two crops are grown together in intercropping, fertilizer requirement has not been standardized. Therefore, a study on cereal-legume intercropping patterns is needed to evaluate the soil properties, performance and economic benefits of the crops to smallholder farmers.

Despite the multiple benefits of intercropping, smallholder farmers plant their intercrops randomly without any defined row arrangements, use local and low yielding varieties.

This has also resulted in lower component crop populations, difficulty in management, low crop yields and overall productivity of the systems (Massawe *et al*., 2016). In Tanzania, most of the intercropping systems that has been researched and repeated on are the use of conventional (1:1) intercropping systems (Keswani and Ndunguru, 1980; Rweyemamu, 1989; Nyasasi and Kisetu, 2014; Massawe *et al*., 2016, 2017). Intercropping patterns have been studied in some parts of East and Southern Africa (Tungani *et al*., 2002; Woomer *et al*., 2004; Undie *et al*., 2012; Matusso *et al*., 2014). All these studies assessed the performance of different distinct alternate row intercropping patterns of maize and legumes. The literature indicates that the use of other crop arrangements such as improved intercropping systems (1:2, 1:3 and 2:2) can be more advantageous in terms of soil fertility improvements, soil conservation, microclimate improvements, land utilization, crop protection and increased yield (Undie *et al*., 2012). Woomer *et al*. (2004) reported that the *MBILI* system increased both legumes by an average of 40% and maize yields by an average of 20%. Matusso *et al*., (2014) reported the same results with maize yield increases in the *MBILI* system. Undie *et al*. (2012) reported the 2:2 arrangement with the highest yield followed by 1:2 arrangement for maize and soybean intercropping in the humid South Southern agro-ecology of Nigeria. In Tanzania information about improved intercropping patterns is very scanty. Therefore, this research was undertaken to gather more knowledge and understanding of this systems.

1.3 Objectives

1.3.1 Overall Objective

To establish the effect of intercropping patterns using improved maize and common bean varieties recommended for low attitude areas (Morogoro) on soil fertility, crop growth and yield.

1.3.2 Specific Objectives

i. To determine the effect of intercropping patterns of maize and common bean on soil fertility improvement through biological N_2 fixation of common bean.

ii. To determine the influence of applied nutrients (P and K) on maize and common bean growth under different intercropping patterns.

iii. To evaluate the effect of different maize and common bean intercropping patterns on yield and yield components.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cereal – legume Intercropping Systems

Intercropping is a common cropping system in Africa, Asia and Latin America which more than 80% of smallholder farmers grow the bulk of food crops and some of the cash crops (Mekuria *et al*., 2004). The practice has been widely used to increase productivity in various continents worldwide, such as Southeast Asia, Latin America and Africa (Yang *et al*., 2015). In intercropping system there is one main crop cultivated with one or more added crops where the main crop is of primary importance due to economic or food production reasons (Brintha and Seran, 2009). The most common combinations in intercropping systems are cereal–legume, particularly maize-beans, maize-cowpea, maize-soybean, maize-pigeonpea, sorghum-cowpea, millet-groundnuts and rice-pulses. In Tanzania smallholders farmers mix crop cereals and legumes such as beans, cowpeas, pigeonpeas, greenpeas and bambaranuts (Mekuria *et al.*, 2004).

In intercropping, an intercrop is generally grown to make best use of interspace which is not fully utilized by main crop in early growth periods. The intercrop may reduce or increase the yield of main crop, depending on the species and spatial arrangements of component crops. Planting system in intercropping is defined by inter-row and intra-row spacing. In the conventional (1:1) intercropping system, one row of maize is alternated with one row of legume. In an innovative, improved intercropping system named *MBILI* for “two”, two or more rows of cereals are alternated by two rows of legume, also known as a two-by-two staggered arrangement (Tungani *et al.*, 2002). Appropriate arrangement can modify the microclimate between component crops as well as further improve radiation utilization, evapotranspiration and soil moisture. Woomer *et al.* (2004) and

Woomer (2007) reported that *MBILI* system allows more light penetration for the under-storey legume component without changing the plant densities. Woomer *et al*. (2004) demonstrated more than 50% higher light penetration, but also suggested that superior cop yields in the *MBILI* system were related to additional advantages in root distribution and reduced below ground competition. Most efficient use of natural resources was always the main reason for increasing productivity in intercropping, especially for light, water and nutrients (Li *et al*., 2011).

2.2 Benefits of Cereal-legumes Intercropping

In the Sub-Saharan Africa region, cereal and grain legumes intercropping is most practiced by smallholder farmers (Sanginga and Woomer, 2009; Odendo *et al*., 2011). The major reason why these farmers intercrop cereals and legumes is because they are particularly important human food as they are rich in protein and sometimes sold for cash income (Odendo *et al*., 2011). In addition, intercrops give them the stability of the yields over several seasons (Ofori and Stern, 1987), when one crop fails, the other might still give a reasonable yield (Prasad and Brook, 2005).

Benefits of intercropping cereal and legumes have been largely proved. Besides the major role of legume in the traditional diets throughout the world, legumes provide a multiple benefits to both soil and other crops through intercropping (Stajkovic *et al*., 2011). Several studies have been carried out in recent years and proven the beneficial effects of legumes on soil fertility improvements (Sanginga and Woomer, 2009). Legume crops have the advantage in obtaining nitrogen (N) through biological nitrogen fixation (BNF) (Giller, 2001). The process of BNF contributes to the increase of nitrogen in the soil and improves soil fertility. Legumes have shown to add organic matter into the system, which can increase soil stability, resistance to soil erosion and activities of soil biota (Beedy *et al*., 2010). In addition, improved soil cover by intercropping with legume, can result in weed control and reduction of nutrient leaching (Mucheru-Muna *et al.*, 2010). Furthermore, intercropping provides yield advantage compared to sole crop because of more efficient use of resources such as light, water and nutrient (Choudhury and Rosario, 1992). On the other hand, it is believed that traditional intercropping systems are better in pests and diseases control. When species are grown as sole crops it attracts many pests and diseases which visually might show less damage when intercropped compared to monoculture (Trenbath, 1993). Traditional intercropping system is also believed to control weeds compared to monocrops. Weed infestation poses competition for natural and applied input, such as light and nutrients. It is also the most important constraint on yield and economic return of maize production due to the wide space between rows (Jamshidi *et al.*, 2013). The legume crop under intercropping suppresses weeds through competition for resources (Gliessman, 1983).

2.3 Biological Nitrogen Fixation (BNF) in Legume

Biological nitrogen fixation is the process whereby atmospheric dinitrogen is converted into ammonia which is subsequently assimilated by the growing legume plants. Various micro-organisms including specific cynobacteria, actinomycetes and bacteria mediate this process. Rhizobia are the predominant group of the N_2 fixing organisms (Giller and Wilson, 1991). These bacteria are symbiotically associated with legumes roots through nodules. In the root nodules the rhizobia reduces atmospheric N_2 to $NH3^+$, and the amount of N_2 fixed in this process depend on characteristics of the host legumes, the rhizobia and soil properties. Biological nitrogen fixation, which depend on atmospheric nitrogen (N), is important in legume-based cropping systems when fertilizer-N is limited (Fujita and Ofosu-Budu, 1996), particularly in Sub-Saharan Africa where nitrogen annual depletion was recorded at all levels at rates of 22 kg ha^{-1} and mineral fertilization is neither available nor affordable to smallholder farmers (Mugwe *et al*., 2011). Legume species commonly used for provision of grain and green manure have potential to fix between 80 to 350 kg nitrogen (N) ha^{-1} (Peoples and Craswell, 1992) from the atmosphere.

2.4 Native Rhizobia in Soil

Many soils contain rhizobia that live on the soil organic matter, without legume partners. These are called native rhizobia while those that farmers add as inoculants are called introduced rhizobia (Woomer *et al*., 2011). The population of native rhizobia in soil can be very diverse, including several species, and many distinct strains within each species. Number can range from zero to more than a million rhizobia per gram (g) of soil. In most parts of the world there is a broad range of rhizobia strains which vary in the degree of effectiveness and competitiveness. Population density, effectiveness and competitiveness ability are the primary characteristics of indigenous rhizobial populations that determine inoculation responses (Thies *et al*., 1991). A quantitative understanding of the role of indigenous rhizobial populations in determining host response to inoculation should help to identify locations at which inoculation will succeed in improving crop yield. Such knowledge can help to determine where and when to use inoculants for inoculums production facilities and production requirements (Thies *et al.,* 1991). Nitrogen fixation is reported to be affected by the nature of rhizobia population such that low rhizobia population may not nodulate the host adequately and the ineffective population may fail to nodulate the host to its nitrogen requirements (Denton *et al*., 2000). Therefore, evaluation of the capability of native nitrogen fixing rhizobia for legume provides a way forward for yield improvement.

2.5 Host Specificity and Symbiotic Effectiveness

Host specificity refers to the ability of particular rhizobia species to form nodules on specific legumes (Gyorgypal *et al.*, 1988). The approach of using effective or superior exotic rhizobia strains as inoculants has failed in various environments due to various reasons including the use of ineffective and non-competitive rhizobia strains as inoculants (Slattery *et al.*, 2004). The host specificity leads to a perfect match between legume and rhizobia resulting into effective nodules formation and nitrogen fixation. If cross inoculation with no perfect match has occurred, ineffective nodules or no nodules may be formed and nitrogen fixation does not occur (Gwata *et al.*, 2004). Some researchers have reported that rhizobia of different genera can infect the same plant species but some plant species can strictly be infected by rhizobia from only one specific genera (Botha *et al.*, 2004). For instance, cowpea has been reported to be nodulated by rhizobia isolated from soybean, groundnuts and bambara groundnuts but these legumes cannot be nodulated by rhizobia isolated from cowpea (Ampomah *et al.*, 2008).

2.6 Biological Nitrogen Fixation (BNF) in Common Bean

Common bean is one of the many legume species able to fix N_2 through BNF and nodulate with many different strains of root nodulating bacteria or rhizobia. Under favorable conditions it can nodulate and fix N_2 abundantly (Giller and Wilson, 1991). However, present day commercial common bean varieties are poor nitrogen fixers and research results in this area are quite variable. Yet under optimal conditions, estimates of symbiotic nitrogen fixation (SNF) of up to 73% of the total plant nitrogen have been obtained for specific genotypes and in beans with longer growing seasons, amount of up to 125 kg/ha have been recorded, showing that the potential for improvement of SNF in common bean is present (Giller, 2001). Kimura *et al.* (2004) reported that the contributions of N from N_2 fixation range from 24 to 50% in field grown beans at different growth stages. Silva and

Uchida (2000) reported BNF range from 40 to 70 kg N ha^{-1} by common bean. Thus being a legume crop, common bean is capable of supplying nitrogen for its growth and intercropped cereals through symbiotic nitrogen fixation, and hence reduces the need for expensive and environmental polluting nitrogen fertilizers.

2.7 Rhizobia Population Estimates using the Most Probable Number (MPN)

The most probable number (MPN) technique is a means to estimate microbial population sizes. The technique is widely used to enumerate rhizobia based upon the ability of rhizobia to nodulate appropriate host legume plants (Bala and Giller, 2006; Olsen *et al.*, 1996). The method relies upon the pattern of positive and negative nodulation responses of host plant inoculated with a consecutive series of dilutions of rhizobia containing sample suspension. Rhizobial MPN enumeration is based on the following major assumptions: 1) a single viable rhizobium cell inoculated onto its specific host in a nitrogen-free medium will cause nodule formation; 2) nodulation is the proof of infective rhizobia. 3) the validity of the test is demonstrated by the absence of nodules on uninoculated plants; and 4) absence of nodules on inoculated plants is proof of the absence of viable infective rhizobia.

Cultivation of legume in area has been reported to influence the population of rhizobia. The repeated cultivation of symbiotic legumes can lead to rapid increase of rhizobia population and significant improvement of soil nitrogen fixation (Dennis and Guchuki, 2011). In Brazil, Andrade *et al*. (2002) reported that rhizobia population nodulating common bean ranged between 7.6×10^4 and 1.57×10^3 cell per gram of soil in the plot with 4% aluminum saturation and unlimed, respectively. In Nigeria using MPN, Aliyu *et al*. (2013) found that native rhizobia population estimates for soybeans were very low in slightly acidic soil and were not found in moderately acidic soils.

2.8 Nitrogen Transfer in Cereal-legume Intercropping Systems

In intercropping systems, legumes can provide N for intercropped cereals through N transfer. The higher N facilitation may enable cereal to absorb more N in intercropping systems than in sole cropping systems, or it may increase the N fixation ability of legumes and may transfer from legume to cereal (Ning *et al*., 2012). According to Fujita *et al*., (1992), an assumption exists stating that a portion of N_2 fixed by an intercropped legume is made available to an associated non-legume crop during the growing season. Also Giller and Wilson (1991) indicated that, if a legume is grown in association with another crop, commonly a cereal, the N nutrition of the associated crop may be improved though N transfer from legume to cereal. Eaglesham *et al*. (1981) showed that 24.9% of N fixed by cowpea was transferred to maize. Willey *et al*. (1986) reported that almost all of the fixed nitrogen goes directly into the plant, however, some nitrogen can be “leaked” or “transferred” into the soil (30–50 lb N/acre which is equivalent to 9.07-13.61 kg N/ acre for neighboring non-legume plants. In addition, the soil may be replenished with N through decomposition of legume residues (Fujita and Ofosu-Budu, 1996).

2.9 Growth Performance and Yield of Cereal-legumes Under Phosphorus and Potassium Fertilization in the Mixed Systems

For proper plant growth and development, the soil must be fertile and contain appropriate levels of essential mineral elements (White *et al*., 2012). The most important plant nutrients for production of high yields are N, P and K. Potassium is required by plants for a number of vital physiological processes including the following: activation of several enzymes, synthesis and degradation of carbohydrates, production of proteins as well as regulation of stomata pores for gas exchange and photosynthesis (Lissbrant *et al.,* 2009). However, P and K are usually very low in soils, a condition which limit proper plant growth resulting in reduced crop growth and yields. Apart from their biochemical and physiological functions in the plants, these elements have other function of enhancing biological nitrogen fixation.

The influence of phosphorus on symbiotic N_2 fixation in leguminous plants has been studied intensively and many researchers have reported that phosphorus improved nitrogen fixation in legumes (Zafar *et al.*, 2011). Studies have shown that plants supplied with appropriate amount of P has resulted in increased yields over the control (Zafar *et al.*, 2011). Belger and Wihmann (1980) stated that, for the nutrients other than N, it is usually recommended that each crop in the association be considered separately and that fertilizer be applied according to the needs of each. The limited availability of soil nutrients, call upon researchers to conduct researches to investigate the response of crops (legumes and cereals) supplied with P and K at different intercropping patterns on N_2 fixation, crop growth and yields.

2.10 Nutrients Uptake by Maize and Common Bean in Intercrop

Mineral nutrients are usually obtained from the soil through plant roots, but many factors can affect the efficient of nutrient acquisition (Hell and Hillebrand, 2001). The rate of nutrient uptake by roots depends on the concentration of the particular nutrient at the root surface, root properties or plant species, and requirement of the plant. For instance, Mohd *et al.* (2007) reported that the nutrient uptake and concentration in leaves depend on the fertilizer types applied and the nutrient available in soil for plant uptake. According to Bisanda *et al.* (1998), a crop of maize that produces 5 to 6 tones ha^{-1} would remove up to 100 to 150 kg N ha^{-1} and 17 to 26 kg P ha^{-1} per cropping season from the soil through harvest. Haag *et al.* (1967), reported that the highest amount of nutrient elements absorbed by the bean plant is nitrogen and potassium. They reported that at the peak of absorption (R6), about 100 kg of N and 100 kg of K are absorbed.

2.11 Intercropping productivity

Undie *et al.* (2012) reported that the total farming system productivity is assessed by land equivalent ratio (LER) and the portion of land saved. Land equivalent ratio was first defined as the relative land area required as a sole crop to produce the yields achieved in intercropping (Carlson, 2008). It measures the effects of both beneficial and negative interactions between the intercropped species. In interpretation, LER values above one indicate that intercropping is more productive and efficient in using environmental resources than sole cropping, and values less than one that sole crops were more productive. For instance, using LER in maize-cowpea intercropping system, Nyasasi and Kisetu (2014) reported that it was greater than one (1.92). Muoneke *et al.* (2007) found that the productivity of the intercropping system indicated yield advantage of 2-63 % as depicted by the LER of 1.02 – 1.63 showing efficient utilization of land resources by growing the crops together. Also Addo-Quaye *et al.* (2011) found that LER was greater than unity, implying that it will be more productive to intercrop maize and soybean than grow them in sole crop.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location

This study was conducted at the Crop Museum located in the main campus of Sokoine University of Agriculture (SUA) in Morogoro, Tanzania. According to the Tanzania meteorological agency (TMA) weather station at SUA, the site is located between latitude $06^{o}50'$S and longitude $37^{o}39'$E at 526 meter above sea level. The experimental site is characterized by well-drained kaolinitic clayey soils, sub-humid to humid climate conditions and irregular rainfall distribution (Mahoo *et al.*, 1999). The mean annual air temperature is 24^{o}C, whereas the annual soil temperature is iso-hyperthermic. The soil is predominantly Ultisols (Kanhaplic Haplustult/Chromic Acrisol) as described by Msanya *et al.* (2003) and generally acidic in reaction with low nutrients (Kisetu *et al*., 2013).

3.2 Planting Materials

3.2.1 Maize

One improved maize variety, *Meru HB 513* was used. *Meru HB 513* was released in 2012. It is a white seeded and medium maturing (100-110 days) variety. The variety is a nitrogen user efficient (i.e. use small amount of fertilizers), tolerant to drought with average grain yield of 3 – 4 t/ha (http://www.meruagro.com).

3.2.2 Common bean

One improved common bean variety was used. *Pesa*, a red seeded variety was breed by the Department of Crop Science and Horticulture at SUA and released in 2008. According to the information obtained from the Department of Crop Science and Horticulture, the variety is non-crawling (bush type) and tolerant to insect pests and diseases. It matures in 62 – 75 days and yields about 4 t/ha (Suzan, F. N. M. personal communication, 2017).

3.3 Experimental Design and Treatments

Experimental layout used was as a randomized complete block design (RCBD) with three replications. The number of treatments were five; Sole grown maize (SM) and common bean (SB), conventional 1maize-1common bean (MB 1:1) and the improved1maize-2common bean (MB 1:2) and 2maize-2common bean (MB 2:2) intercrop patterns. Details of the conventional and the improved intercrops patterns are shown in Figures 1 (a, b and c).

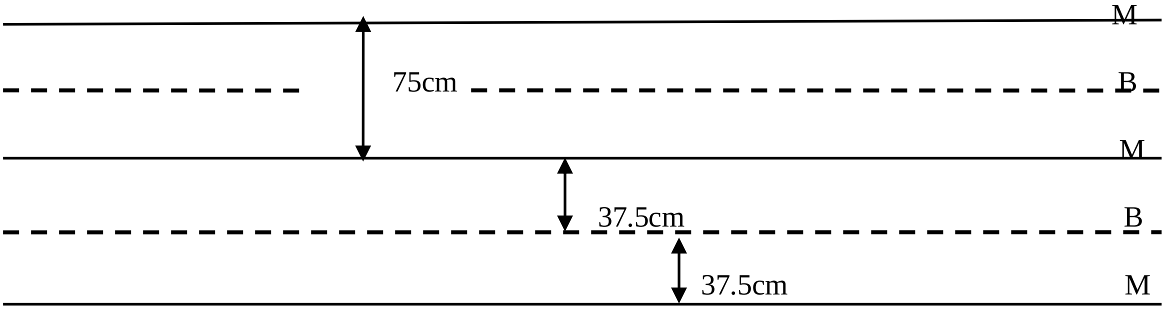

Figure 1a: Showing a conventional 1:1 cropping pattern (Treatment)

Key: ——— Maize row; - - - - - - Common bean row

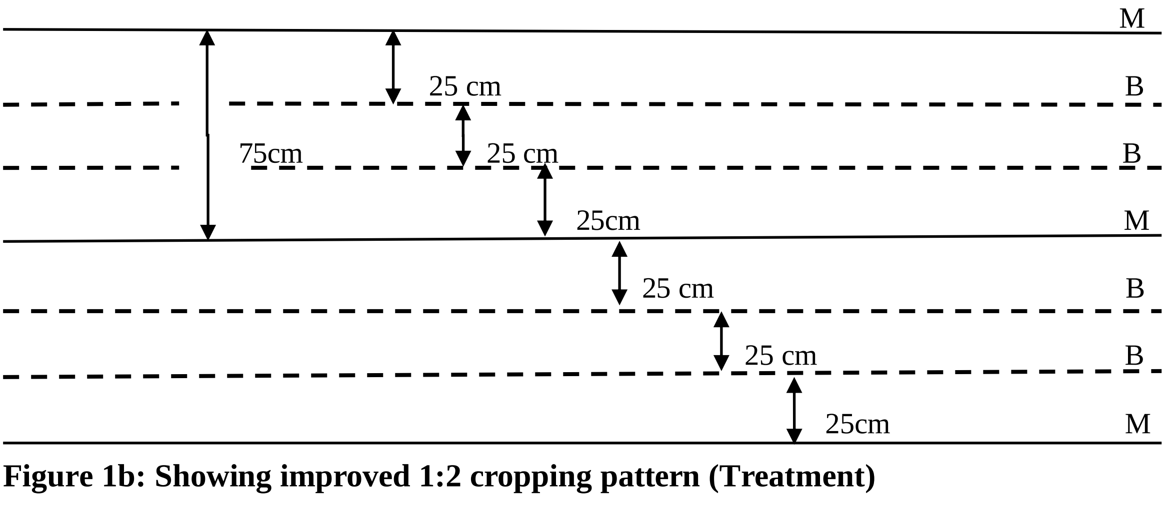

Figure 1b: Showing improved 1:2 cropping pattern (Treatment)

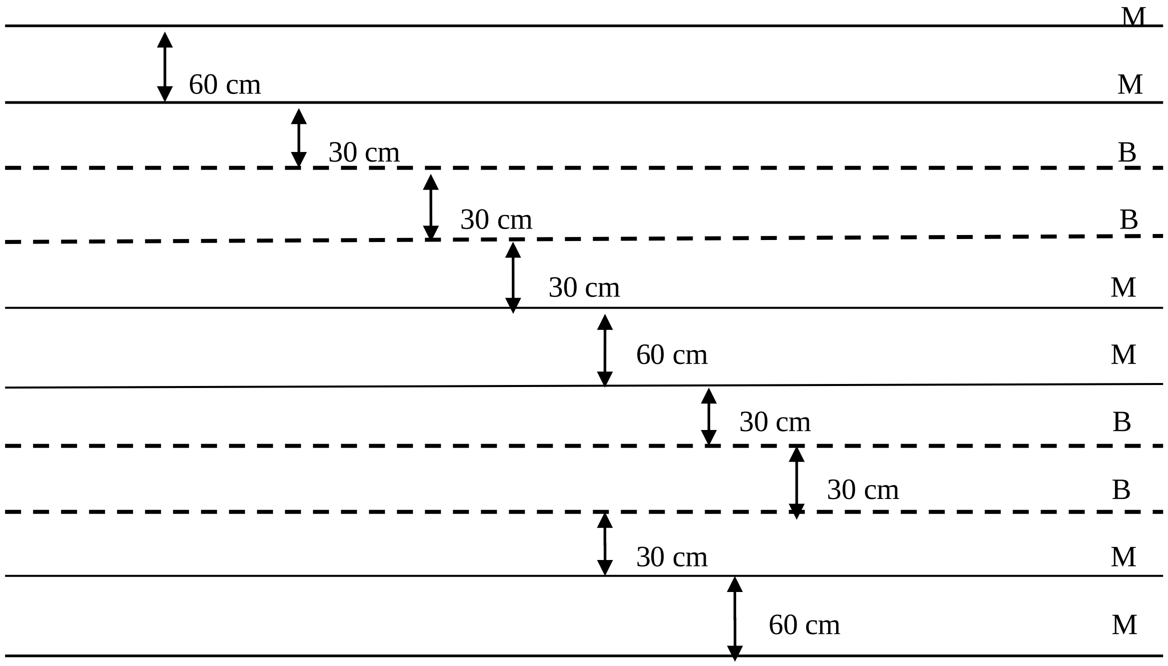

Figure 1c: Showing improved 2:2 cropping pattern (Treatment)

One sole crop of each maize and common bean were added for comparison. The plot size was 4.5m x 3m, giving area of 13.5m^2. The grand total area of the experiment was 21m x 21m giving a total area of 441m^2. The experimental layout and treatment application is shown in Appendix 1.

3.4 Agronomic Practices

The experimental area was prepared by tractor ploughing and leveling was done using hand hoes and rakes. The experiment was initiated in the first week of February (6th), 2018. The field was irrigated to field capacity one day before sowing. The sole maize was planted at a spacing of 75cm by 30cm. Spacing for sole common bean was 50cm by 20cm (Kanyeka *et al.*, 2007) while 37.5cm by 20cm, 25cm by 20cm and 30cm by 20cm were applied for the common bean in the conventional (1:1) and the improved (1:2), (2:2) intercrop patterns, respectively. At planting 27 kg P ha^{-1} from TSP and 20 kg K ha^{-1} from MOP were applied. Details on spacing, plant populations and fertilizer calculations for two nutrients (P and K) are shown in Appendix 2 and 3. Other crops managements were applied as recommended by Kanyeka *et al*. (2007).

3.5 Data Collection

Data collected included weather data, soil physical, chemical and biological characteristics, plant and development characteristics, yield and yield components.

3.5.1 Laboratory and screen house experiment

3.5.1.1 Soil physical, chemical and biological characteristics

The disturbed and undisturbed soil samples were collected from the experimental site within the area of 21 by 21 m. Soil sample for physical and chemical characteristics determination were collected randomly from 0 – 20cm depth as described by Motsara and Roy (2008) in January, 2018 before the initiation of the experiment. Composite samples were parked in clean plastic bags and brought to the Department of Soil and Geology Sciences laboratories at SUA for laboratory analysis. One composite sample was air-dried and analyzed for soil physical and chemical characteristics. The second composite sample was stored at 4 ^{o}C and analyzed for soil biological characteristics. Detailed methods are indicated in Table 1.

Table 1: **Soil characteristics determined at the initiation of experiment (January 2018)**

Property	Method of analysis	Reference
Physical characteristics		
Particle size analysis	Hydrometer method	Moberg, (2000)
Bulky density	Core method	Saka and Haque, (1993)
Chemical characteristics		
Total nitrogen	The micro-Kjedahl method	Moberg, (2000)
Total organic carbon	Walkley-black method	Moberg, (2000)
Available phosphorus	Bray and Kutz 1 method	Moberg, (2000)
Cation exchange capacity (CEC)	Ammonium acetate saturation method	Moberg, (2000)
Exchangeable bases (Na^+, K^+, Ca^{2+} and Mg^{2+})	Ammonium acetate saturation Method	Moberg, (2000)
Soil pH.	Potentiometry (1:1.25 water saturation)	Moberg, (2000)
Biological characteristics		
Quantity of active nitrogen-fixing microsymbiont for common bean.	MPN-Plant infection technique	Vincent, (1970)
Total symbiotically fixed Nitrogen.	Modified Nitrogen Difference method	Vincent, (1970)

At the end of the experiment soil analysis was done as indicated in Table 2 to determine the soil chemical changes that may have occurred during the experimentation time. The soil samples (0 – 20cm depth) were taken at eight different spots per plot then bulked to give one composite sample for each plot, this aimed to reduce variability of nutrients.

Table 2: **Soil characteristics determined at the end of experimentation (May 2018).**

Property	Method of analysis	Reference
Chemical characteristics		
Total nitrogen	The micro-Kjedahl method	Moberg, (2000)
Available phosphorus	Bray and Kutz 1 method	Moberg, (2000)
Total organic carbon	Walkley-black method	Moberg, (2000)
Cation exchange capacity (CEC)	Ammonium acetate saturation method	Moberg, (2000)
Exchangeable bases (Na^+, K^+, Ca^{2+} and Mg^{2+})	Ammonium acetate saturation Method	Moberg, (2000)
Soil pH	Potentiometry (1:1.25 water saturation)	Moberg, (2000)

3.5.1.2 Biological properties of the soil

Soil biological characteristics evaluation was done to quantify the rhizobia population from soil at the experimental site and determine their competitiveness and infectiveness in nodulating and N-fixing with common bean.

3.5.1.2.1 Preparation of growth medium and planting material

The growth medium used in this study was river sand. The sand was washed in five changes of tap water and airy dried. Sand was washed in five changes of tap water and airy dried. The common bean variety used was *Pesa*. The seeds were cleaned in water to remove storage chemicals and then surface sterilized using the procedures as described by Olsen *et al*. (1996).

3.5.1.2.2 N-free nutrient solution preparation and Leonard Jar assembly

Five N-free nutrient stock solutions were prepared in the Soil and Geological Sciences Microbiology laboratory following the composition in Table 3 by Somasegaran and Hoben

(1985). The nutrient solutions for irrigating the plants in Leonard jars was prepared by diluting 2.0 ml of each stock solution per four liters of distilled water. The five stock solutions were stored in the refrigerator throughout the experiment period and dilution was done to supplement when the amount in Leonard jars was decreasing. The solutions were sterilized by autoclaving at 121 ^{o}C for 15 minutes before supplemented in Leonard jar bottoms.

Table 3: **N-free plant nutrient composition**

Stock solution	Element	Chemical	Quantity g/l
1.	Ca	$CaCl_2.2H_2O$	294.1
2.	P	KH_2PO4	136.1
3.	Mg	$MgSO4.7H_2O$	123.3
	K	K_2SO4	87.0
	Mn	$MnSO4.H_2O$	0.338
4.	**B**	H_3BO_3	0.247
	Zn	$ZnSO4.H_2O$	0.288
	Cu	$CuSO4.5H_2O$	0.1
	Mo	$NaMoO_2.H_2O$	0.048
	Co	$CoSO4.7H_2O$	0.056
5.	Fe	Fe Citrate +	5.4

Source: Somasegaran and Hoben (1985)**.**

The Leonard jar shown in Fig. 2 was assembled following the procedures as described by Somasegaran and Hoben (1985). The jar assembly was wrapped with brown manila sheet then followed by aluminum foil wrapping to protect roots and nutrient solution from light. The complete assembly and nutrient solution was sterilized by autoclaving for 30 minutes at 121 ^{o}C and left overnight in the autoclave to cool.

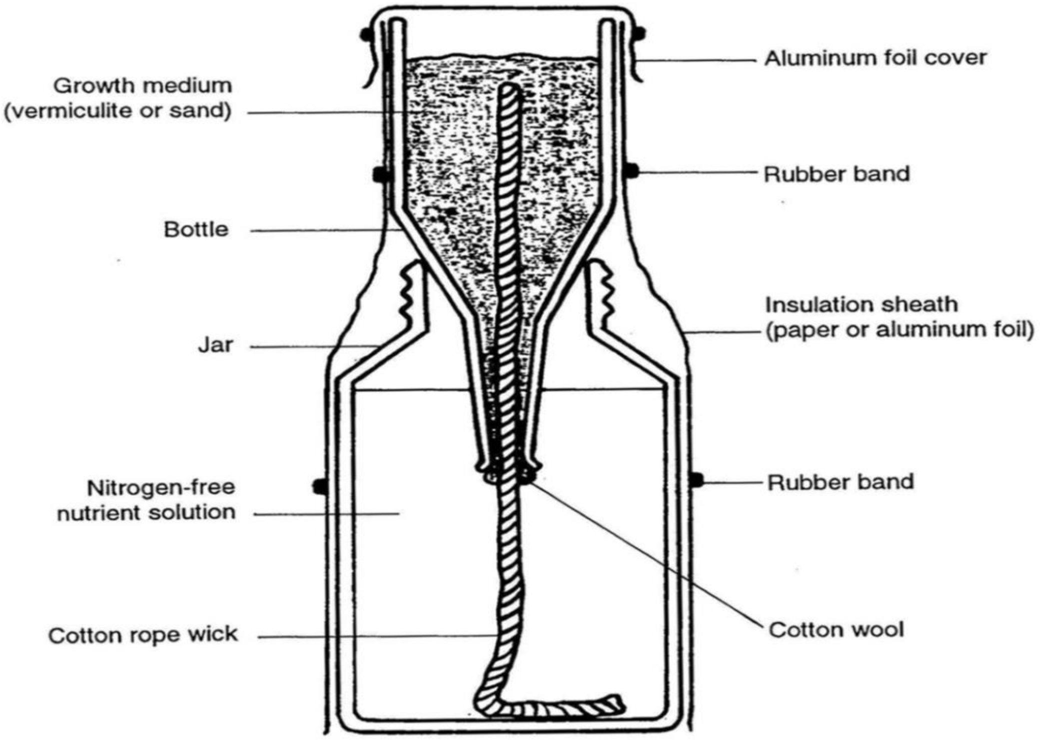

Figure 2: **The Leonard jar (above) assembly (Somasegaran and Hoben, 1985)**

3.5.1.2.3 Serial dilution preparation, planting and inoculation

Serial dilutions of soil from the experimental site were done for inoculation of common bean in Leonard jars. Tenfold serial dilution was made from10^{-1} to 10^{-5}following the procedures as described by Vincent (1970). Four seeds were planted in Leonard jar and thinned two plants four days after emergence. Then inoculation was done after six days since emergence. An aliquot of 2 ml of diluents was used to inoculate common bean seedlings grown in Leonard jars. Four Leonard jars were inoculated with each four dilutions. Two uninoculated control Leonard jars were included for each dilution to determine if cross contamination of Leonard jars occurred. Plants were managed by regular addition of the nutrient solution and data collection was done when they started to flower.

3.5.1.2.4 Estimation of rhizobia population and Determination of its infectiveness

Plants were harvested carefully, retaining their nodules. Nodulation was observed (+, for nodulation or – for no nodulation) and the number of nodulated (+) plants was recorded besides each dilution. The presence of a single nodule in a Leonard jar was considered as a positive score (Vincent, 1970). The total number of nodulated units was obtained by summing up the nodulated units at each dilution level. Plant shoots were oven dried at 70 ^{o}C to constant weight. The dried plant shoots were weighed and ground to pass 0.5 mm sieve and analyzed for N using the micro-Kjeldahl method (Moberg, 2000). The numbers of rhizobia in soil were determined using the Most Probable Number (MPN) plant infection technique. The MPN was calculated from the most likely number (m) obtained from the MPN results Table, according to the formula:

$$MPN = \frac{m \ x \ d}{v} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

Where: *m* is the most likely number from MPN tables, *d* is the lowest dilution in the series and *v* is the aliquot used for inoculation (Vincent, 1970).

3.5.2 Field experiment

3.5.2.1 Plant growth and developmental characteristics

The following growth variables were determined: Plant heights in cm, above total dry matter, leaf area, plant nutrients concentration and uptake were recorded for both maize and common bean during the growing season. Days to various growth stages for maize plants were recorded as described by Ritchie *et al.* (1992) at22 DAP (fourth leaf stage, V4), at 52 DAP (first tasseling stage, VT), at 61 DAD (75% tasseling, R1), 79 DAP (physiological maturity, R6) and 99 DAP (harvest maturity, R9). Common bean growth stages was also identified and recorded as described by Schwartz *et al.* (2004)at 22 DAP (fourth trifoliolate leaf stage, V4), at 30 DAP (one open flower, R1), at 38 DAP (early pod stage, R3) at 65 DAP (physiological maturity stage, R7) and at 77 DAP (harvest maturity, R8).

3.5.2.2 Plant height (cm)

Plant heights at 22, 52 and 61 days after planting (DAP) were measured from five plants from each of the two central rows and an average was obtained. Also, plant height was measured from five common bean plants at 22, 30and 38 DAP. Plant height was measured from ground surface up to the base of the apex. Measurement was done by using tape measure.

3.5.2.3 Total dry matter (gm^{-2})

Five plants from two central rows per m^{-2} area were sampled from each plot and cut at ground level for the above total dry matter. Plant sampling was done at 22, 52, 79 and 99DAP. Three common bean plants were also sampled from rows per plot at 22, 30, 65 and 77 DAP. The above plant materials were oven- dried for 48 hours at 70 ^{o}C and the total dry matter in each plot was recorded. Growth variables like crop growth rate (CRG) and relative growth rate (RGR) were determined using formula (ii) and (iii). According to Clawson *et al*. (1986), CGR measures the accumulation of dry matter per unit area and is a reasonable approximation of canopy photosynthetic rate per unit ground area. RGR is a measure used to quantify the speed of crop growth.

$$\text{CGR (g m}^{-2}\text{ day}^{-1}\text{)} = \frac{W_2 - W_1}{SA(t_2 - t_1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

Where: CGR is the crop growth rate, W_1 and $W_2$are crop dry weight at the beginning and at the end of the interval, t_1 and t_2 are corresponding days, SA is a soil area occupied by plants at sampling (Brown, 1984).

$$\text{RGR [g (g dry wt.)}^{-1}\text{ day}^{-1}\text{]} = \frac{\text{In}W_2 - \text{In}W_1}{t_2 - t_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(iii)}$$

Where, In is the natural log, W_1 is the dry weight of plant/m^2 recorded at time t_1, W_2 is the dry weight of plant/m^2 recorded at time t_2, t_1 and t_2 were the interval of time, respectively (Radford, 1967).

3.5.2.4 Leaf area (cm) and Leaf area index (LAI)

Leaf area index was determined from five plants in the central rows at 22 and 61 DAP for maize and three plants at 22 and 38 DAP for common bean. The product of length and widest width of individual plant leaves multiplied by 0.75 (Dwyer and Stewart, 1986) and 0.6 (Setegn, 2006), correction factor for cereal and legume, respectively, was used to estimate individual leaf area. The total leaf area of plants divided by the leaf area of land occupied per m^{-2} was used to calculate leaf area index:

$$\text{LAI} = \text{LA/GA} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(iv)}$$

Where; LA is the total leaf area of a plant, and GA is the total ground area of a plant, (Radford, 1967).

3.5.2.5 Nodulation and N-fixation of common bean

Plant sampling in sole and intercropping patterns was done at 30 DAP for nodulation assessment, determination of N-fixed and nutrients (N, P and K) uptake. Nodules were detached, counted and oven dried at 70 ^{o}C to constant weight. The shoots were oven-dried at 70 ^oC for 48 hours and ground to pass a 0.5 cm sieve for chemical analysis. Laboratory chemical analysis for N, P and K were done in the Soil Science and Geology department laboratory. Nitrogen content was measured by micro Kjeldahl method, P content by wet oxidation method (Spectrophotometer) and K concentration by wet oxidation method (Frame Photometer) Moberg (2000). Biological nitrogen fixation was determined using the modified Nitrogen-Difference method. This was done by comparing total nitrogen of legume by that of a non-legume (Ashworth *et al.*, 2015). The amount of N fixed was calculated by subtracting of the reference crop (maize) from that of the legume (common bean) and the difference value is assumed as N derived by BNF (N_2 fixed).

Thus, N_2 fixed = Total N in legume – Total N in reference crop …………….……….. (v)

Total N_2 fixed in plants (kg/ha) = (matter yield (kg/ha) x % N in plants)/100 ……… (vi)

The percentage of nitrogen derived from the atmosphere (%Ndfa) was determined as follows:

$$\%N_{dfa} = \frac{(\text{Total Nin legume} - \text{Total N in reference crop})}{\text{Total N in legume}} \times 100 \quad \text{……………………} \quad \text{(vii)}$$

3.5.2.6 Yield and yield components

Maize and common bean plants were harvested at maturity stage. Common bean was harvested first in April at 77 DAP followed by maize in May, 2018 at 99 DAP. At harvest, the number of plants in the harvest area was recorded. The harvest area consisted of the inner four rows of maize plants giving a harvest area of 7.2 m^2 for sole maize, maize-common intercropping patterns and an area of 8.4 m^2 for sole common bean. At harvest, yield and yield components of maize and common bean were determined according to Polthanee and Trelo-ges (2003). Hundred grain/seed weight was obtained from randomly samples grains at 12% moisture content and yield per m^{-2} converted into tones per hectare using the formula:

$$\text{Grain yield (t ha}^{-1}) = \frac{\text{Plot yield (kg) x 10000 m}^2}{\text{Plot size (m}^2\text{) x 1000 kg}} \ldots\ldots\ldots\ldots\ldots\ldots\text{(viii)}$$

The productivity for different cropping systems was assessed and evaluated using the land equivalent ratios (LER) and percentage of land saved. LER and the percentage of land saved were determined as described by Ijoyah *et al*. (2013) and Workayehu (2014) using the formulae below:

$$\text{LER} = \frac{Y_{AB}}{Y_A} + \frac{Y_{BA}}{Y_B} \ldots\ldots\ldots\ldots\ldots\ldots\text{(ix)}$$

Where:

Y_{AB} is the intercropped yield of maize

Y_A is the sole yield of maize

Y_{BA} is the intercropped yield of common bean

Y_B is the sole yield of common bean

$$\text{Land saved (\%)} = 100 - (1/\text{LER}) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots \text{(x)}$$

3.6 Data analysis

Data collected was analysed using GenStat 15th edition statistical software. The analysis included analysis of variance (ANOVA) using the following statistical model;

$$Y_{ij} = \mu + T_i + B_j + e_{ij}\ldots\ldots\ldots\ldots\ldots\ldots \text{(xi)}$$

Where: Y_{ij} = any observation for which $_i$th is the treatment factor and *j*th is the blocking factor

μ = is the overall mean

T_i = the effect for being in treatment $_i$

B_j = the effect for being in block $_j$

The mean separation test was done using Last significant difference (LSD) at 5% probability. Correlation analysis was calculated to assess the inter-relationship among crops growth variables and nutrients uptake.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Soil Physical and Chemical Characteristics at the Experimental Site

4.1.1 Soil texture

Analysis of soil from the experimental site was conducted to evaluate the fertility status and its suitability for cereal and legumes crop performance. The physical and chemical properties of the soil from the experimental site at the initiation of experiment are shown in Table 4. According to the USDA textural class triangle, the textural class of soil was clay (Moberg, 2000). From the soil analytical results, the major soil fertility limitations included low total nitrogen (0.17 %), available phosphorus (4.98 mg/kg), potassium (0.03 cmol_c(+)/kg) and medium organic matter (3.1 %), hence the soil was categorized as of low fertility status and moderately suitable for cereal and legumes production.

4.1.2 Soil bulky density

The bulky density of soil from the experimental site was 1.30 g/cm^3 (Table 4). The bulky density of the soil within the range of 1.0 and 1.3 g/cm^3 is categorized as low according to Pam and Brian (2007). According to Cass (1999), limiting values of bulky density for plant growth depend on soil texture. Soil with lower bulky densities such as clay and clay loam reflect good structure and less compaction help in good root growth of plants. The soils with higher bulky densities reflect greater compaction and reduce/restrict root growth (Landon, 1991). Therefore the bulky density obtained indicates that the site used was appropriate for maize and common bean production.

Table 4: **Physical and chemical properties of soil at the crop museum, SUA**

Parameter	SI-unit	Value	Status	Rating according to:
Sand	%	41.96		
Clay	%	47.76		
Silt	%	10.28		
Textural class			Clay	Moberg (2000)
Bulky density	g/cm3	1.30	Low	Pam and Brian (2007)
pH (H_2O)		6.14	Slightly acidic	Pam and Brian (2007) and Msanya (2012)
Total nitrogen	%	0.17	Low	Landon (1991)
Available phosphorus	mg/kg	4.98	Low	Landon (1991)
Soil organic carbon	%	1.79	Medium	Landon (1991)
Soil organic matter	%	3.1	Medium	Msanya (2012)
Calcium	$cmol_c$ (+)/kg	6.01	Medium	Pam and Brian (2007)
Sodium	$cmol_c$ (+)/kg	0.65	Low	Landon (1991)
Magnesium	$cmol_c$ (+)/kg	2.12	High	Landon (1991)
Potassium	$cmol_c$ (+)/kg	0.03	Low	Landon (1996)
Cation exchange capacity (CEC)	$cmol_c$ (+)/kg	12.6	Low	Landon (1991)

4.1.3 Soil pH

The pH value of the soil at the experimental site was 6.14 (Table 4). According to Pam and Brian (2007) and Msanya (2012), the pH of the studied soil falls in slightly acidic ranges of 6.1 to 6.5, which are suitable for production of most crops. The optimal soil pH range for maize production is between 6.0 to 7.0 (Timbula, 2003) and 6.0 to 6.8 for common bean (Kay, 1979). Acidity influences both the growth of legume plant and the infection process. Bordeleau and Prevost (1994) reported that nitrogen fixation by rhizobia to most leguminous plants is effective at neutral (6.6 to 7.3) or slightly acidic (6.1 to 6.5) soils.

4.1.4 Total nitrogen (N)

According to Horneck *et al*. (2011), 1 - 4% of the total N becomes plant-available N. Landon (1991) reported that N requirement is categorized as low when the values of nitrogen are in the range of 0.1 to 0.2%. In a study conducted by Deng *et al*. (2000), the authors observed low total N observed and asserted it might have been due to limited use of organic soil amendments, denitrification, nitrogen mining through crop harvests without incorporation of plant residues after harvest to support gradual depletion of the available nitrogen as a consequence of ammonium and nitrate uptake by crops and microbes. The low total nitrogen of the soil at the experimental site suggests that the soil is suitable for BNF process of legumes. Biological nitrogen fixation which is important in legume-based cropping systems when fertilizer-N is limited (Fujita and Ofosu-Budu, 1996). High N in soil inhibits legumes nodule formation and symbiotic nitrogen fixation (Weria *et al*., 2013).

4.1.5 Available phosphorus (P)

The plant available phosphorus (Bray 1) content in the soil was 4.98 mg/kg (Table 4). According to Landon (1991), P <15 mg/kg is rated as low. Deficiency of phosphorus and nitrogen has been identified as a major problem affecting crop productivity in many parts of the country (Ikerra *et al*., 2006). Continuous intensive cropping with insufficient nutrient or no fertilizer input is a major contributor to progressive decline in soil nutrients, resulting in farm household becoming locked into a cycle of declining crop yields and poverty (Semoka, 2002). Soils are considered deficient in P if the soil plant-available P contents are less than 40 mg kg^{-1} determined by Bray-1 method (Mourice and Tryphone, 2012). Therefore, to meet the crops P requirements, P-fertilizer materials need to be applied to address P deficiencies in soil.

4.1.6 Exchangeable Potassium (K)

Exchangeable K in soil at the experimental site was 0.03 cmol$_c$(+)/kg. According to Landon (1996), exchangeable K is rated as follows; 0.03 – 0.2 cmol$_c$(+)/kg (low values), 0.2 – 0.4 cmol$_c$(+)/kg (medium values) and 0.4 – 0.8 cmol$_c$(+)/kg (high values). From this study, the exchangeable K in soil at the experimental site was rated as low. Abbott (1989), reported that exchangeable potassium levels below 0.2 cmol$_c$(+)/kg suggest that a plant response to application of potassium fertilizer is possible, particularly where heavy removal of potassium by harvesting or grazing occurs.

4.1.7 Organic carbon (OC)

The organic carbon (% OC) content in the soil was 1.79% (Table 4) and ranked as medium according to Landon, (1991). The values of organic carbon determine organic matter contents in the soil which also indicates soil fertility status. According to Thiagalingam (2000), soil organic carbon of less than 1.0% indicates problems of low nutrient holding capacity. Therefore, the results in this study indicate marginally holding capacity of soil nutrients.

4.1.8 Cation exchange capacity (CEC)

Cation exchange capacity (CEC) is a measure of the general fertility of soil and is widely used for agricultural assessment. The CEC of the soil from the experimental site was 12.6 $cmol_c(+)kg^{-1}$ (Table 4) and categorized as low according to Landon, (1991). The low CEC may be associated with low levels of P and K. Thiagalingam (2000), stated that low CEC is associated with low levels of total P and K. Pam and Brian (2007) categorized the cation exchange capacity of 12-25 as being moderate for crops production. Therefore, from these analytical results the soil at the experimental site is categorized as being marginally suitable for maize and common bean production. The values of other exchangeable bases (Ca Na and Mg) for soil from the study site are presented in Table 4.

The exchangeable calcium in soil was 6.01 $cmol_c(+)/kg$. Pam and Brian (2007) reported that Ca requirement is categorized as moderate when the levels of exchangeable Ca values are in the range of 5 – 10 ($cmol_c(+)/kg$). Therefore, the soil in this study is rated as having medium exchangeable calcium moderately suitable for maize and common bean production.

The exchangeable Na in soil was 0.65 $cmol_c(+)/kg$. Based on the rating by Landon (1991), the soil had low Na content. The findings from this study suggests that soil at the experimental site is free from salts, especially Na containing salts indicating positive attributes in terms of soil fertility. Although Na may, in particular circumstances, be utilized by some plants as a partial substitute for K, it is not an essential plant nutrient Landon (1991). Its absence or presence in only small quantities is therefore not usually detrimental to plant nutrition. However, when Na is present in the soil in significant quantities, particularly in proportion to the other cations present, it can have an adverse effect, not only on many crops, but also on the physical conditions of the soil. The exchangeable Mg in soil was 2.12 cmol$_c$(+)/kg. Based on categorization by Landon (1991), exchangeable Mg level in the soil was high suggesting that it is not one of the nutrients contributing to low yield of crops in the study area. The high value of Mg in soil might be attributed to its high content in the parent materials of the soil.

4.2 Evaluation of Soil Biological Characteristics

4.2.1 Indigenous rhizobial population in soil

The results of MPN counts (Table 5) indicated that the rhizobia numbers (populations) in soil were 8.5 x 10^4 cells per gram of soil. The level of rhizobia populations observed in this study is adequate to give satisfactory results on nodulation and nitrogen fixation of common bean. This suggests that common bean production in this area does not require inoculation. For nodulation to be optimum, the rule of thumb is that, soil should contain rhizobia numbers not less than10^3 cells per gram of soil (Herridge *et al*., 2000).

Table 5: **MPN counts of rhizobia in soil**

	Nodulation				
	Number of jars				**Number of nodulated units**
Dilution	**I**	**II**	**III**	**IV**	
10^{-2}	+	+	+	+	4
10^{-3}	+	+	+	+	4
10^{-4}	+	+	+	+	4
10^{-5}	+	+	+	+	4
Control	-	-	-	-	0
Total					**16**

Number of replication (n) = 4; dilution steps (s) = 10; number of nodulated units (+) = 16; lowest dilution in the series (d) = 10^{-2}, volume of aliquot (v) = 2 ml.

4.2.2 Infectiveness and competitiveness of native rhizobia strains

The results (Table 6) show the infectiveness of rhizobia in nodulating and N-fixing with common bean. Generally, no significant differences were observed between nodulation parameters, shoot dry matter and total shoot N accumulation. There were no nodules in the control treatment while higher numbers of nodules were observed in treatments that were inoculated with different levels of soil diluents. The results on nodulation and N-fixation of common bean indicate that native rhizonia strains in soil at the experimental site were infective and competitive. This means that the native rhizobia in soil were competitive and infective in fixing nitrogen to meet host nitrogen requirements level thus there was no need to use inoculants at such site (Kremer and Peterson, 1982). According to Simon *et al.* (2014), a single rhizobia cell in an inoculant or soil can cause nodulation whereas the absence of nodules on inoculated plants maybe a proof of the absence of infective rhizobia.

Table 6: General fixation parameters of common bean system

Treatments (Dilution levels)	**Nodule Number**	**Nodule dry weight (mg plant^{-1})**	**Shoot DM (g plant^{-1})**	**Shoot TN(%)**
10^{-2}	73.0	49.0	0.17	0.72
10^{-3}	53.3	58.0	0.17	0.79
10^{-4}	62.0	63.7	0.17	0.75
10^{-5}	64.3	91.3	0.19	0.93
Grand mean	63.3	65.5	0.175	0.80
CV (%)	36.1	44.0	16.4	58.4
LSD	42.97	54.28	0.054	0.876
P value	0.773ns	0.369ns	0.781ns	0.946ns

ns – not significant.

4.3 Field Experiment

4.3.1 Effect of intercropping patterns on biological nitrogen fixation of common bean

4.3.1.1 Nodule numbers and weights as affected by intercropping patterns

The effect of intercropping patterns on nodulation was assessed by quantifying two key nodulation parameters, namely nodule number and nodule dry weight per plant. Results (Table 7) show that nodule numbers and weights were highly significantly (P<0.001) reduced by intercropping patterns. The observed reduction in the number and weight of nodule of intercropped common bean when compared to sole common bean as per the present study might be as a result of poor plant nutrition and shading effect of maize. The results in this study are in agreement with those of Latati *et al.* (2016) who reported a significant decrease of common bean nodule dry weight when intercropped with maize. In other results, Egbe (2007) and Egbe and Egbo (2011), reported a decreased nodulation in intercropped cowpea, pigeonpea and groundnuts the reduction in nodulation was attributed to the adverse effect of shading.

Table 7: Effect of intercropping patterns on nodulation and N-fixation of common bean systems

Treatment	**Nodule number (plant^{-1})**	**Nodule dry (mg plant^{-1})**	**Plant N conc.(%)**	**Ndfa (% ha^{-1})**	**N_2 fixed (kg ha^{-1})**
SB	83.7	104	1.04	66.6	9.97
MB(1:1)	28.3	31	1.01	68.5	5.29
MB(1:2)	16.3	7	1.11	69.2	11.67
MB(2:2)	19.0	15	1.15	78.2	3.79
Grand mean	36.8	39	1.08	70.6	7.68
CV (%)	21.3	36.4	6.2	19.0	29.6
LSD	14.8	0.03	0.13	25.3	4.29
P-value	<0.001***	<0.001***	0.125ns	0.730ns	0.008**

ns – not significant; **significant at P≤0.01; ***significant at P≤0.001

4.3.1.2 Quantities of N_2 fixed and %Ndfa as affected by intercropping patterns

The amounts of biologically fixed N and %Ndfa on common bean as influenced by intercropping patterns are as presented in Table 7. Results of variance analysis indicated that there was significant (p=0.008) effects on N-fixed as influenced by different intercropping patterns of maize and common bean. Common bean in the improved (1:2) intercrop patterns recorded significantly the highest value (11.67 kg ha^{-1}) of N_2-fixed than all the other treatments. An increased amount of N_2-fixed by common bean under the improved (1:2) intercrop patterns as per the present study could have been enhanced by competition effects between species for nutrients since the soil in the experimental site were deficient in N and P and/ or since P was supplied in fewer quantities in the improved (1:2) intercrop patterns as compared to other treatments. The higher competition effects could be related to higher number of plant densities as recorded in the improved 1:2 intercrop patterns compared to all the other treatments. These results are in agreement with those of Giller *et al*. (1991) who reported that intercropping of grain legumes generally results in the legume deriving a greater proportion of its N from N_2-fixation than when grown alone. In other studies, Li *et al*. (2009) and Naudin *et al*. (2010) reported an increase of N_2 fixation by common bean as a consequence of the competition with the intercrop durum wheat.

4.3.1.3 Weather conditions during experimentation

Data on weather characteristics during the experiment period are shown in Fig. 3. Daily rainfall (mm), minimum and maximum temperature (^oC) during the course of the experiment were recorded daily at the Tanzania meteorological agency (TMA) SUA station. The meteorological data recorded during the experiment showed that the crops received a total rainfall of 555.9 mm during the growing period which was higher than the amount required especially for common bean production. The ideal amount of rainfall for production of common bean is in the range of 300 – 500 mm during the growing season. Maize needs from 500 to 800 mm of water per growing season (FAO, 1991). The results show that the experimental site received the average minimum temperature ranging from 19.9 to 22.5 °C while the maximum temperature ranged from28.4 to 32.5 °C. These results show that the mean and maximum temperatures at the experimental site were within the ranges for optimum growth of both maize and common bean. According to Salcedo *et al*.(2006), common bean grows well at temperatures ranging from 15 to 27 °C and will withstand temperatures up to 29 °C. Maize grows well at temperature range of between 21 and 27 °C.

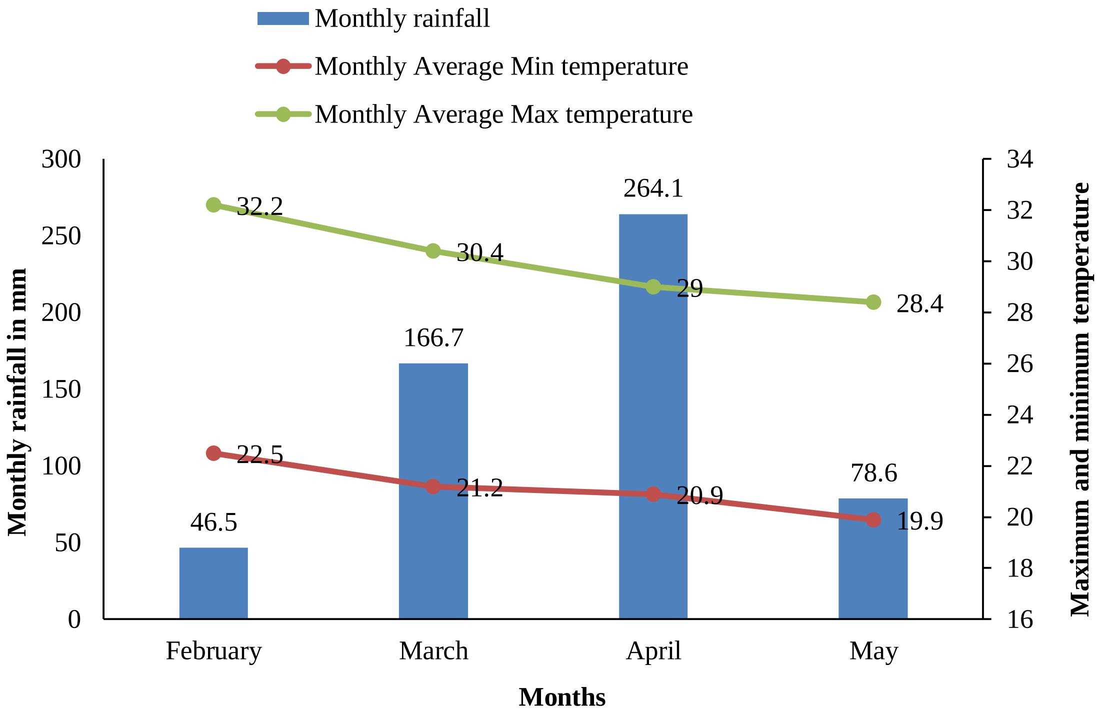

Figure 3: **Monthly average Rainfall, minimum and maximum temperature values of the experimental area during growing season (2018)**

4.4 Effects of Intercropping Patterns on Maize Growth Variables

4.4.1 Plant height (cm)

The effects of intercropping patterns on growth variables of maize are presented in Table 8. Statistical analysis results showed that maize plant height was not significantly affected by intercropping patterns as determined at 22, 52 and 61 DAP. However, maize in maize-common bean intercrop patterns recorded numerically between (171.3, 169.3 and 156.0 cm for conventional 1:1, improved 1:2 and 2:2 intercrop patterns, respectively) plant height of intercrops to sole crop (178.3 cm). This might be because of reduced vegetative growth as a result of competition for growth resources such as light and nutrients, since P and K were supplied in lower quantities as compared to sole crops. These findings are in support of those by Habte *et al.* (2016) working in Ethiopia, in which there were no significant difference in terms of plant height between sole maize and maize-common bean intercrop treatments. Also, Muoneke *et al.* (2007) reported non-significant differences of plant height and leaf production of maize as influenced by its association with soybean. In other results, Lemlem (2013) found that intercropping maize with cowpea reduced maize plant height as determined by environmental factors and competition between the two crops.

4.4.2 Total dry mater (g m^{-2})

The results (Table 8) from statistical analysis indicated that the intercropping patterns had no significant effects on maize total dry matter determined at 22 and 52 DAP; however, the effect was highly significant ($p<0.001$) at 79 DAP. Maize under sole crop recorded significantly larger total dry matter (301.3 gm^{-2}) at 79 DAP as compared to maize in maize-common bean intercrop patterns. The differences observed in shoot dry matter between sole maize and maize in intercrop patterns could be explained by the competition between plants differing in nutrients acquisition and utilization. Total dry matter of sole maize was positive and significantly (r=0.999;p=0.027) correlated with K uptake as shown in appendix 4.Better utilization of available resources such as nutrients in sole maize may have increased the LAI and so increased dry matter production of plant. The findings in this study agree with those of Nyasasi and Kisetu (2014) in Tanzania, the authors found that above-ground total dry matter of maize were low in the intercrop as opposed to the sole maize system. In other studies, Morgado and Willey (2003) reported that dry matter yield accumulation in an individual maize plant decreased with increase in bean plant population when grown under intercrop.

4.4.3 Leaf area index (LAI)

There were no statistically significant differences in LAI as determined at 22 DAP (three weeks after planting) between sole grown maize and maize-common bean intercrop patterns, however, the effect was significant (p=0.014) at 61 DAP. At 61 DAP sole maize recorded significantly the larger (3.36) LAI than maize in all maize-common bean intercrop patterns (Table 8). The decrease in LAI index recorded for maize in different intercrop patterns with growth stage progresses as per the present study could be related to lesser growth as a result of competition with common bean for growth resources and most carbohydrate being sent to reproductive organs such as maize cobs and tassels formed at that time. For instance competition for light and nutrients could possibly be the most important growth resources limited in this trial, because of inadequate supply of nutrients (P and K) in intercrop patterns as compared to sole crop.

Several studies have reported greater indices of leaf area in sole cropping treatments in comparison with intercropping treatments. The findings in this study are in agreement with those of Yavas and Unay (2016) who reported the highest LAI of maize with legume intercropping early in the growth stages and values were decreased with crop growth progresses. Choudhary *et al*. (2014) working in India found a decrease in LAI of maize when it was intercropped with vegetables (radish, spinach and carrot) over sole cropping. Ren *et al*. (2016) reported that the LAI values of the sole crop treatments for both maize and soybean were greater than that of the intercropping system, indicating that maize and soybean suppressed the LAI values of the competing crop when intercropped.

Table 8: Effects of intercropping patterns on plant height, total DM and leaf area index of maize plant

		Plant height (cm)			Total DM (g m^{-2})			Leaf area index	
Treatments	**Crop**	**22DAP**	**52DAP**	**61DAP**	**22DAP**	**52DAP**	**79DAP**	**22DAP**	**61DAP**
SM	Maize	65.3	163.0	178.3	12.8	127.8	301.3	0.48	3.36
MB(1:1)	Maize	56.7	156.3	171.3	10.1	126.7	232.3	0.55	2.85
MB(1:2)	Maize	54.8	161.3	169.3	8.0	123.4	186.3	0.91	2.66
MB(2:2)	Maize	51.0	149.0	156.0	6.9	125.1	209.7	0.57	2.86
Grand mean		56.9	157.4	168.8	9.4	125.8	232.4	0.63	2.93
CV (%)		9.8	14.1	9.4	42.7	13.8	9.8	33.5	6.9
LSD		10.45	41.93	29.98	7.58	32.56	43.04	0.40	0.38
P-value		0.068ns	0.867ns	0.429ns	0.350ns	0.990ns	<0.001∗∗∗	0.134ns	0.014∗∗

ns – not significant; ∗∗significant at $P \leq 0.01$; ∗∗∗significant at $P \leq 0.001$

4.4.4 Crop growth rate (CGR) (g m^{-2} day^{-1})

The statistical analysis results on maize crop growth rate are presented in Table 9. Intercropping patterns indicated non-significant (p=0.350 and p=0.993) effects on CGR as determined at 22 and 52 DAP, respectively; however, the effects were highly (p<0.001) significant at 79 DAP. The absence and presence of significant effect on CGR determined at 22, 52 and 79 DAP could be related to the fact that during the early growing season the intercrop patterns had higher leaf (LA) which increased with decrease as growth stages progresses. This could probably result due to competition for growth resources such light and soil nutrients. The findings in this study are in support with those of Addo-Quaye *et al.* (2011) who reported that CGR for sole crop was higher than the mean of the mixed plots. Yang *et al.* (2018) in pea/maize intercropping reported that the CGR of sole maize was always greater than intercropped maize as obtained in two different years. In other studies, (Pandey, 2016) reported that successive increase of nutrients caused a progressive increase in crop growth rate (CGR) of maize.

Table 9: Effect of intercropping patterns on crop growth

		CGR (g m^{-2} day^{-1})			**RGR** [g (g dry wt.)$^{-1}$ day^{-1}]		
Treatments	**Crop**	**0-22 DAP**	**22-52 DAP**	**52-79DAP**	**0-22 DAP**	**22-52 DAP**	**52-79 DAP**
SM	Maize	0.26	1.70	4.54	2.48	4.84	5.69
MB(1:1)	Maize	0.20	1.73	2.76	2.25	4.83	5.42
MB(1:2)	Maize	0.16	1.71	1.64	2.01	4.80	5.19
MB(2:2)	Maize	0.14	1.75	2.21	1.91	4.83	5.32
Grand mean		0.19	1.72	2.79	2.16	4.83	5.40
CV (%)		42.7	12.8	12.7	18.6	2.9	2.0
LSD		0.15	0.42	1.67	0.76	0.265	0.203
P-value		0.350ns	0.993ns	<0.001∗∗∗	0.366ns	0.991ns	0.003∗∗

ns – not significant; ∗significant at P≤0.01; ∗∗∗significant at P≤0.001

4.4.5 Relative growth rate [g (g dry wt.)$^{-1}$ day^{-1}]

In the same trend as in CGR, intercropping patterns had no significant (p=0.366 and p=0.991) effects on crop RGR as determined at 22 and 52 DAP, respectively, but the effects were significant (p=0.003) at 79 DAP (Table 9). Similar to crop growth rate, these findings also indicates reduced relative crop growth rate in intercrop treatments as compared to sole crop treatment, which is related to competitions for growth resources such as nutrients. These results agrees with those of Elfeel *et al*. (2013) who reported that crop forage yield and RGR were reduced with intercropping compared with sole crop. In other studies, Pandey and Singh (2015) stated that RGR values in wheat was initially high but with time it decreases and much of the decrease would be attributed to an increase of shading.

4.5 Effects of Intercropping Patterns on Common Bean Growth Variables

4.5.1 Plant height (cm)

The results on effects of intercropping patterns on common bean growth variables are presented in Table 10. Intercropping patterns had significant (p=0.004 and p=0.009) effect on common bean plant height at 22 and 38 DAP, respectively; however, the effect was not significance at 30 DAP. Common bean in maize-common bean 1:2 intercrop patterns recorded significantly highest height (62.7 cm) followed by 2:2 intercrop patterns (57.7 cm). The highest plant height as observed in the improved 1:2 and 2:2 intercrop patterns could be related to inter-specific competition between species for growth resources such as sun light. Competitions for light have been reported to induce taller plants in legumes at different intercropping patterns as compared to sole cropping. For instance, Muoneke *et al*. (2007) reported increased soybean plant height under intercrop with maize. Ijoyah *et al*. (2013) reported that the competition for light from the greater population of plants in intercropping might have induced taller soybean plants. Similarly, Undie *et al*. (2012)

reported in maize soybean intercropping that soybean plant height was increased above its sole crop height at all intercrop arrangements.

4.5.2 Total dry matter (g m^{-2})

Intercropping patterns had no significant effects on total dry matter as determined at 22 DAP and 30 DAP; however, the effect was highly ($p<0.001$) significant at 65 DAP (Table 10).In this study, growth effect demonstrated by low total dry matter of common bean in different intercrop patterns as compared to sole common bean was probably related to competition for growth resources such as nutrients which reduced vegetative growth and hence inhibited vegetative biomass production. On the other hand, the absence of significant effects on total dry matter between sole crops and intercrop patterns at vegetative growth stages indicates that competition for growth resources was minimal early in the growing season. For instance, total dry matter of common bean in the improved 1:2 intercrop patterns was positive and highly significant ($r=1$; $p<0.001$) correlated with P uptake as shown in Appendix 5. The results in this study are in line with those of Polthanee and Trelo-ges (2003) who found that intercropping reduced the top dry weight at 30, 45 and 75 DAS for peanut and soybean as compared with single cropping. According to Polthanee and Trelo-ges (2003), in legume crops, leaf area and top dry weight per plant were reduced by intercropping with corn, indicating competition for growth resources between them during the overlapping period.

4.5.3 Leaf area index (LAI)

Statistical analysis results (Table 10) of LAI determined at 22 DAP indicated non-significant ($p=0.204$) effects between sole grown and intercropped common bean. However, highly ($p<0.001$) significant differences were observed on LAI determined at 38 DAP. The decrease in LAI of common bean under intercropping patterns as determined at

38 DAP may be related to competitions for growth resources such light and nutrients that could lead to reduced vegetative growth of the intercrops as compared to sole crop. For stance, LAI of common bean in the improved 1:2 intercrop patterns was positive and significantly (r=0.999; p=0.027) correlated with N uptake. The results in this study are in agreement with those of Kassahum (2013) and Habte *et al.* (2016) who reported that sole common bean had significantly higher leaf area and leaf area index than intercropped common bean. Issahaku (2010) reported that the LA and LAI's of intercropped legume were lower than LA and LAI's of legume monocrops, which suggested that grain legumes were dominated by corn. Ren *et al.* (2016) reported that the LAI values of the sole crop treatments for both maize and soybean were greater than that of the intercropping system, indicating that maize and soybean suppressed the LAI values of the competing crop when intercropped.

Table 10: Effect of intercropping patterns on plant height, leaf area index and total dry matter of common bean

		Plant height (cm)			**Total DM (g m^{-2})**			**Leaf area Index**	
Treatments	**Crop**	**22DAP**	**30DAP**	**38DAP**	**22DAP**	**30DAP**	**65DAP**	**22DAP**	**38DAP**
SB	Beans	28.03	41.3	49.4	3.53	7.96	42.67	0.49	1.38
MB(1:1)	Beans	29.77	42.5	47.9	2.70	7.54	24.33	0.82	0.98
MB(1:2)	Beans	39.77	54.2	62.7	3.65	7.60	16.83	0.76	0.91
MB(2:2)	Beans	37.70	49.1	55.7	2.80	6.44	22.17	0.48	1.12
Grand mean		33.82	46.8	53.9	3.17	7.39	24.19	0.64	1.10
CV (%)		9.3	11.5	7.7	18.9	20.5	12.9	35.1	6.5
LSD		5.92	10.17	7.85	0.49	2.85	8.1	0.42	0.13
P-value		0.004**	0.061ns	0.009**	0.196ns	0.652ns	<0.001***	0.204ns	<0.001***

ns – not significant; **significant at P≤0.01; ***significant at P≤0.001

4.5.4 Crop growth rate (g m^{-2} day^{1})

Table 11 presents the effect of intercropping patterns on crop growth.

Intercropping patterns had significant (p=0.008 and p=0.003) effect on crop growth rates as determined at 22 and 65DAP, respectively; thought the effects were not significant at 30 DAP. The reduced CGR in intercrop patterns as compared to sole crop treatment could be attributed to less vegetative growth due to competition for light and nutrients. The growth rate of common bean in the improved 1:2 intercrop patterns was positive and significantly (r=0.995; p=0.058 and r=0.997; p=0.043) correlated with N and P uptake, respectively. Similar to N and P uptake, growth rate of common bean in the improved 1:2 intercrop patterns was positive and significantly (r=0.997; p=0.034) correlated with total dry matter. These findings are in support by those of Addo-Quaye *et al.* (2011) who reported that values of crop growth rate of sole soybean were always higher than the intercropped mean. Similar results were reported by Mandal *et al.* (2014) who observed higher CGR in sole stand of maize compared to soybean as an intercrop.

Table 11: Effect of intercropping patterns on crop growth

		CGR (g m^{-2} day^{-1})			**RGR [g (g dry wt.$^{-1}$) day^{-1}]**		
Treatments	**Crop**	**0-22** DAP	**22-30** DAP	**30-65** DAP	**0-22** DAP	**22-30** DAP	**30-65** DAP
SB	Beans	0.27	0.92	2.86	1.25	2.01	3.74
MB(1:1)	Beans	0.27	1.35	2.39	0.99	1.96	3.13
MB(1:2)	Beans	0.55	1.65	1.72	1.27	1.92	2.66
MB(2:2)	Beans	0.35	1.26	3.25	1.02	1.81	3.16
Grand mean		0.36	1.30	2.80	1.13	1.93	3.17
CV (%)		22.0	30.5	16.9	16.3	11.5	6.7
LSD		0.15	0.74	0.89	0.35	0.42	0.40
P-value		0.008**	0.238ns	0.003**	0.205ns	0.714ns	0.002**

ns – not significant; **significant at P≤0.01; ***significant at P≤0.001

4.5.5 Relative growth rate [g (g dry wt.$^{-1}$) day^{-1}]

Results (Table 11) of statistical analysis indicated that intercropping patterns had no significant (p=0.205 and p=0.714) effects on relative growth rate of common bean as determined at 22 and 30 DAP, respectively, though the effect was significant (p=0.002) at 65 DAP. These results agree with those of Pandey and Singh (2015) who stated that RGR values in wheat was initially higher but with time it decreases and much of the decrease would be attributed to shading. Pandey (2016) in which at initial stage of crop growth, C_6 additive series (two row of soybean planted in-between two row of maize) showed the highest value of RGR but at a later stage of growth sole soybean showed the highest value whereas both additive series (C_5 and C_6) exhibited the lower value among six crop arrangements.

4.5.6 Effect of intercropping patterns on N, P and K uptake by maize

Results (Table 12) of statistical analysis indicated that intercropping patterns had no significant effects on nutrient (N, P and K) uptake (%) between sole maize and maize in maize-common bean intercrop patterns. However, maize in the improved 1:2 treatments indicated numerically highest N and P uptake (0.39% and 0.07%, respectively) than all other treatment without N application. The highest N and P uptake by maize under the improved 1:2 intercrops pattern was not expected in this study without N application, and/ or since P was applied at low quantities under intercrop patterns as compared to sole crops. The study expected similar uptake of N in all treatments and low P uptake under intercrop treatments since no N applied and/ or P was applied at low quantities under intercrop treatments compared to sole crop. These results could be attributed to facilitation mechanisms made by common bean in increasing P availability and N through N_2 fixation.

Increased acquisition of N has been mostly demonstrated in cereal-legume intercrops compared to sole crops; only a few recent studies have reported P or N-P interaction effect (Latati *et al*., 2016; Betencourt *et al*., 2012; Hinsinger *et al*., 2011; Callawy, 1995). Indeed, most of the former studies on cereal-legume intercropping implicitly assume that the legume enhances P and N acquisition by cereal because of legumes' ability to increase large amounts of P-mobilizing compounds that ultimately increase P availability (Wang *et al*., 2015; Latati *et al*., 2014; Betencourt *et al*., 2012). Recent studies under field experiments indicated a significant increase in P availability in the rhizosphere of both common bean and cowpea intercropped with maize (Latati *et al*., 2016; Latati *et al*., 2014).

An increase in P availability was reported in P deficient soils through the root-induced processes by legumes, for example, rhizosphere acidification, nodule root respiration, exudation of phosphatases, carboxylates and/ or indirectly through microbial activities (Latati *et al*., 2014; Devau *et al*., 2011). Li *et al.* (2007) reported that roots of faba bean secrete protons, malate and citrate into the rhizosphere, which mobilize sparingly soluble P and contribute to increased P uptake by maize in P-deficient calcareous soils. Hinsinger *et al*. (2011) reported increased N_2 fixation in legumes as a consequence of competition of cereals for nitrate further stimulates P acquisition. Callaway (1995) reported that interaction between species increase resource availability of some species intercropped by facilitative mechanisms which changes environmental conditions. Such positive interactions are particularly valuable when resources are limited, which could have been the case as per the present study. The greater N acquisition by a non-legume when intercropped with a legume has been reported by Shata *et al*. (2007). In maize and soybean intercropping, Ning *et al*. (2012) reported that higher N-uptake was perhaps due to the difference in competitive abilities of maize and soybean which may increase N uptake by cereal. Matusso (2014) observed the highest N concentration (1.75 percent N) on maize plant under MBILI treatment than all other treatments, followed by maize under 2M:6S.

Table 12: Effects of intercropping patterns on N, P and K uptake by maize and common bean plants

Treatment	Nutrient uptake on maize (% plant^{-1})			Nutrient uptake on common bean (% plant^{-1})		
	N	**P**	**K**	**N**	**P**	**K**
SM	0.25	0.05	0.59	1.04	0.13	1.26
MB(1:1)	0.26	0.05	0.64	1.01	0.14	1.24
MB(1:2)	0.39	0.07	0.58	1.15	0.13	1.30
MB(2:2)	0.26	0.05	0.70	1.11	0.13	1.27
Grand mean	0.26	0.06	0.63	1.08	0.14	1.27
CV (%)	26.0	30.3	9.0	6.2	2.7	11.3
LSD	0.14	0.03	0.11	0.13	0.01	0.3
P-value	0.142ns	0.680ns	0.104ns	0.125ns	0.041∗	0.958ns

ns – not significant; ∗significant at $P \leq 0.05$

4.5.7 Effect of intercropping patterns on N, P and K uptake by common bean

Statistical analysis results (Table 12) indicated that there were no significant effect on N and K uptake of common bean as influenced by intercropping patterns; however, the effect was significant (p=0.041) for P uptake. Common bean in the improved 1:2 intercrop patterns recorded numerically the highest (1.15 and 1.3%) nutrients N and K uptake, respectively, than all the other treatments. The N concentrations were low in maize plant than in common bean, indicating that the higher N in common bean was derived from N-fixation. These results are in agreement with those of Latati *et al.* (2013) who reported that intercropping increased N concentration in common bean shoot and seed. Also, the authors stated that common bean intercropped with maize decreased interspecific competition for nitrogen use through N_2 fixation, especially at low N concentration in indigenous soil, which could be the case for this study. Latati *et al.* (2014, 2016) reported that the advantage of intercropping for cereal through facilitation mechanisms made by legume increased inorganic P availability by nodule root-respiration and rhizosphere acidification during N_2-fixation as compared to monocropping systems. It has been reported that facilitation was more pounced by interspecific competition when P and N are more limiting for crop growth (Latati *et al*., 2016). This legumes facilitation would have been related to root-induced changes modifying N and P bioavailability in the rhizosphere, as a results of enhancing in efficiency use of the rhizobial symbiosis (EURS) in low P soil conditions (Latati *et al*., 2016).

4.6 Effect of Intercropping Patterns on Yield and Yield Components of Maize

The results on effects of intercropping patterns on yield and yield components of maize are indicated in Table 13. Maize grain yield, number of cobs per plant, cob yield and 100-grain weight were unaffected by intercropping patterns. These data suggest that the competition effect for growth resources between maize and common bean was low during the period when maize and common bean overlap. Such results were reported by Undie *et al.* (2012) who observed no significant differences on grain yield and 100-grain weight of sole maize and maize-soybean intercrop patterns. However, sole maize recorded numerically the highest 100-grain weight and grain yield than intercrop arrangements. Findings by Matusso *et al.* (2014) showed no significant effects in yield by intercropping patterns (p=0.0074). However, sole maize treatment recorded numerically the highest value of 3.36 t ha^{-1} while 2M:6S treatment recorded the lowest yield. Similarly, Egbe *et al.* (2010) in maize-cowpea intercropping and Saleem *et al.* (2011) in maize-legume intercropping systems found no significant effect in grain yield.

Table 13: Yield and yield components of maize as influenced by intercropping patterns

Treatment	Crop	Cobs plant^{-1}	Cob yield (g)	100-grain wt. (g)	Plant harvested (ha^{-1})	Grain yield (t ha^{-1})
SM	Maize	1.26	128.0	26.23	43 981	5.09
MB(1:1)	Maize	1.07	114.8	27.80	43 056	4.91
MB(1:2)	Maize	1.02	129.4	24.70	43 519	4.26
MB(2:2)	Maize	1.01	108.5	23.90	43 056	3.75
Grand mean		1.09	120.2	25.66	43 404	4.50
CV (%)		13.8	10.3	7.0	2503.7	16.9
LSD		0.28	23.39	3.4	3.1	2.1
P-value		0.226ns	0.189ns	0.114ns	0.802ns	0.198ns

ns – not significant.

4.7 Effect of Intercropping Patterns on Yield and Yield Component of Common Bean

The effects of intercropping patterns on yield and yield components of common bean are indicated in Table 14. The number of pods per plant and seed yield were affected ($p<0.001$ and $p=0.011$, respectively) by intercropping patterns, but the number of seeds per pod and 100 seed weight were unaffected. Sole common bean significantly recorded the highest number of pods (18.0) per plant, seed yield (1.35 t ha^{-1}) than that of common bean in maize-common bean intercrop patterns. The observed reduction in number of pods and seed yield under different intercrops pattern as per this study could be attributed to the decreased crop growth, leaf area index and total shoot dry matter as a result of reduced vegetative growth. Undie *et al*. (2012) reported similar effects on number of pods per plant in soybean as significantly influenced by intercropping and crop arrangement, with the highest number of pods produced by the sole crop. Also, Undie *et al*. (2012) reported that grain yield obtained by sole crop was statistically higher than that of 1:1, 2:2 and 1:2

intercrop arrangements by 86, 64 and 74% respectively. In other studies, Nyasasi and Kisetu (2014) reported that the number of pods per plant differed significantly in sole crop than those obtained from the intercropping system. Meena *et al*. (2006) also found that increasing levels of fertility in intercrop soybean significantly increased seed yield of the crop.

Table 14: Yield and yield components of common bean as influenced by intercropping patterns

Treatment	**Crop**	**Number of pods plant^{-1}**	**Number of seed pod^{-1}**	**100-seed weight (g)**	**Plants harvested ha-^{1}**	**Seed yield (tha^{-1})**
SB	Beans	18.00	5.33	31.33	114 683	1.35
MB(1:1)	Beans	7.33	5.33	32.90	66 667	0.73
MB(1:2)	Beans	6.67	4.67	36.80	114 352	0.95
MB(2:2)	Beans	6.67	4.67	33.40	71 759	0.60
Grand mean		9.92	5.00	33.61	91 1865	0.91
CV (%)		13.3	10.3	5.4	8.1	14.7
LSD		2.49	1.09	3.79	14 084.6	0.39
P-value		<0.001***	0.330ns	0.054ns	<0.001***	0.001**

ns – not significant; **significant at P≤0.01; ***significant at P≤0.001

4.8 Effect of Maize-common Bean Intercropping Patterns on Land Productivity

The effects of intercropping patterns on land use efficiency as determined using the land equivalent ratio (LER) and percentage of land saved are shown in Table 15. Land equivalent ratios in maize-common bean intercropping patterns were 1.51, 1.59 and 1.28 for the conventional 1:1, improved 1:2 and 2:2 intercrop patterns, respectively. Land equivalent ratios were greater than one in all the intercrop patterns indicating that it is advantageous to grow maize and common bean as intercrops than in sole crops. The improved (1:2) maize-common bean intercrop patterns gave the highest LER (1.59) value indicating that this intercropping system is the best system for maize-common bean intercropping. The results of LERs as calculated using the method developed by Ijoyah *et al*. (2013) and Workayehu (2014) as shown in section 3.5.2.6 of this thesis gave 37.1% of land saved in the improved (1:2) intercrop patterns indicating that is the best combination compared to 1:1 (33.8%) and 2:2 (21.9%) maize – common bean intercrops.

The land saved as intercropping potential could be used for other land productivity related activities. Similar results were reported by Matusso (2014) who observed the highest LER value (1.81) under the MBILI treatment than all the other treatments. Yilmaz *et al*. (2008) reported higher LERs in maize-beans intercrops planted in different patterns. In a study by Ijoyah *et al*. (2013) which involved intercropping soybean and maize gave LER greater than one, indicating high productivity per unit area achieved by growing two crops together. Massawe *et al.* (2016) working in maize and legume intercropping in Tanzania reported LERs from 2.063 to 2.119 indicating land use efficiency by more than 100%.

Table 15: **Land equivalent ratio (LER) as affected by intercropping patterns**

Treatment	**Maize LER**	**Beans LER**	**Total LER**	**Land saved (%)**
MB(1:1)	0.98	0.52	1.51	33.8
MB(1:2)	0.90	0.69	1.59	37.1
MB(2:2)	0.85	0.43	1.28	21.9
Grand mean	0.95	0.66	1.46	
CV(%)	1.58	23.0	18.5	
P-value	0.271ns	0.008∗∗	0.400ns	

ns – not significant; ∗significant at P≤0.01

4.9 Effects of intercropping patterns on soil chemical properties at the end of experimentation

The results (Table 16) show the effect of intercropping patterns on soil chemical properties at the end of the experimentation. The study did not find a significant effects of the maize common bean intercropping patterns on soil nutrients (N and K); however, there was significant ($p=0.002$) increase on soil available P. At the initiation of experiment the soil available P and exchangeable K was 4.98 mg/kg and 0.03 $cmol_c(+)/kg$ while at the end of experimentation the soil available P and exchangeable K ranged from 13.11 to 21.73 mg/kg and 1.10 to 1.26 $cmol_c(+)/kg$, respectively, which could be attributed to addition of P from P_2O_5 and K from K_2O. The improved (1:2 and 2:2) intercrop patterns recorded significantly the highest soil available P values which might also be promoted through root-induced processes of common bean. This study also observed numerical increase (0.18% for sole maize, sole common bean and the conventional 1:1 intercrop patterns), decrease (0.16% for conventional 1:2 and 2:2 intercrop patterns) in soil total nitrogen and increase in soil exchangeable potassium. The decline in soil total N under the improved intercropping patterns might be due to higher N uptake by plants, leaching and denitrification. The increase and decrease in soil total N observed in this study is also documented in other studies such as those by Mucheru-Muna *et al*. (2010) who reported that the MBILI system accelerated N depletion because of the higher maize yields and subsequent N removal.

These results are also supported by recent researches which reported an increase in inorganic P availability (Olsen-P) in the rhizosphere of both intercropped legumes and cereals (Latati *et al*., 2014; Devau *et al*., 2011). Dahmardeh *et al*. (2010) found that intercropping of maize-cowpea significantly increased phosphorus and potassium in soil, and the lowest P level was observed in the sole maize treatment. Previous studies conducted by Prasad and Power (1997) indicated that high soil P could be attributed to the very slow diffusion and immobilization of applied P.

Table 16: Soil chemical properties before and after maize-common bean experiment

Treatment	**pH**	**%OC**	**%N**	**P**	**Ca**	**Na**	**Mg**	**K**	**CEC**
Before	**6.14**	**1.79**	**0.17**	**4.98**	**6.01**	**0.65**	**2.12**	**0.03**	**12.6**
After									
SM	6.52	1.4	0.18	17.27	2.83	0.32	3.1	1.18	13.73
SB	6.39	0.9	0.18	18.17	2.36	0.31	2.57	1.10	11.80
MB(1:1)	6.69	1.1	0.18	13.11	5.04	0.38	2.66	1.26	15.27
MB(1:2)	6.64	1.1	0.16	18.66	4.65	0.35	2.91	1.10	14.87
MB(2:2)	6.50	1.2	0.16	21.73	2.81	0.32	2.84	1.22	13.89
Grand mean	6.55	1.2	0.17	17.79	3.54	0.34	2.82	13.91	13.91
CV (%)	1.0	24.6	7.9	9.7	5.6	9.1	15.3	8.7	8.7
LSD	0.12	0.51	0.3	3.14	0.36	0.06	0.78	0.13	2.2
P-value	0.002∗∗	0.347ns	0.354ns	0.002∗∗	<0.001∗∗∗	0.093ns	0.600ns	0.076ns	0.042∗

ns – not significant; ∗∗significant at P≤0.01; ∗∗∗significant at P≤0.001

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Native rhizobia population detected in soil from the study site were sufficient (above 10^3 cells per gram of soil) and effective in nodulating with common bean variety, *Pesa*. Despite the higher reduction in numbers and dry weight of nodules, intercropping effects significantly enhanced higher N-fixation of common bean in the improved 1:2 intercrop patterns. This study did not find a significant increase in soil total nitrogen; however, as the experiment was conducted in one season, probably the period was not enough for common bean to explore large soil mass, nitrogen build-up and transformations of other soil nutrients.

Intercropping effects of maize and common bean significantly enhanced higher nutrients (N, P and K) uptake of common bean in the improved 1:2 intercrop patterns as compared to all other treatments. It is also concluded that intercropping patterns had negative effect on growth rate, leaf area index and plant total dry matter on both maize and common bean which was related to poor plant nutrients acquisition and utilization. It can also be expected that, application of the correct levels of fertilizers in different intercropping patterns is necessary to increase and achieve maximum crop growth and yields of the intercrops.

Intercropping patterns had no significant effect on maize yield and yield components, however, some of yield components and yield of common bean were significantly reduced by different intercropping patterns effects. Though, the results from this study confirmed the advantages of intercropping maize and common bean over sole cropping. It is concluded that all the intercropping patterns were more productive than sole cropping since they all resulted in LERs ranging from 1.28 to 1.59. However, the improved 1:2 intercrop pattern is the most beneficial in terms of cropping performance as it produced the highest LERs and land saved values.

5.2 Recommendations

From this study, it is recommended that more research studies using similar cropping patterns and treatments be conducted for at least two to three consecutive seasons in order to get reliable results. Also, further studies should be conducted to establish appropriate fertilizer levels for different intercropping patterns for better crop growth and maximum yield.

Farmers in low attitude areas (Morogoro) are advised to apply the improved (1:2) intercrop patterns because it showed efficient use of resources compared to other intercrop patterns, however, to get more consistent results for recommendation two to three cropping seasons are required.

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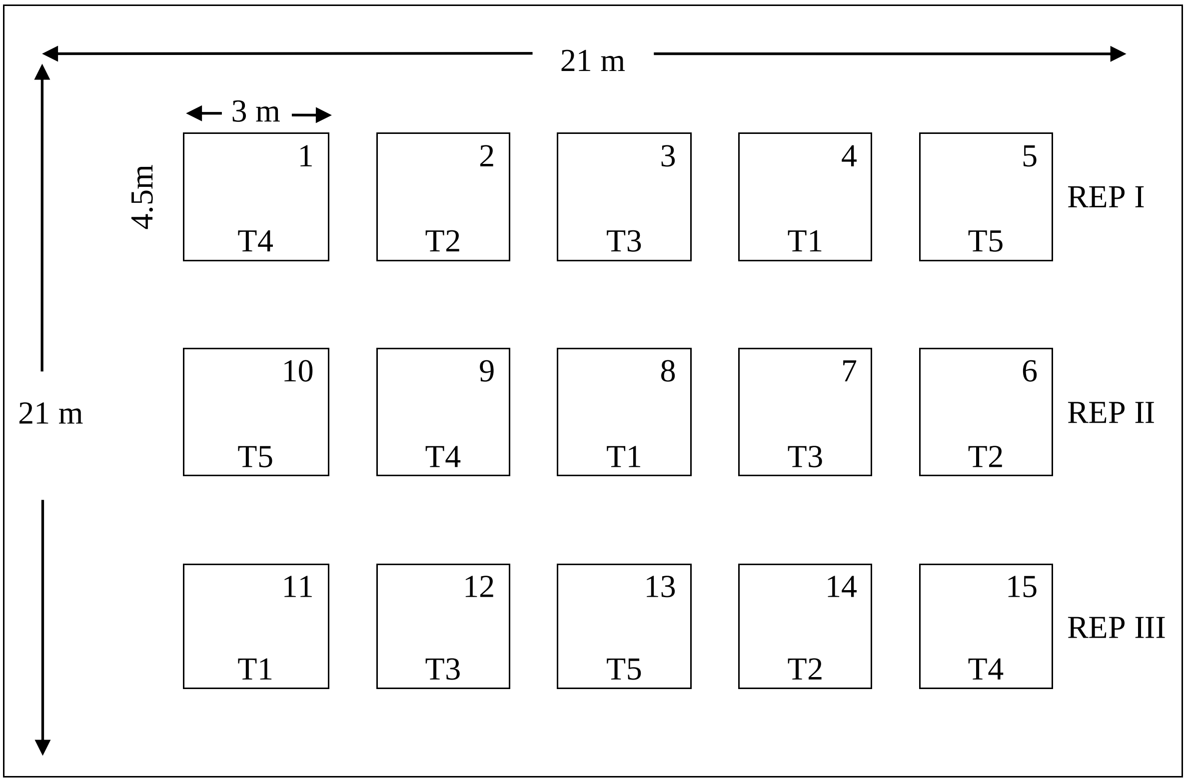
APPENDICES

Appendix 1: Field experimental layout



Key: 1 – 15 refers to plot numbers

T1 – T5 refers to treatment numbers

REP I, REP II and REP II refers to replication numbers

T1 refers to sole maize (SM)

T2 refers to sole common bean (SB)

T3 refers to 1maize:1common bean (MB 1:1)

T4 refers to 1maize:2common bean (MB 1:2)

T5 refers to 2maize:2common bean (MB 2:2)

Appendix 2: Expected plant population for maize and common bean

Treatment	Plant/Hill		Plant population per hectare		
	Maize	Common bean	Maize	Common bean	Total plants/ha
SM	1	-	44 444	-	44 4444
SB	-	2	-	160 000	160 000
MB(1:1)	1	2	44 444	106 667	151 111
MB(1:2)	1	2	44 444	177 777	222 221
MB(2:2)	1	2	44 444	71 111	115 555

Appendix 3: Fertilizers calculations

P as TSP (Triple super phosphate).

Recommended rate = 40 kg P/ha (Kanyeka *et al*., 2007: Marandu *et al*., 2013).

Treatments: SM, SB, MB (1:1), MB (1:2) and MB (2:2)

TSP contains: 46% P_2O_5

Soil available P = 4.98 mg/kg

4.98 mg P = 1 kg of soil

? = 2.6 x 10^6 kg of soil/ha

(4.98mg * 2.6 x 10^6 kg)/ 1 kg = 12,948,000mg P/ha = 12.948 kg/ha

Deficit of P in soil: 40kg – 12.948kg = **27 kg/ha**

$$\% P = \frac{P_2O_5}{P} = \frac{46}{2.29} = 20.087$$

20kg = 100 kg TSP

27kg =? = <u>135 kg of TSP/ha</u>

135 kg TSP = 10,000 m^2

? = (4.5m x 3m) = 13.5 m^2 **<u>= 182 g/ 13.5 m^2 of TSP</u>**

TSP/ m^2 = 13.5g m^2

TSP/ plot = 13.5 x 13.5 = 182 g/ plot

TSP/ repl. = 182 x 5 = 910 g/ repl.

TSP/ field = 910 x 3 = 2 730 g/ field.

Total TSP = 2.73 kg TSP which is equivalent to 27 kg TSP/ha

K as MOP (Murate of potash).

Recommended rate = 50 kg K /ha (Semoka, J. R.M.personal communication, 2017)

Soil available K = 0.03 cmol/kg

0.03 cmol/kg = 0.03 x 390 = 11.7mg/kg

11.7 mg/ K = 1 kg of soil

? = 2.6×10^6 kg of soil = 30 kg of K/ha

Deficit of K in soil: 50 kg – 30 kg = **20 kg K/ha**

MOP contains 60% K_2O

$$\% K = \frac{K_2O}{K} = \frac{60}{1.23} = 48.78 = 50$$

50kg P = 100 kg MOP

20kg P = ? = **40 kg of MOP/ha**

40 kg MOP = 10 000m^2

? = 13.5m^2 = 54g of MOP/13.5M^2

MOP/ m^2 = 54/ 13.5 = 4g/ m^2

MOP/ plot = 13.5 x 4 = 54 g/ plot

MOP/ repl. = 54 x 5 = 270 g/ repl.

MOP/ field = 270 x 3 = 810 g/ field

Total MOP = 810/1000 = 0.81 kg MOP which is equivalent to 20 kg of MOP/ha

Appendix 4: Correlations among growth variables and nutrients uptake of maize under different cropping patterns at 52 DAP

Growth variables	**Cropping system**	**LAI**	**DM**	**CGR**	**N**	**P**	**K**
LAI	SM				0.364ns	0.234ns	0.235ns
	MB(1:1)				0.371ns	0.451ns	0.271ns
	MB(1:2)				0.513ns	0.115ns	0.925ns
	MB(2:2)				0.568ns	0.702ns	0.359ns
DM	SM	0.163ns			0.200ns	0.072ns	0.027∗
	MB(1:1)	0.729ns			0.458 ns	0.278ns	0.987ns
	MB(1:2)	0.877ns			0.610ns	0.762ns	0.199ns
	MB(2:2)	0.980ns			0.413ns	0.279ns	0.661ns
CGR	SM	0.172ns	0.009∗		0.389ns	0.062ns	0.260ns
	MB(1:1)	0.848ns	0.119ns		0.0.576ns	0.397ns	0.894ns
	MB(1:2)	0.869ns	0.008∗		0.618ns	0.754ns	0.207ns
	MB(2:2)	0.976ns	0.005∗		0.408ns	0.274ns	0.666ns

ns – not significant; ∗significant at P≤0.05

Appendix 5: Correlations among growth variables and nutrients (N, P and K) uptake of common bean under different cropping patterns at 30 DAP

Growth variables	Cropping system	LAI	DM	CGR	N	P	K
LAI	SB				0.968ns	0.834ns	0.855ns
	MB(1:1)				0.212ns	0.480ns	0.579ns
	MB(1:2)				0.027∗	0.129ns	0.318ns
	MB(2:2)				0.955ns	0.63ns	0.89ns
DM	SB	0.934ns			0.034∗	0.100ns	0.210ns
	MB(1:1)	0.349ns			0.561ns	0.131ns	0.230ns
	MB(1:2)	0.129ns			0.102ns	8.2E-17	0.189ns
	MB(2:2)	0.639ns			0.316ns	0.340ns	0.807ns
CGR	SB	0.935ns	0.131ns		0.097ns	0.231ns	0.079ns
	MB(1:1)	0.272ns	0.077ns		0.485ns	0.208ns	0.307ns
	MB(1:2)	0.086ns	0.043∗		0.058∗	0.043∗	0.232ns
	MB(2:2)	0.721ns	0.638ns		0.322ns	0.298ns	0.553ns

ns – not significant; ∗significant at $P \leq 0.05$