MAIZE PERFORMANCE AND SOIL MOISTURE RETENTION UNDER INOCULATED COWPEAS INTERCROP IN MERU AND THARAKA NITHI COUNTIES

IAN MWENDA KIRIMI

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented for an award of a diploma or conferment of a degree in any other institution.

Signature.. Date: 13/9/2019

Ian Mwenda Kirimi
NM17/29139/17

Recommendation

This thesis has been examined, passed and submitted with our approval as University supervisors.

Signature.. Date: 13/09/2019

Dr. Munyiri Shelmith PhD
Chuka University

Signature.. Date: 18/09/2019

Dr. Ndukhu Haggai PhD
Chuka University

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DEDICATION

This thesis is dedicated to my parents Mr. George Kirimi Richard and Mrs. Harriet Ruguru Kirimi for their continued encouragement and unceasing support.

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ABSTRACT

Agriculture is the main source of livelihood in Kenya with maize being produced in diverse environments. However, in Meru and Tharaka Nithi counties, small holder maize productivity has been diminishing due to declining soil fertility and frequent droughts. Nitrogen (N) is the principal nutrient limiting maize production hence the need for intercropping using cowpeas that are inoculated with the correct exotic bacterial strain that fix N in the soil. There was need to assess N fixation capacity using exotic bacteria by inoculating cowpeas with the correct bacterial strain. The use of N fixing legumes in intercrops with cereal crops remains a cheaper and viable option available for the resource constrained farmers to enhance soil fertility. The objective of the study was to contribute towards improved maize performance through rhizobium inoculated cowpeas intercropping. The study was conducted at two locations i.e. Kenya Agricultural Livestock Research Organization (KALRO) Igoji substation and Magutuni secondary school in Meru and Tharaka Nithi counties respectively, during the long rains of the year 2018. The experiment was laid out in a Randomized Complete Block Design and replicated three times. The treatments included maize hybrid Duma 43 variety sown as a sole crop (TI); Rhizobium inoculated variety K80, cowpeas maize intercrop (T2), cowpeas maize intercrop without inoculation (T3) and non-inoculated cowpeas K80 sole crop (T4). Data collected on maize included plant height, stem girth, canopy cover, leaf area index, light extinction coefficient and yield. Data collected on cowpea was yield. Moisture retention capacity was determined by use of a neutron probe after every week by recording the moisture from the soil in millimeters up to grain filling. Soil samples for N analysis were taken before planting and after harvesting on each treatment plot basis and the homogenous sample analyzed at University of Nairobi (UoN) soil chemistry laboratory. A general linear model was performed and data subjected to analysis of variance (ANOVA) using GENSTAT statistical package (VSN International, 2011). Means were separated using Fischer's protected least significant difference (LSD) at 5% probability level. Results indicated that intercropped patterns under inoculated cowpeas recorded a greater leaf area index of 3.75 at Igoji and 3.16 at Magutuni. Light extinction coefficient was high in intercrops than in sole stands and ranged between 0.52 and 0.34 at Igoji and between 0.57 and 0.37 at Magutuni. Intercropped patterns intercepted more photosynthetically active radiation (PAR) (581.54 MJm^{-2}) than pure stands (88.35 MJm^{-2}). At kernel development stage, significantly higher soil moisture content was observed under intercropping patterns T2, (255.5±3.7mm, 253.0±1.9mm) and T3, (250.7±2.9mm, 240.5±1.3mm) than in pure maize stand T1, (245.3±4.0mm, 230.8±2.7mm) and sole cowpeas T4, (248.9±5.6mm, 233.7±3.7mm) in Igoji and Magutuni, respectively. Nitrogen fixed in T2, (0.20 g/kg, 0.18 g/kg) was higher than in T3, (0.18 g/kg, and 0.17 g/kg) and T4, (0.19 g/kg, 0.17 g/kg) at Igoji and Magutuni respectively and this was attributed to the effect of inoculation in cowpeas. The results of this study underpins the importance of intercropping maize with inoculated cowpeas as a cheaper soil fertility improvement method and as a moisture retention strategy for resource poor farmers in Meru and Tharaka Nithi counties.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ASALS	Arid and Semi-Arid Lands
ASC	African Seed Company
BNF	Biological Nitrogen Fixation
CIMMYT	International Maize and Wheat Improvement Center
CP	Cropping Pattern
DAIS	Digitalization of Agricultural Innovation Systems
DAP	Days after Planting
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Statistical Database
g	Grammes
GDP	Gross Domestic Product
GOK	Government of Kenya
Hrs	Hours
ICRISAT	International Crops Research Institute for the Semi-arid Tropics
IITA	International Institute of Tropical Agriculture
KALRO	Kenya Agriculture and Livestock Research Organization
K 80	Katumani 80
LAI	Leaf Area Index
LSD	Least significant difference
MDS	Maize Development Stages
MOA	Ministry of Agriculture
mm	Millimeters
MEY	Maize Equivalent Yield
NH_4^+	Ammonium Ions
No_3^-	Nitrate Ions
No_2	Nitrite Ions
No	Nitrous Oxide
N	Nitrogen
NCPB	National Cereals and Produce Board
PAR	Photosynthetic Active Radiation
SAS	Statistical Analysis Software

SMC	Soil Moisture Content
SSA	Sub-Saharan Africa
UN	United Nations
UNICEF	United Nations International Children’s Emergency Fund
USAID	United States Agency for International Development

CHAPTER ONE
INTRODUCTION

1.1 Background Information

Maize (*Zea mays* L.) is one of the most important cereal crops in the world and is extensively grown in irrigated and rain fed areas (Nyoro *et al*., 2004)). Maize ranks third in the world among cereal crops after wheat and rice. It is produced in diverse production environments, and consumed by people with varying food preferences and socio-economic backgrounds (Ranum *et al*., 2014). More than 300 million people in sub Saharan Africa (SSA) depend on maize as a source of food and livelihood (FAOSTAT, 2015[a]). The land under maize and grain production has increased significantly across regions in SSA since 1961 (FAOSTAT, 2015[b]). The average yield of maize in SSA (estimated at <1.8 t/ha) is still far below the global average of maize 5 t/ha (CIMMYT, 2015). The poor maize production level in Africa does not meet the growing demand for food hence the region is therefore, increasingly dependent on maize imports (Kangethe, 2004).

Successful maize production depends on the correct application of production inputs that will sustain the environment as well as agricultural production. These inputs include adapted varieties, plant population, soil tillage, fertilization, weed, insect and disease control, harvesting, marketing and financial resources. These positively affect leaf area index and photosyntheticaly active radiation. Several intervention projects such as the drought tolerant maize for Africa, the improved maize for African soils, the water efficient maize for Africa and the nutritionally enriched maize for ssEthiopia among others have been attempting to improve maize production in SSA. Previous studies have shown that intercropping maize with cowpeas produces higher maize yield than sole crop (Mpairwe *et al*., 2008). This research will determine the performance of maize when intercropped with inoculated cowpeas. In such intercropping systems, the yield increases are not only due to improved nitrogen nutrition of cereal component, but also due to other unknown causes (Connolly *et al.,* 2001).

Photosynthetically active radiation that is often abbreviated as PAR designates the spectral range (wave band) of solar radiation which ranges from 400 to 700 nanometers that photosynthetic organisms are able to use in the process of photosynthesis. PAR measurement is used mostly in agriculture to evaluate agricultural investment potential. PAR sensors measure the pattern of PAR availability and utilization. The rate of Photosynthesis and related parameters can be measured non-destructively by use of a photosynthesis system, and these instruments measure PAR and sometimes control PAR at set intensities **(**Ptushenko *et al*., 2015). The leaf area index (LAI) is an important parameter in plant ecology. This is because it tells the accumulation of foliage, it is a measure of the photosynthetic active area, and also at the same time the area subjected to transpiration. It is also the area which comes in contact with air pollutants. The LAI is also an indication of how much light is coming through the canopy; in the case of a multi-layer canopy, the LAI of an upper layer is important for the light received by lower ground vegetation (Damme *et al*., 2008).

In Kenya, agriculture employs more than 40 percent of total population and more than 70 percent of Kenyan rural people (FAO, 2017). Maize is a staple food and the diet feeds over 85 per cent of the population in Kenya. The per capita consumption ranges between 98 to 100 kilograms translating to at least 2700 thousand metric tones, per year (Nyoro *et al.*, 2009). The overall production in small scale accounts for about 70 percent, while the remaining 30 per cent of the output is from large scale commercial producers (EPZA, 2005). Small scale producers mostly grow the crop for subsistence, retaining up to about 58 per cent of their total output for household consumption (Mbithi and Huylenbroeck, 2000). Maize is produced throughout the country under diverse environment and it is a major contributor of the gross domestic product.

Maize production is relatively low at an average of <1.8 t/ha per annum compared to a global average of about 5 t/ha (CIMMYT, 2015) and has been attributed to several constraints including; declining soil fertility, inadequate and poor rainfall distribution. Meru and Thraka Nithi counties experiences the same challenges of increased loss of soil fertility, and inadequate rainfall leading to poor maize production due to persistent crop failures.

Nitrogen (N) is the most limiting nutrient in small holder farms in the lower parts of Meru and Tharaka Nithi counties (Itabali *et al.*, 2013). The region is semi-arid and the low N in the soil with inadequate moisture during the cropping seasons have resulted to low maize yields leading to the inhabitants traveling far distances in search of this staple food. Successful maize production depends on the correct application of production inputs that will sustain the environment as well as proper agronomic practices. This research of inoculated cowpea-maize intercrop may assist in fixation of some N which could benefit the component maize crop.

Nitrogen is important for normal plants growth. Some of its functions in plants include; playing an important role in protein formation, it is a constituent element of proteins and protoplasm of all living cells, forms part of chlorophyll molecule and makes the plant succulent with a deep green color that enhances the process of photosynthesis, it encourages vegetative growth which is necessary in crops where leaves in some crops are harvested like in kales, cabbages and pasture grasses. It regulates the availability of phosphorous and potassium in plants and increases the size of grains cereals and their protein content (Kahuria *et al.*, 2011).

Growing of legumes in association with cereal crops is an alternative strategy for the resource-constrained farmers to improve yield of cereals and enhance soil fertility through biological nitrogen fixation, and consequently achieve food security and increased income (Fujita *et al.*, 1992; Akibode, 2011). The intercrop maximizes production by effectively utilizing rain water resource, nutrients and solar radiation (Ahmed and Sulimon, 2010). A legume cereal intercrop improves soil conservation owing to the good ground cover, increases crop enterprises from same piece of land and the nitrogen fixed benefit the cereal crop. It is one of the potential ways to address some of the associated obstacles with modern agriculture, including low yield, pest and pathogens infections, soil degradation and environmental deterioration (Dzemo *et al.*, 2010).

Intercropping offers farmers the opportunity to engage nature's-principle of diversity on their farms (Sullivan, 2003). It is a system of cultivating a cereal as the primary food crop, but on a legume base. Intercrop of inoculated cowpeas with maize increases the net returns of maize than non-inoculated cowpeas maize intercrop (Chabu Olaye *et al*., 2002). Intercropping also plays an important role in increasing bio-diversity, land use efficiency and enhanced ecological services (Alika and Emede, 2005). Studies have also shown that farmer's socio-economic benefit has been greatly increased with intercropping of legumes-cereal crops due to reduction in production cost (Fasoranti, 2008).

Cowpea (*Vigna unguiculata* L.) is a major grain legume grown mainly in Semi-Arid regions owing to its drought tolerance disposition when compared to other legume crops. It is a major source of protein and a cheap source of quality protein for both rural and urban dwellers in the world (Mwandalu and Mwangi, 2013). Its leaves and green pods are consumed as vegetables and the dried grain is used in different food preparations. The cowpea plants harbors the rhizobia bacteria which fix atmospheric nitrogen within the soil. Protein content of cowpea leaves ranges from 21 to 33% and protein concentration of a dry grain ranges from 27 to 43% (Singh *et al*., 2003). Cowpea is a very valuable livestock fodder that makes the dual purpose cultivars appealing to farmers (Singh *et al*., 2003). Cowpeas are grown by millions of smallholders in Africa and is estimated that 200 million people live off the plant consuming the seeds daily whenever available (Kamara *et al.*, 2012). In Kenya cowpeas is a very important traditional component of cropping systems because it contributes to soil fertility improvement and fixes atmospheric nitrogen particularly in smallholder farming systems, where inadequate or no fertilizer is used and its canopy acts as ground cover. Cowpea is commonly grown in Meru and Tharaka Nithi counties because it is fast growing, drought tolerant and yields well in the dry environments (Cattivelli *et al*., 2008). It has deep root system that stabilizes the soil and enables absorption of water from the sub soil. It also forms an effective canopy cover that conserves moisture and can fix up 49.8 kg N/ha (Hagan *et al*., 2010).

A study carried out in Kenya showed that cowpeas respond well to inoculation (Onduru *et al.,* 2008). The leguminosae families are unique in their ability to form N fixing relationship between the legume and the rhizobium bacteria. This forms the basis for the ecological importance of legumes in natural and agricultural ecosystems in promoting increased crop yield (King and Purcell, 2005). The existing indigenous bacteria are present in farmers' fields but may not be the appropriate strain for optimum nitrogen fixation using cowpeas, and are also constrained by environmental factors (Onduru *et al.,* 2008).

There is need to assess the effects of N fixation on maize performance under exotic bacteria through cowpeas seed inoculation in Meru and Tharaka Nithi counties. When introduced, the inoculant bacterium adapts to prevailing soil conditions, multiplies in the soil and the host rhizosphere (Sanginga, 2003). It further increases the microbial activity that increases organic matter decomposition. Inoculation using rhizobium strain is one of the strategies that can be employed to enhance symbiotic nitrogen fixation by legumes hence improving maize production due to more nitrogen fixation in the soil. This study tested whether intercropping maize with inoculated cowpeas seeds would be a cheaper way of increasing the performance of maize than using inorganic fertilizers.

Most farmers in lower arid regions of Meru and Tharaka Nithi counties are poorly capitalized and therefore, mostly unable to meet the high cost of N fertilizers. Rhizobium is cost effective in comparison with inorganic fertilizers, since it is affordable by most of the farmers and helps in fixation of nitrogen in the soil required by maize for proper growth (Adesemoye *et al.,* 2009). There is limited information on maize performance under rhizobium inoculated cowpeas intercrop in Meru and Tharaka Nithi counties. This study focused on determining the effect of inoculated and non-inoculated cowpeas-maize intercrop on maize growth rate and yield, moisture retention capacity under maize-cowpeas intercrop, sole maize and cowpeas crops, the amount of nitrogen fixed in the soil under inoculated and non-inoculated cowpeas- maize intercrop and the cost benefit analysis and equivalent yield of maize-cowpeas intercrop verses sole cropping.

1.2 Statement of the Problem

Continuous cropping without nutrient replenishment in Meru and Tharaka Nithi counties has resulted in nutrient mining and poor soil fertility. This has led to decreased maize production. In some instances the farmers have attempted to apply fertilizers but the amount has been suboptimal, with further negative effects. This has been aggravated by climate change where there is inadequate amount of moisture for good fertilizer medium. Canopy leaves provide a good ground cover that gives a microclimate which reduces moisture stress to the primary crop. The current work examined the insight of integrated nutrient and moisture management with aim of improving maize (the main staple crop in Kenya) performance in Meru and Thraka Nithi counties with insufficient rainfall. It explored to look at various possible interventions on improvement of soil fertility through inoculation of cowpea maize intercrop under exotic commercially available bacteria strain and related agronomic practices for improved food security

1.3 Objectives of the Study

1.3.1 Broad Objective

To contribute towards improved maize performance through intercropping with rhizobium inoculated cowpeas.

1.3.2 Specific Objectives

i. To determine the amount of nitrogen fixed in the soil under inoculated and non-inoculated maize cowpeas intercrop.
ii. To evaluate the effect of inoculated and non-inoculated maize cowpeas intercrop on maize growth rate and yield.
iii. To assess the soil moisture retention under different maize cowpeas intercropping patterns.
iv. To analyze the cost benefit analysis and maize equivalent yield in intercrop and sole cropping patterns.

1.4 Hypotheses (H_0)

H_{01} There is no significant difference in the amount of nitrogen fixed in the soil under inoculated and non-inoculated maize cowpeas intercrop.

H_{02} There is no significant difference under inoculated and non-inoculated maize cowpeas intercrop on maize growth rate and yield.

H_{03} There is no significant difference in soil moisture retention under maize cowpeas intercrop, sole maize and cowpeas crops.

H_{04} There is no significant difference on cost benefit analysis and maize equivalent yield in intercrop and sole cropping patterns.

1.5 Justification of the study

Improving soil fertility could trigger rural and national economic development, contribute to achieving food security and improve farmer's standards of living, while mitigating environmental degradation (GOK, 2009). Proper interventions on improvement of soil fertility through inoculated cowpeas-maize intercrop and agronomic practices may enhance productivity of maize in the region to improve food security of maize as a staple food in Meru and Thraka Nithi counties. The enhanced soil cover and thus improved moisture through the intercrop may reduce the problem of crop failures and contribute to improved maize production leading to improved livelihoods. The soil moisture conserved by the canopy cover prevents excessive evaporation. This would be expected to lead to increased growth rate of maize and yield owing to the extra moisture retained in the soil. Since cowpeas inoculation increases nodulation, this enhances greater fixation of N leading to improved maize yields (El-Shamy *et al.*, 2015). The use of rhizobium inoculated cowpeas is a cheaper source of nitrogen in maize production as compared to use of inorganic fertilizers which are costly. It also reduces the negative effects of inorganic fertilizers in the soils, and improves soil moisture retention through forming a dense canopy that covers the ground fast minimizing excessive evaporation (El-Shamy *et al.*, 2015).

Total grain and plant nitrogen yield can often be increased by intercropping of legumes with non-legume (Karanja *et al.,* 2014). This tends to raise the acidic levels of the soil making the environment unfavorable for most crops. Maize requires nitrogen for growth and performance and the use of inoculated cereal-legume in lower parts of Meru and Tharaka Nithi has not been practiced. Tropical legumes fix 354 kg/ha when inoculated and grown in a complete nutrient culture as compared to 157 kg/ha when not inoculated (Salvagiott *et al.*, 2008). Since the cost of Rhizobium bacteria is affordable at Ksh 30 for 10 g sachet which can inoculate 1 kg of legume seeds, this ultimately justifies the use of the inoculums. Further, the inoculum adds the benefit of increased microbial activity in the soil which is important for nitrogen fixation. There is limited information on the yield attainable from the maize cowpeas cropping patterns with regards to rhizobium inoculation. Therefore, the strategy of intercropping maize with rhizobium inoculated cowpeas could enhance efficient nodulation for N fixation leading to improved maize yields in Meru and Tharaka Nithi counties. The results of this study will inform extension agents and policy makers in drafting guidelines on legume-cereal intercropping in drought prone regions of Kenya.

1.6 Significance of the Study

Bearing in mind that Meru, Tharaka Nithi counties and many other parts of the country experience moisture stress during maize crop growth period, this study significantly contributes to knowledge and can be used to testify and document that N deficiency and moisture challenges in these regions, can be partly mitigated through use of legume crops such as cowpeas which are used as intercrops in maize fields.

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview of Maize Production and Cost

Poverty levels in SSA remain the highest in the world (FAO, 2010). In Kenya a considerable number of people are continuously facing the threat of hunger and absolute poverty (MOA, 2012). This has led to severe food insecurity amongst the Kenyan population. Recent estimates showed that half of the nation population of 38.5 million people was poor; 7.5 million lived in extreme poverty, while over 10 million suffered from chronic food insecurity (GOK, 2011). The problems of poverty and hunger in Kenya are felt more in the Arid and Semi-Arid lands (ASALs) where agriculture is the principle source of livelihood (Anon, 2010).

Many farmers in $ASAL_S$ face declining crop yields, which has constrained economic growth (Cattivelli *et al.,* 2008). These constraints include pests and diseases, low and rainfall that are not reliable and inherently infertile soils. Infertile soils are related mainly to the low nutrient status while the qualities of some soils have declined due to continuous and over cultivation without returning enough nutrients to the soil. It is also mainly attributed to continuous removal of soil nutrients through crop harvest, with little or no soil fertility replenishment. Soil is also leached by uninterrupted mono cropping of cereals without external inputs (Muui *et al.*, 2013). Weeds significantly decrease yield of maize due to competition for space, water and nutrients. It is recommended to weed twice or more depending on the extent of weed infestation. Most farmers who grow high-yielding varieties weed twice to reduce competition for resources.

These resources include; light, soil water and nitrogen. Fertilizer prices can either influence maize production negatively or positively; decreases in fertilizer prices will lead to farmers purchasing more, meaning they will apply more fertilizer leading to higher yields while Increases in fertilizer prices, farmers purchase less fertilizers hence applying inadequate quantities' that in turn lead to less yields (Sanginga and Woomer, 2009). An alternative and cheaper way of increasing nitrogen in the soil without use of inorganic fertilizers in ASALs is though intercropping with an inoculated legume.

Maize is the most important staple food crops in Kenya. It is estimated to contribute more than 25% of agricultural employment and 20% of total agricultural production (GOK, 2009). Despite maize playing a key role in food security and income generating in Kenya, its productivity has not been adequate where stagnation/decline in maize yield has led to frequent food security problems. The decline in maize yield has been attributed to declining soil fertility and increase in world fertilizer prices (Alika and Emede, 2005). The situation has been exacerbated by maize price fluctuation and occasional importation of cheap maize grains (Mbithi, 2000). The problem of declining maize yields is magnified by a continued increase in population annually at a rate of about 2.9% leading to decreasing per capita consumption.

The poor maize yields on the country cannot feed the increasing human population which is accelerated annually (GOK, 2011). Soil degradation and low use of fertilizers are the major Contributory factors. Enhanced soil management has been recognized as very important in replenishment of soil fertility and enhanced agricultural productivity. But in improvement of soil Fertility it has been reported that, farmers apply inorganic fertilizers that are well below the recommended rate levels, or not at all (Alika and Emede, 2005). This case applies to most of the farmers in lower regions of Meru and Tharaka Nithi counties.

Sometimes the government imports fertilizer which it delivers to the farmers when it is late, this contributes to poor crop or crop failure. (Ariga and Jayne, 2011). This incidence could be traced way back in 2008 when the government imported fertilizers but delivered it late to the farmers. National cereals and produce board (NCPB) imported fertilizer in 2008 but delivered it late, which contributed to a poor crop. This created pressure from some farmers for increased subsidization of inputs (fertilizer and seed) so that the productivity of maize would be raised in order to counter an expected increase in hunger in 2009. In 2009 the GOK imported a good amount of fertilizer through NCPB that were distributed through its branches and selected private retailers at subsidized prices. The relationship between maize prices and revenues from fertilizer sales is positive and significant, which confirms the dominant perception in Kenya of a positive correlation between demand for fertilizer and returns to maize production. If the high prices of fertilizers are not subsidized by the government, it becomes difficult to achieve the high returns in maize production. There is need to undertake research that is geared towards improving soil fertility, increasing food security and enhancing livelihood in these vulnerable areas (Kihanda *et al*., 2007; MOA, 2012; Mwandalu and Mwangi, 2013).

Crop production in most small holder farming systems in ASALs is characterized by continuous cultivation without adequate input use, hence lowering native soil fertility and productivity (Mucheru Muna *et al.,* 2003). Maize allows efficient conversion of carbon dioxide (CO_2) into carbohydrates and finally green biomass and yield especially under conditions of maximal N supply (Ghanbari *et al.,* 2010). The practice of intercropping cereals and legumes has increased because of the potential to increase area productivity (Mucheru-Muna *et al.,* 2003).

2.2 Growth Rate and Productivity of Maize

Maize is widely grown throughout the world producing an approximate of 717 million metric tons per year (Ranum *et al*., 2014). It requires nitrogen to enhance growth rate and productivity. It can be processed into a variety of food and industrial products including starch, sweeteners, and oil, beverages, glue and fuel ethanol. Maize is also widely grown in Africa by small holders and forms an important part of the transformation of smallholder's agricultural systems that has taken place this century.

In Kenya the production is a highly relevant activity due to its importance as it is a dominant food crop (Karuku *et al.,* 2014). It is mostly produced under rainfall conditions. The per capita consumption ranges from 98 to 100 kgs which translates to at least 2.7 million metric tons per year (Nyoro *et al*., 2009). Over 38% of the food crop producers in Kenya grow maize (GOK, 2004). Small scale production accounts for about 70 percent of overall production. The remaining 30% of the output is from large scale commercial producers (EPZA, 2005). Small scale producers mainly grow the crop for subsistence, retaining up to 58% of their total output for household consumption (Mbithi, 2000).

Kenya has experienced a trend of maize deficit along in the years which has been met through imports. This has attributed to poor weather and declining soil fertility. Yields have remained at an average of two tons per hectare below the possible six tons per hectare, a situation attributed to inadequate absorption of modern production technologies such as high yielding maize varieties and fertilizers use because of high input cost, lack of access to credit and inadequate extension services to small scale producers (Karanja *et al.,* 2014).

2.3 Growth Rate and Productivity of Cowpeas

The worlds annual production of cowpea (*Vigna unguiculata* L.) is estimated at 7.56 million tones and about 12.76 million ha out of which SSA accounts for about 70% of total world production (IITA, 2002). In Kenya, cowpea is the third most important grain legume crop after beans and pigeon pea, and features well in several cereal based cropping systems of the ASALs (Kimiti *et al*., 2009). Cowpea is fast growing, drought tolerant and yield well in dry environments (Cattiveli *et al*., 2008). It has a deep root system that stabilizes the soil and enables absorption of water from the sub soil. It also forms an effective canopy cover that covers soil moisture (Hagan *et al*., 2010).

The marginal rainfall areas of eastern Kenya account for 85% of total cowpea production (Onduru *et al*., 2008; Kimiti *et al.*, 2008). However, cowpeas average grain yield is about 0.5 t/ha in farmer's field which is in contrast to the potential yield of 2.5 t/ha (Faraj *et al.*, 2012). Cowpeas are preferred by farmers because they grow within a short time hence a source of food, feed and income (Saidou *et al.,* 2007; Kimiti *et al*., 2009). It also improves nitrogen availability in N depleted soils. Through its high nitrogen fixing capacity, cowpeas can fix up to 88 kg N/ha annually, while in an effective rhizobium symbiosis it can fix more than 150 kg N/ha annually which can supply 80 - 90 % of plants total nitrogen requirement (Farokum *et al*., 2000). Maize plants requires 0.029 t/ha of nitrogen to sustain 1 t/ha of grain maize crop (YARA, 2019). There is little attention that has been given on rhizobium inoculation studies in cowpeas, in spite of the fact that it has the potential to widen the food base hence improving food security in Meru and Tharaka Nithi counties.

2.4 Determination of Nitrogen Amount Fixed in the Soil under Inoculated and Non-Inoculated Maize Cowpeas Intercrop

Soil analysis is a process by which elements are chemically extracted from the soil and analyzed for their plant available content within a sample of soil (Akkaya and Vamarcke, 2003). It increases the knowledge of what nutrient are available in the soil. It reduces the environmental impact due to unnecessary soil amendments. Soil analysis increases the efficiency of resource inputs like fertilizers and water and also helps to predict the nutritional values needed for crop production (Akkaya and Vanmarcke, 2003). Additionally, soil analysis facilitates fertilization management, by also revealing the current soil pH level. Soil pH is important due to its influence on the uptake of soil nutrients. The intention of managing soil pH was to be able to adjust the acidity as needed, to the point where there are no toxic metals exposed to the crops, as well as to ensure that nutrients availability is at its maximum. Every crop has its own optimal pH range. Because of this, some crops grow better and can achieve their full potential in acid, while for others this takes place in a more alkaline-based soil. It is recommended to perform a soil analysis every 3-4 years (FAO, 2010).

2.4.1 Biological Nitrogen Fixation

Biological nitrogen fixation is the process that changes inert N_2 into biologically useful NH_3. This process is mediated in nature only by nitrogen fixing rhizobium bacteria (Webster and Wilson, 2008). Other plants benefit from nitrogen fixing bacteria, and when the bacteria die it releases nitrogen to the environment. When the bacteria live in close association with the plant in legumes and a few other plants, the plants live in small growths on the roots called nodules. Within these nodules nitrogen fixation is done by the bacteria and the ammonia (NH_3) they produce is absorbed by the plant. Nitrogen fixation by legumes is a partnership between a bacterium and a plant.

The quantity of nitrogen fixed by legumes is difficult to quantify and varies according to the species that is involved and the location (Webster and Wilson 2008). The average consumption of nitrogen fertilizer globally has increased from 8 to 17 kg N/ha for agricultural purposes, and this increase that is significant has occurred in both countries that are developing and those that have developed (Peoples *et al*., 2005; FAO, 2010). Fertilizer nitrogen requirements are predicted to increase in future (Subba, 2000). However, with current technologies in fertilizer application, both ecological cost of fertilizer usage and economic eventually becomes prohibitive. Currently the issue of biological nitrogen fixation (BNF) is of great importance because the use of nitrogenous fertilizer has led to unacceptable levels of water pollution and the eutrophication of lakes and rivers (depleted low oxygen levels and poor water quality) (Morad *et al.,* 2013). While BNF may be tailored to the need for organisms, fertilizers are mainly applied in few or large dosages which may be leached (Sprent and Sprent, 2001). This not only leads to wastage of energy and money but also to serious pollution problems particularly in waste supplies.

Cowpeas nitrogen fixation starts with the formation of a nodule. Rhizobium invades the roots and multiplies within the cortex cells and the plant supplies all the necessary nutrients and energy for the bacteria (Sprent *et al.,* 1989; Wagner, 2012). In the field small nodules can be seen 2-3 weeks after planting, depending on the legume species and germination conditions (Maingi *et al.,* 2006). When nodules are young and not yet fixing nitrogen they are usually white or grey inside. As nodules grow in size they gradually turn pink or reddish in color, indicating nitrogen fixation has started. The red or pink color is caused by leg hemoglobin that controls oxygen flow to the bacteria. Mature nodules may resemble a hand with a center mass (palm) and protruding portions (fingers) but the entire nodule is normally about 2.5 cm in diameter (Wagner, 2012).

2.4.2 Nitrogen Availability, Uptake and Utilization by Plants

Soil nitrogen can either be organic or inorganic. The inorganic forms of nitrogen are NH_4^+, No_3^-, No_2, No and elemental N. Basing on soil fertility NH_4^+, No_3^- and No_2 have a significant use in crop production. Up to 90% of the total nitrogen in soils N is estimated to be in organic form, although in some cases significant amounts exist as NH_4^+ bound in clay colloids (Wagner, 2012). Most of nitrogen is absorbed by plants in forms of NH_4^+ and No_3^- . The amount of these two ions available to the crop roots greatly depends on the amount of nitrogenous fertilizer supplied and released from the reserves of the organically bound soil N. Conversion of NH_4^+ into

$N0_3^-$ is a two-step process in which ammonia is first converted to nitrite and then nitrate. Nitrite conversion is effected by a group of autotrophic bacteria known as nitrosomonas whereas conversion from nitrite to nitrate is effected by nitrobacter which is also a group of autotrophic bacteria (Rowe, 2005).

Nitrifying bacteria are less abundant or active in acidic soils or poorly aerated soils; hence NH_4^+ becomes a more important nitrogen source than No_3. Many plants make use of No_3- and may also utilize NH_4^+, although various impairments by the plants may be suffered when only ammonium furnishes nitrogen (FAO, 2010). Nitrogen is a constituent of proteins, purines and many coenzymes hence an interference with protein synthesis, growth becomes a major biochemical effect of nitrogen deficiency. Lack of nitrogen leads to reduced photosynthesis which causes a nitrogen deficient plant to lack amino acids which is the machinery for synthesis of the necessary carbohydrates and carbon skeletons. Plants deprived of nitrogen show decreased cell division, expansion and elongation, prolonged dormancy that lead to delaying swelling of buds in some plants (Wagner, 2012).

2.4.3 Legume-Rhizobium Symbiosis

Legumes have the remarkable ability to establish a symbiotic relationship with nitrogen-fixing soil bacteria known as rhizobia (Simsek *et al*., 2007). Among plant-microbe interactions, the legume-rhizobium symbiosis forms a unique system (Maingi *et al*., 2006). This interaction results in the formation of nodules on the host plant. The symbiosis depends on the host plant gaining a constant supply of reduced N from rhizobia and the rhizobia in return are supplied with photosynthetic (carbon) and other nutrients by the host plant. The two partners first establish contact with each other at the surface of growing tip of root hair. If the initial dialogue is successful, the root hair begins an inverse tip growth, forming a long and narrow passage in which bacteria travel by continuously dividing at the leading edge (Ortiz *et al*., 2011). The root nodules are then formed within which the micro symbiosis converts atmospheric nitrogen into ammonia. This biological process plays a role in sustainable agriculture, because it reduces the need for exogenous nitrogen fertilizer while providing an efficient way of producing protein-rich foods. Rhizobium infection and nodule development follow a well-defined morphological program (Simsek *et al.*, 2007).

Legumes are rhizobium specific which can occur both at early and late stages of interaction that are associated with bacterial infection. Domesticated crop species have fewer compatible symbiont than their wild counterparts (Mutch and Young, 2004). If a legume is grown in association with another crop, commonly a cereal, the nitrogen nutrition of the associated crop may be improved either by direct nitrogen transfer from the legume to the cereal, or by a simple sparing of the available soil nitrogen. The legumes use fixed atmospheric nitrogen rather than the soil mineral nitrogen which can be exploited by the companion cereal crop. Inoculation of cowpeas will therefore, assist in addition of more nodules in the roots of the legumes hence increasing the nitrogen fixation capacity of the soil.

2.5 Effect of Inoculated and Non-Inoculated Maize Cowpeas Intercrop on Maize Growth Rate and Yield

2.5.1 Cereal–Legume Intercropping

Multiple cropping systems have been practiced traditionally by small-scale farmers in the tropics in different forms. Cereal and legume intercropping is recognized as a common cropping system throughout tropical developing countries. Cereal crops such as maize, millet and sorghum are dominant crop species whereas legume crops such as beans, cowpeas, groundnuts, pigeon pea and soybeans are the associated legume plant species. Fertilizers are used in most of the SSA although the amounts applied are inadequate to meet crop demands fully (Okalebo, 2009). This has led to the need for an immediate strategy using farmer viable resources. Grain legumes through biological N fixation offer complementary, cheap and viable soil fertility improvement strategy for the resource–poor farmers to realize improved grain yields and sustained farm productivity (Mucheru-Muna *et al*., 2003).

In addition, cereal–legume intercropping systems improve in profit maximization, risk minimization, soil and water conservation and improvement of soil fertility, weed control, pest and disease control in SSA (Amedie *et al.*, 2010). Inoculation of cowpeas with effective rhizobia can improve maize grain yield when intercropped and also offer greater yield stability than sole cropping systems (Chamango, 2001; Karanja *et al*., 2014). There is not much information on intercropping of inoculated cowpeas with maize in Meru and Tharaka Nithi counties, thus the need for this study.

This was irrespective of the fact that in Kiarie *et al*., (2011), cereal-legume intercropping systems were reported to be more productive than sole crops grown on the same land. However this study focused on intercropping maize with inoculated cowpeas. The same study identified legumes as having the highest potential to improve soil fertility at relatively low cost compared to inorganic fertilizers (Kiarie *et al*., 2011).

2.5.2 Nitrogen Transfer in Intercropping Systems

In order to reduce the use of N fertilizers and their unfavorable economic and environmental impacts, N-fixing legumes that are grown in rotations or under intercropping systems are considered an alternative and sustainable way of introducing nitrogen into agro ecosystems (Fustec *et al*., 2010). Some of the authors have shown that in grass-legume mixture, legumes enhance the soil nitrogen pool and that the grass benefits from the nitrogen which is provided by legumes (Gylfadottir *et al.,* 2007). Nitrogen can also be transferred within plant mixtures by different path ways (Fustec *et al.,* 2010). In ryegrass-clover mixtures, it has been shown that 10% of the nitrogen fixed by clover is transferred to the grass and accounts for up to 50% of the nitrogen in ryegrass (Rasmussen *et al*., 2007).

There is evidence in transfer of nitrogen between the legumes and non-fixing plants, since any tracer which is incorporated into the legume and detected in the non-legume receiver plant shows the transfer. A study conducted by Cortes-Mora *et al*. (2010), demonstrated that in an intercrop of Faba bean to rape seed, nitrogen was detected at the early stages of growth in the rape seedling. Cowpeas fix nitrogen in the soil and the intercrop consequently benefits from this nitrogen fixed. The amount of nitrogen transferred by inoculated cowpeas intercrop has not been researched in Meru and Tharaka Nithi counties, hence this study attempted to compare the amount of N fixed by inoculated and non-inoculated cowpeas-maize intercrop.

2.5.3 Leaf Area Index (LAI)

Leaf area is an important variable for most Ecophysiological studies in terrestrial ecosystem concerning light interception, evapotranspiration, photosynthetic efficiency, fertilizers and irrigation response and plant growth (Blanco and Folegatti, (2005). Leaves are important structures for plant organs that associate with evapotranspiration and photosynthesis. The leaf area capacities are required in most physiological and agronomic studies concerning plant growth (Guo and Sun, 2001). Photosynthesis yields carbohydrates for growth (Lakso and Flore, 2003). Leaf area index is one of the most important parameters for canopy architecture. In coincidence with sunlight interception leaf area index is useful as a basis for analyzing canopy productivity (Cohen and Naor, 2002). Leaf area index varies depending on a number of factors including recurrent climate, water and nitrogen availability and to some extent $C0_2$ elevation (Cowling and Field, 2003).

The leaf area index reflects leafiness of the crop. The leafiness in one way reflects photosynthetic capability of the crop. The development of a grain size depends on a number of factors such as the leaf-grain ratio, leaf area index, genetic and climatic factors, position in the plant and number of seeds, water and nutrient supply (Dennis, 1996). Leaf area index being an important agronomic parameter, it reflects crop growth and predicts yield (Fageria *et al*., 2006). Differences in leaf area can affect plant spatial distribution and the micro environment within population (Giunta *et al*., 2008), which plays a decisive role in the photosynthetic efficiency and light energy distribution of crops (Boedhram *et al*., 2001). Intercrop with legumes provides nitrogen that enables an increased leaf area index as compared to sole crops. A suitable leaf area index is a major sign of high crop yield that coordinates the relationship between sink and source of crops and balance the development of each organ in crops.

2.5.4 Photosynthetic Active Radiation (PAR)

The production of dry matter by plants depends on the amount of photosyntetically active radiation (PAR) which is absorbed by the plant leaves and how it is efficient in conserving into chemical energy. The amount of radiation that is absorbed depends on efficiency of interception of solar radiation by leaves. How the PAR is intercepted efficiently, it is dependant on the leaf area of the plant population (Varlet-Grancher *et al*., 1989) as well as the leaf shape and inclination into the canopy. It was observed by Gallo and Daughtry (1986), that the difference between intercepted and absorbed PAR, along the maize crop cycle, was lower than 35%. Muller (2001) showed that maize leaves absorbed 92% of radiation that was intercepted by the canopy. The efficiency of a canopy interception corresponds to the capacity of the plant population in intercepting solar radiation incidence. The efficiency of radiation interception is also influenced by the level of nutrients in plants (Green *et al.*, 2003). The interception of PAR by plants in intercrops is greater comparing with sole cropping since intercrops fix nitrogen in the soil, increasing the level of nutrients in plants (Green *et al*., 2003).

2.5.5 Light Extinction Coefficient

Light extinction coefficient is dependent on PAR and LAI. The efficiency of PAR interception depends on the leaf area of the plant population as well as on the leaf shape and inclination into the canopy (Varlet-Grancher *et al*., 1989). Radiation and moisture are basic meteorological parameters of significance to agriculture. Under optimal conditions, with adequate moisture and fertility, radiation plays the role of a decisive factor for crop growth and development, thus manipulation of radiant energy within the crop field by an appropriate adoption of crop stand geometry, like row orientation and row spacing can provide a means to create light saturated conditions for crop canopy for the purpose of efficient harvest of solar energy for agricultural production.

The crop canopy structure plays a vital role in the population structure because it plainly affects the interception of sunlight, the photosynthetic efficiency and crop yield of the population with the influence on micro climate of water, heat, and atmosphere on the canopy (Zhao *et al*., 2002). The light use efficiency of crop population is directly related to its canopy structure. Canopy light interception can be influenced positively or negatively by the LAI and it rises along with the increasing LAI and also lowers along with the decreasing LAI. Light interception reaches the peak when LAI is at its optimum. The photosynthetic rate can be affected by the interception of light and an appropriate increase in interception of light can improve the photosynthetic capacity hence increasing the production (Huang, 1999). Canopy *K* value at all levels reflects vertical distribution of the leaf area and leaf angle and also the vertical diminishing status of canopy light.

2.6 Soil Moisture Retention under Different Maize Cowpeas Intercropping Patterns

Climate change as a result of global warming is considered to be ongoing and is expected to result in a long-term trend towards higher temperatures, greater evapotranspiration and increased incidences of drought (Srinfeld and Pandis, 2012). These trends, coupled with an expansion of cropping into marginal areas are generating increasingly drought prone maize production environments (Eakin and Wehbbe, 2009). Drought stress is a major climatic factor limiting production of maize in the tropics (Ortiz *et al.,* 2008). Since water is one of the major physical constrains to crop production in semi-arid areas, there is need to use it efficiently by ensuring that all that is available and directed to the crops being produced (Passioura, 2006). Moisture stress affects crop plants at all growth stages, but its effect on maize grain yield is less severe when it occurs at vegetative stages than when it occurs at the tasseling and silking stages. Drought stress occurring at grain filling can reduce the final size and weight of maize kernels therefore negatively affecting yields (Castiglioni *et al*., 2008).

Agronomic interventions that aim at maximizing water availability at key growth stages are important (Qadir and Drechse, 2011). Reducing the shortage of soil water and loss from evaporation by using surface mulches and by planting shelter belts is critical in improving the water use efficiency of a cropping system (Cheminingwa and Theuri, 2007). The need for more water efficiency crop management practices may be one of the strongest incentives for adopting a cropping system in ASAL areas (Mertz *et al.,* 2009). A cowpea crop is quick in forming a thick canopy that cover the ground surface, thus maintaining good soil cover that helps prevent excessive evaporation and also prevents the soil from being exposed to agents of erosion. There's a very obvious and direct use for measurements of soil moisture. It allows the need for irrigation to be quantified in advance of a crop showing signs of distress. Knowing the soil moisture status enables highly efficient irrigation, providing the water as and when required, and eliminating the wasteful use of water when irrigation is not needed. In this study it is important to record soil moisture since it will show the comparison of moisture retained in sole and intercrops which promotes maize performance. Production of drought tolerant maize varieties and coupling such with drought tolerant cowpeas varieties into the intercropping systems will enhance production of maize in Meru and Tharaka Nithi counties and other moisture deficient regions.

2.7 Cost Benefit Analysis and Maize Equivalent Yield in Intercrop and Sole Cropping Patterns

Small holder farmer benefits enormously from intercropping with low input application (Reddy and Reddi, 2007). A cereal and legumes intercrop which has become a popular combination among farmers is probably due to the legumes ability to combat erosion, improves moisture use efficiency, raise soil fertility levels and as a source of proteins (Matusso *et al*., 2012). Flexibility, maximization of profits, minimization of risk, soil conservation and soil fertility improvements are some of the principle reasons for small holder farmers to intercrop their crops (Matusso *et al*., 2012). Further to that, they have the potentials to give higher yields than sole crops, have greater yield stability and enhance the efficient use of nutrients (Seran and Brintha, 2010). Similarly, intercropped systems can be the insurance that farmers need, especially when the region is vulnerable to extreme weather conditions during the crops cycle (Ijoyah, 2012).

A maize-cowpeas intercrop offers greater financial returns for a farmer due to multiple types of produce in the farm (Richmondvale, 2017). It helps the farmer to use the same land available and yield more as well as diversify the produce. This generates more income for the farmer without really taking up any major expenditure while the land used remains the same (Kawasaki, 2010). The same labor is used for the two component crops hence saving production costs than when they are grown separately. When anything is grown on a farm land, the crop tends to absorb as much water and nutrients as it needs, averts soil run off and can prevent the growth of weeds (Nyawade *et al*., 2018). Intercropping is good for primary crops since secondary crops can provide shelter and even protect the primary crops. It allows a farmer to grow cash crops that will supplement the primary crop in some way. The use of twin lather than single irregular rows of each species improves intercrop cowpeas yield without materially varying maize performance comparative to mono cropping (Maluke *et al*., 2005).

Maize equivalent yield (MEY) is a systematic approach used to determine options which provide the best approach to achieving maize benefits while preserving savings (David *et al*., 2013). It will help in determining the cropping patterns with the greatest returns between intercrops and sole cropping patterns. Intercropping increases maize equivalent yield (MEY) per unit area by intensifying land use. It does not only contribute to increase in productivity, but also increases the farmer's income (Islam *et al.,* 2004). Intercropping system is an important approach of cropping system for increasing crop yield. Plant competition is inevitable in intercrops and it reduces intercrop productivity. Greater productivity in intercropping systems is commonly achieved by minimizing competition and minimizing complementary use of growth resources.

Intercropping is basically achieved through growing of cereals and legumes. Most farmers' traditionally practiced mixed cropping even though sole cropped cowpeas produces higher grain yields when sprayed with an insecticide (Blade *et al*., 1997). It has been reported that intercropping is more productive than monocropping (Ghosh *et al*., 2006). This can be through use of light energy efficiently and other growth resources. Also optimizing the resources of land use can be achieved through intercropping and increasing plant densities. Intercropping offers potential advantages for resource utilization, decreased input and increased sustainability in crop production (Egbe *et al*., 2010). The higher (MEY) of the intercrop system compared to the sole crop may have resulted from complementary and efficient use of resources by the component crop (Liu *et al*., 2006).

CHAPTER THREE

NITROGEN FIXED IN THE SOIL UNDER COWPEAS-MAIZE INTERCROP AND SOLE CROPS

3.1 Introduction

Multiple cropping patterns have been practiced traditionally by small-scale farmers in the tropics. Cereal and legume intercropping is recognized as a common cropping system throughout tropical developing countries. This system improves in profit maximization, risk minimization, soil and water conservation, and improvement of soil fertility; weed control, pest and disease control in sub Saharan Africa (Amedie *et al.,* 2010). Fertilizers are used in most of the sub Saharan Africa although the amounts applied are inadequate to meet crop demands (Okalebo *et al*., 2006). This has led to call for an immediate strategy using farmer viable resources. To reduce the use of N fertilizers and their adverse economic and environmental impacts, nitrogen-fixing legumes which are grown in rotations or under intercrops are considered an alternative and sustainable way to fix nitrogen into agro ecosystems (Fustec *et al*., 2010).

Grain legumes through biological nitrogen fixation offer complementary, cheap and viable soil fertility improvement strategy for the resource –poor farmers to realize improved grain yields and sustained farm productivity (Mucheru-Muna *et al*., 2003). Nitrogen fixation in legumes depends on the formation of nodules by rhizobium. Without sufficient nodule mass filled with an efficient, nitrogen fixing strain of rhizobium, nitrogen fixation will be inadequate. Inoculation of legume seed assures rhizobium is present in the root environment. Some rhizobium is specific and nodulate only specific legumes while others may nodulate several legumes. Native rhizobium may be insufficient numbers to nodulate both native and introduced legumes. Often the native rhizobium is low in numbers, and if the strain for the introduced legume is not efficient nitrogen fixer, inoculation usually corrects these problems (Kiarie *et al*., 2011).

Inoculation of cowpeas with effective rhizobia can improve maize grain yield when intercropped and also offer greater yield stability than sole cropping systems (Chamango, 2001; Karanja *et al*., 2014). Intercropping of inoculated cowpeas with maize have been reported to be more productive than sole crops grown on the same land with legumes being demonstrated to have the highest potential to improve soil fertility at relatively low cost compared to inorganic fertilizers though the quantity of nitrogen fixed by legumes is difficult to quantify and varies according to the species involved and the location (Webster and Wilson, 2008, Kiarie *et al*., 2011).

3.2 Materials and Methods

3.2.1 Description of the Experimental Sites

The experiment was conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) Igoji field research station (0^{o} 10'26.54S, 37^{o} 42'21.23E) and at Magutuni primary school (0^{o} 12'44.03S, 37^{o} 44'32.50E) in Meru and Tharaka-Nithi Counties, respectively. Both areas lie in a semi-arid area with a mean annual minimum and maximum temperature of 23 and 25.9°C for Igoji and Magutuni, respectively. Rainfall is bimodal with mean annual rainfall ranging between 800 – 1100 mm (Recha *et al.*, 2017) for both sites. Agriculture is the main source of livelihood in the areas, and crops grown include millet (*Panicum miliaceum*), sorghum (*Sorghum* spp.), cowpea (*Vigna unguiculata* L.), maize (*Zea mays*) and cassava (*Manihot esculentum*) in a small scale. Rain fed agriculture in the area is not feasible without the use of moisture conservation techniques or supplemental irrigation. Most farmers in the region are resource poor and unable to meet the high cost of fertilizers for effective crop production. The predominant soils in the two study sites are deep, well drained and are classified as Rhodic Nitisols (FAO-UNESCO, 1994). These soils have low organic matter content, are deficient in essential plant nutrients (especially nitrogen), are prone to leaching, and have a pH ranging between five and seven (Mureithi *et al*., 1995).

3.3 Experimental Design

The maize and cowpea varieties used in the experiment were SC Duma 43 and Katumani 80 (K80), respectively. The experiment was laid out in a randomized complete block design replicated three times. There were a total of 12 experimental plots in each site. Each treatment plot was 4 m x 3 m in size. The distance between the replications was 1 m while the distance between treatment plots was 0.5 m. The treatments were four namely:

T1 = Sole maize stand

T2 = Maize intercropped with inoculated cowpea

T3 = Maize intercropped with non-inoculated cowpeas

T4 = Sole stand of non-inoculated cowpeas

3.3.1 Choice for SC Duma 43 and K 80 Varieties

Duma 43 variety is a very early white maize streak and mottle virus tolerant hybrid, with a relatively short, flinty ear and excellent yield stability over a range of environments (African Seed Company, 2017). It takes 90 days to mature with exhibited yields ranging between 30-32 bags (90kg) per acre (ASC, 2017). It is compatible when intercropped with cowpeas Katumani 80 (K80) variety which assists in increasing yield. Cowpeas variety K80 is a dual purpose variety grown for both leaves and grain. It flowers within 55 – 60 days where it requires a lot of light than maize during intercrop. It matures within 80-90 days. The yield ranges from 8 – 17 t/ha. It is tolerant to yellow mottle virus and scab and moderately tolerant to septoria leaf spot and powdery mildew. It has field tolerance to aphids and thrips (Shambaza, 2017).

3.3.2 Trial Management and Agronomic Activities

Previously the land was planted with maize but had been left furrow for one season. The land was cleared using a panga and ploughed using a fork jembe. After laying out the trial, hills were made at a spacing of 75 cm x 30 cm for maize and 40 cm x 20 cm for cowpeas as recommended by the ministry of agriculture.

The four (4) treatments were randomly assigned within each of the three replications. Each plot consisted of four (4) rows of maize plants with each row having 16 plants (two seeds per hill), which were later thinned to one plant per hill at three weeks, giving eight (8) plants per row. Thirty two (32) plants were then left per plot giving a plant population of 44,444 plants/ha. Data was collected from the twelve (12) inner plants in each plot.

Similar maize plots as described above were established at a spacing of 75 cm x 30 cm and two (2) rows of cowpea that had initially been inoculated with a commercial

rhizobium bacterial strain was established in between the maize rows. The cowpeas spacing was 40 cm x 20 cm giving a plant population of 169,444 plants/ha.
Plots with sole crop of maize and non-inoculated cowpeas were also established using the spacing stated above.

Cowpea was established as a sole crop at the spacing of 40 cm x 20 cm. Each plot consisted of four (4) rows with each row having 20 plants, later thinned to one plant per hill at three weeks leaving 40 plants per plot giving a plant population of 125,000 plants/ha. Data was collected from 16 inner plants in each plot.

This research was established without application of any mineral fertilizers to depict the farmers practice. The treatment plots were manually kept weed free to reduce competition for moisture and nutrients. Three weeding's were done. Maize stalk borer was controlled by spraying with a pesticide (Pestox ® 100 EC) at a rate of 20 ml/20 litre knapsack spry at knee high, then repeated three weeks later.

3.3.3 Inoculation

The commercial inoculant for cowpea was obtained from MEA Limited Nairobi which is an authorized producer and supplier of legume inoculants in Kenya. Inoculation of cowpea was done by adding one tablespoon of sugar that was used as a sticker to 100 ml clean water in a soda bottle then shaking it to dissolve and forming a sugar solution (Kyei-Boahen *et al*., 2017). Cowpea seeds were then poured in a clean container and the sugar solution added into the container then mixed thoroughly until the seeds were well wetted. The inoculants was then added on the wet seeds and mixed thoroughly until all the seeds were uniformly covered. Seeds were kept under a shade for about an hour to dry and planted in moist soil (Ulzen *et al*., 2016).

3.4 Measurement of Rainfall and Temperature Data

The amount of rainfall and temperature received during the experimental period was recorded immediately after every rainfall and temperature event using a manual rain gauge and thermometer installed at the experimental sites.

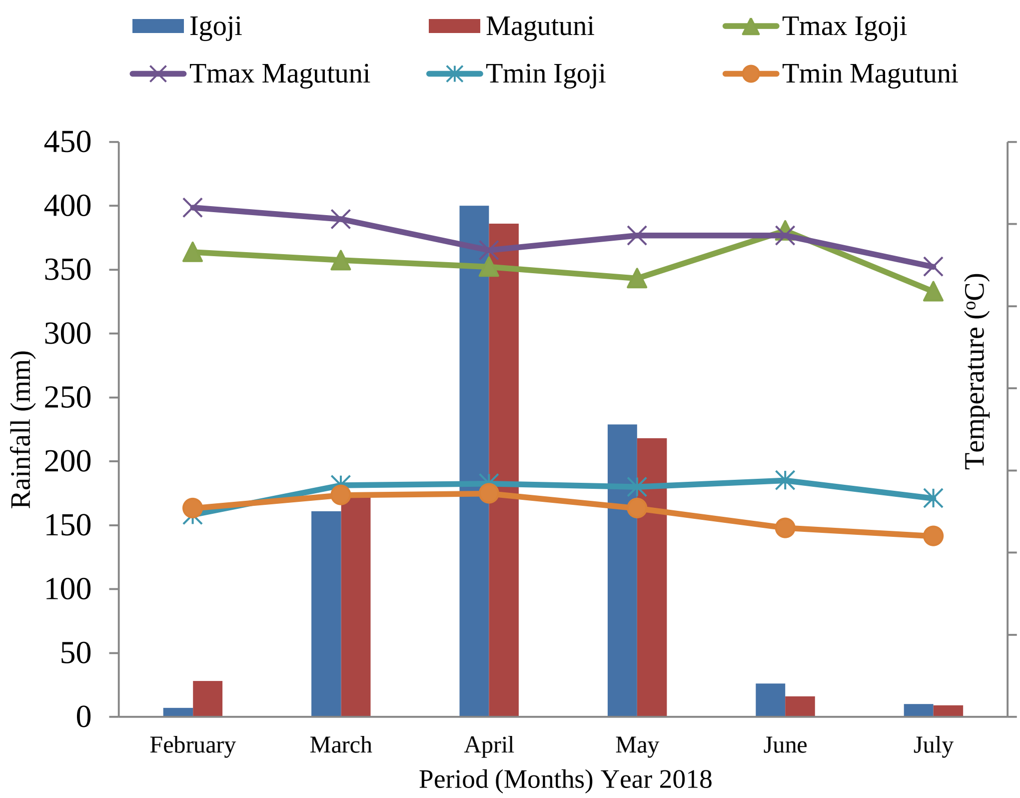


Figure 3.1: Rainfall, minimum (Tmin) and maximum (Tmax) temperatures recorded, during the study period.

3.5 Collection of Soil Sample to Determine the Amount of Nitrogen

The mixture of soil sample was taken before planting and after harvest from each treatment plot. A traverse unit was made then spot cleaned, from where the soil sample was collected using a soil auger. The soil auger was inserted to a depth of 0-20 cm in the soil, creating an opening. The soil auger was then removed with the slice intact and then removed a 2.5 cm wide core strip from the center down the entire length. Grass blades, stems, thatch stones and other inert matter were removed from the sample. A core was then added to the sample bag and labeled then the remaining soil returned to the opening, pressing firmly in place. The procedure was repeated until the sample bag held a random soil core from each plot. The core from each plot was then thoroughly mixed to make a uniform sample and then filled a well labeled sample bag with composite of 500 g. This homogenous portion was taken to the soil chemistry laboratory at University of Nairobi for analysis of total nitrogen using the Kjeldahl digestion method (Bremner, 1996).

In this method, one gram (1g) of soil sample sieved in apertures of 0.5 and air dried was transferred into a Kjeldahl digestion flask followed by 2.5 g of Kjeldahl catalyst (mixture of 1 part selenium powder + 10 parts $CuSO_4$ + 100 parts Na_2SO_4) and the mixture was heated at 100 ^{o}C for two (2) hours. The content was then allowed to cool after which eight (8) ml of concentrated sulphuric acid (H_2SO_4) (95%) was added and the mixture heated at 330^{o}C for four (4) hours when a colorless digest was obtained. The volume of the solution was then made up to 75 ml with distilled water. The percent nitrogen was calculated using the Equation (Bremner, 1996).

$$\mathbf{Nitrogen}\ (\%) = \frac{[(\boldsymbol{a}-\boldsymbol{b}) \times \mathbf{75}]}{\boldsymbol{Weght\ of\ soil\ sample\ used\ (g)}} \times \mathbf{1000}$$

Where,

a = nitrogen content of the soil sample

b = nitrogen content of the blank

1000 = coefficient of conversion from ppm N to percent N

75 ml = final diluted volume of the digest

3.6 Data Analysis

The data were subjected to analysis of variance (ANOVA) using GENSTAT statistical package. Means were separated using Fischer's protected least significant difference (LSD) at 5% probability level. General linear model regression analyses was performed to establish the interactive relation of data on the total nitrogen fixed in the soil before planting and after harvesting, the percentage change in the amount of nitrogen fixed by cowpea in the inoculated and non-inoculated plots and yield.

3.7 Ethical Considerations

Clearance from Chuka University Ethics Review Committee was obtained approving the suitability of the research proposal (Appendix 2). The research permit was acquired from county (Appendix 3) and also from the national commission of science, technology and innovation (NACOSTI) (Appendix 4 and 5). The study ensured that the research was done in an ethical manner by ensuring security and confidentiality of all data gathered. In this regard, all the data collected were used solely for the purpose of this thesis reporting with no reference to individuals. Further, the study ensured that the laid down policies were followed and should there be need for use of the study results for policy matters, the information will be availed to requesting institution in consultation with Chuka University.

3.8 Results

3.8.1 Nitrogen Fixed under Sole and Maize Cowpea Intercrop

Site had no significant effect on total nitrogen fixed in the soil before planting and after harvesting (0.055 and 0.352) in Igoji and Magutuni respectively (Table 3.1). This probably was because there were no limiting factors in one site significantly different over the other. Across the cropping patterns, there was a difference in amount of nitrogen fixed by T2 being greater than T3 and T4 but the difference was not significant at ($P \leq 0.05$). (0.732 and 0.137) in Igoji and Magutuni respectively.

Table 3.1: Soil Mineral Nitrogen Content Before and After Planting Cowpea Under Sole and Maize-Cowpea Intercrop and Percent Change in Soil Nitrogen in Magutuni and Igoji.

a) Before Planting

Magutuni	Igoji
Soil mineral N (g/kg)	Soil mineral N (g/kg)
0.16	0.18

b) After Harvesting

Cropping pattern	Magutuni		Igoji	
	Soil mineral N (g/kg)	% change in N	Soil mineral N (g/kg)	% change in N
T2	0.18±0.03a	6.3±1.8a	0.20±0.01a	5.2±1.2a
T3	0.17±0.04a	6.2±1.6a	0.18±0.01ab	5.0±1.4ab
T4	0.17±0.01a	6.2±1.3a	0.19±0.00a	5.1±1.2a
LSD	0.62	8.02	0.84	9.23
CV	8.2	18.3	3.9	11.8

Values are means ± standard error. Means considered significant different at ($P \leq 0.05$). T2=maize intercropped with inoculated cowpea, T3=maize intercropped with non-inoculated cowpea, T4=pure non-inoculated cowpea stand.

3.8.2 Effect of Maize-Cowpea Intercropping on Grain Yield

Yield had a significant difference between the treatments at ($P \leq 0.05$). Across the sites, maize yield (mean ± SE) was highest in pure maize stand (2.2±0.7 t/ha and 2.9±0.9 t/ha in Magutuni and Igoji respectively) than when intercropped with cowpea (Figure 3.2 a). Cowpea recorded yield ranging from 0.69 t/ha under (T2 and T3) in to 1.3 t/ha under (T4) in Igoji (Figure 3.2 b).

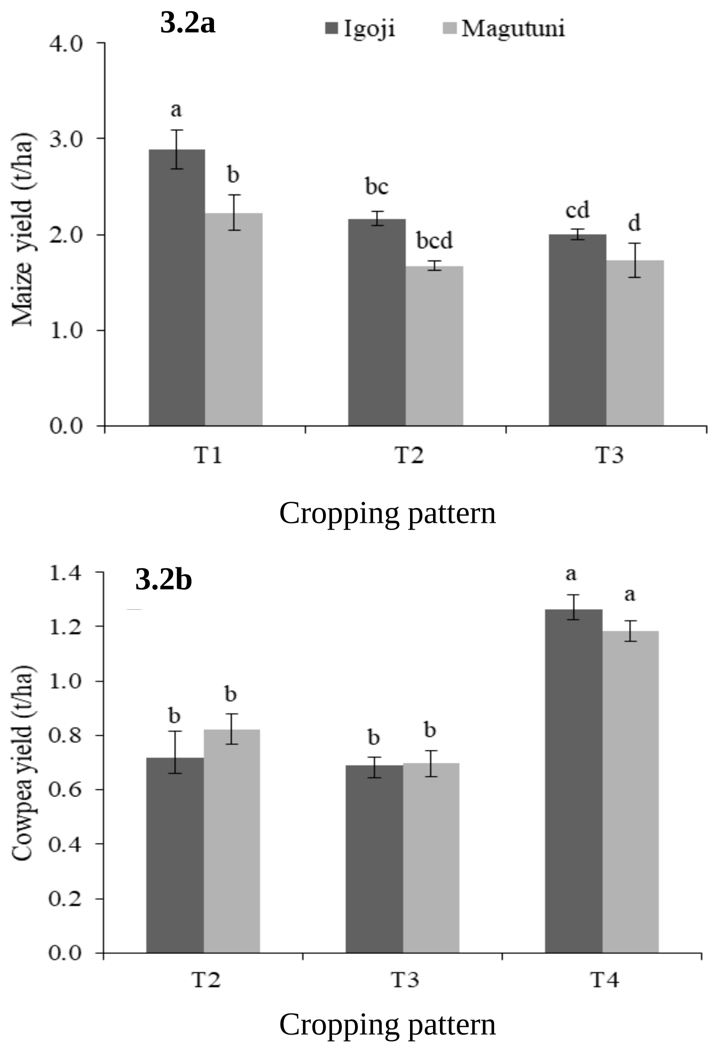


Figure 3.2: Maize grain yield (a) and cowpea grain yield (b) under different cropping patterns.

Vertical error bars represent standard error of mean. Different lowercase letters represent significant differences between treatments ($P \leq 0.05$). T1 = pure maize stand, T2 = maize intercropped with inoculated cowpea, T3 = maize intercropped with non-inoculated cowpea and T4 = pure non-inoculated cowpea stand.

3.9 Discussion

3.9.1 Nitrogen Fixed under Sole cowpea and Maize Cowpea Intercrop

Site having no significant effect on total nitrogen fixed in the soil before planting and after harvesting was an indication that the prevailing edaphic and agro ecological conditions of both sites favored nitrogen fixation in a similar manner and rate. There were no limiting factors in one site significantly different over the other. The inherent nitrogen fixed before planting was 0.18 g/kg and 0.16 g/kg in Igoji and Magutuni respectively (Table 3.1 a).

This probably was due to the previous crops planted per site and how the crops used the available nitrogen. Sanginga and Woomer (2009) showed that the residue quality as determined by N, lignin and polyphenol contents is one of the factors that affect the rate of nutrient release and availability for plant uptake. The other reason why the difference was not significant was probably because the experiment was conducted in two different sites hence the residue N could not have accumulated in one season to bring the difference and also competition with all of the negative and neutral microbes presented in the soil. This was in agreement with (Montañez, 2000) that inoculum strains when applied to the target ecosystem have to compete with all of the negative and neutral microbes presented in the soil.

The percentage change in the amount of nitrogen fixed in (T2, 5.7%) was higher than in (T3, 5.55% and T4, 5.65%), respectively (Table 3.1 b). Nitrogen fixed across the sites did not have a significant difference though there was a slight increase on the amount of nitrogen fixed in comparison to before planting and after harvesting. Nitrogen fixed in (T2) was higher than in both T3 and T4 due to the effect of inoculation in cowpeas, but the difference was not significant ($P \leq 0.005$). This increase could be attributed to increase in number of root nodules due to inoculation. This collaborates with the findings by Makoi and Ndakidemi (2009) and Mohammadi *et al.* (2012), who reported that the rate of nitrogen fixation is affected by a number of factors, including temperature, moisture, soil reaction, available nitrogen, presence of effective rhizobial strains, availability of various essential plant nutrients, cropping systems, tillage practices and the influence of vesicular arbuscular mycorrhizal.

However in this study, the non-significant factor could be attributed to the inherent nitrogen fixed per site and the fact that the experiment was done in two different sites as compared to when experiments are done in one site, and in two different seasons that may have led to accumulation of fewer residues N. This gives a chance to increase the inherent nitrogen that is fixed by the previous crop in the season. The N fixed in the plots positively increased maize equivalent yield (MEY) with T2, (4.70 t/ha, 4.58 t/ha) and T3, (4.44 t/ha, 4.19 t/ha) at Igoji and Magutuni respectively having the highest values as compared to T1, (2.88 t/ha, 2.23 t/ha). This could be attributed to efficient use of light energy and other growth resources. Egbe *et al.* (2010), collaborates with the findings that intercropping offers potential advantages for resource utilization, decreased input and increased sustainability in crop production.

3.9.2 Effect of Maize-Cowpea Intercropping on Grain Yields

The lower maize yield in T2, (2.1 t/ha, 1.6 t/ha) and T3, (2.0 t/ha, 1.7 t/ha) at Igoji and Magutuni respectively under maize-cowpea intercropping pattern compared to pure maize stand (2.9 t/ha and 2.2 t/ha) was attributed to the increased competition for resources such as nitrogen between the component crops resulting in lower maize cowpeas yield. Similar results were reported when maize was intercropped with potatoes (Mushagalusa *et al.*, 2008). Similarly, Ngwira *et al.* (2012) reported a decrease in yield when maize was intercropped with pigeon pea (*Cajanus cajan*) and *Lablab purpureus* (*L.*).

The low cowpea yield in maize-cowpea intercrop as compared to pure cowpea stand could be attributed to competition for resources like nitrogen and water. Ghosh *et al*. (2006) reported that competition for soil N in a pigeon pea/soybean intercrop was attributed to growing habits of the two crops. The slightly higher cowpea yield in T2 compared to T3 suggested a positive effect of inoculating legumes. This could be explained by the differences in biological-nitrogen fixation between the two patterns. In T2, inoculation of cowpea with elite rhizobia bacteria increased the amount of available nitrogen, resulting in higher maize yields (Figure 3.1 a).

In Magutuni, (1.8 t/ha) maize yield was slightly lower compared to Igoji (2.3 t/ha). This could be attributed to the inherent nitrogen which was more present in Igoji at (0.18 g/kg) than Magutuni (0.16 g/kg). The amount of rainfall received during that season was 5% higher in Igoji than Magutuni. Given that maize cultivation under monoculture requires 500−800mm of water in a growing season (Brouwer and Heibloem, 1986), the less amount of soil moisture recorded in Magutuni might have resulted in some less moisture conditions, which could have resulted in reduced nutrient uptake and translocation of assimilates into the kernels leading to low yields (Niu *et al.*, 2018). This argument is consistent with findings by Steward *et al*. (2018), who reported that water stress reduced maize grain yield significantly.

3.10 Conclusion

The amount of nitrogen fixed in the soil under inoculated cowpeas-maize intercrop was slightly higher than in non-inoculated maize cowpea intercrops and sole crops. This led to increased yield in T2 (inoculated) than T1, T3 and T4. This study demonstrated that the productivity in these soils can be improved by intercropping using rhizobium inoculant since the soils are deficient of N. Thus there is need for inoculation of cowpea with commercial rhizobium strain to enhance BNF in both sites for increased maize production.

3.11 Recommendation

There is need to study methods and strategies that increase the efficacy of final product under Rhizobium performance in maize-cowpea intercrop since inoculation increases the percentage of nitrogen fixation.

CHAPTER FOUR
EFFECT OF INOCULATED AND NON-INOCULATED COWPEAS-MAIZE INTERCROP ON MAIZE GROWTH RATE AND YIELD

4.1 Introduction

Maize (*Zea mays* L.) is among the essential grain crops in the world and grows under different ecological conditions. In sub-Saharan Africa (SSA), maize is a staple food (IITA, 2009) and occupying a third of the cultivated area in Kenya (Blackie, 1990). Application of environmental friendly agronomic practices will both enhance maize production and sustain the environment. However, soil fertility especially nitrogen deficiency limits maize growth and productivity in many sub-Saharan Countries, including Kenya. Intercropping cereals with legumes can also improve the growth and yield of the respective crops (Dusa and Stan, 2013). The advantages of legume/cereal intercrops are often assumed to arise from the complementary use of N sources by intercropping with legumes, because intercropped legumes can meet their N demand between symbiotic N_2 fixation, soil N acquisition and intercropped cereals uptake of more N from the soil than they stand in sole cropping (Musa *et al*., 2012). This is of particular interest for developing low-input and sustainable cropping systems. In addition, legume/maize intercropping has higher land use efficiency, lower water consumption and more ecological and environmental benefits compared to a cereal-cereal intercropping (Li *et al*., 2011). Studies have reported different responses to maize growth under maize-legume intercropping systems (Lemlem, 2013; Hirpa, 2014). Nevertheless, there is little information on the growth response of maize intercropped with *Rhizobium* inoculated cowpea. Therefore, this study assessed the growth response of maize intercropped with cowpea with or without *Rhizobium* inoculation.

4.2 Materials and Methods

4.2.1 Description of the Experimental Sites

As described in chapter three section 3.2.1

4.3 Experimental Design

As described in chapter three section 3.3

4.3.1 Choice for SC Duma 43 and K 80 Varieties

As described in chapter three section 3.3.1

4.3.2 Trial Management and Agronomic Activities

As described in chapter three section 3.3.2

4.3.3 Inoculation

As described in chapter three section 3.3.3

4.4 Measurement of Rainfall and Temperature Data

As described in chapter three section 3.4

4.5 Data Collection on Maize Growth Rate and Yield

The growth rate of maize was assessed by measuring the selected 12 inner data plants which were tagged in each plot. The heights of experimental plants were measured at two weeks interval from second week up to 119 days after planting (DAP). Leaf area index and light interception was measured at two weeks intervals starting from the second week to physiological maturity. Maize stem girth was measured from the sixth week to physiological maturity while maize grain yield was done at harvesting.

4.5.1 Plant Cover

Percentage plant cover (PPC) was measured once every two (2) weeks using a sighting frame from three (3) points within each plot and expressed in percentages as described by Elwell and Wendelaar (1977). A sighting frame was placed on top of the vegetation then the tubes that sighted the vegetation were counted divided by the total number of the tubes on the frame. This method was then repeated three times in every treatment plot. Plant cover data was taken from seven (7) to 119 days after emergence (DAP) when maize was harvested and was expressed as follows.

$$\mathbf{PPC}\ (\%) = \frac{\textbf{No. of tubes in where vegetation was sighted}}{\textbf{Total no. of sighted tubes}} \times \mathbf{1\ 00}$$

4.5.2 Plant Height

This was measured from the soil surface to the tip of the same plants using a meter rule on each sampled plants at two (2) weeks intervals from the second week up to 119 days after planting (DAP) then evaluated at 28, 42, 56, 84, and 119 days after planting (DAP**)**. It was expressed in centimeters (cm).

4.5.3 Light Interception

The light interception of the photosynthetically active radiation (PAR) was measured from 14 days after sowing and progressively at two (2) weeks interval up to the end of grain filling (90 DAP) in each plot, using a Sunfleck Ceptometer sourced from UoN (Decagon Devices, Pullman, WA, USA). All measurements were taken on clear cloudless days between 11.30 am and 1:30 pm (Kenyan/local time) to eliminate the effect of solar elevation on PAR interception. If the day was cloudy, data was collected the following day. For each measurement, one above-canopy reading and five below-canopy readings were taken at an angle of 60^{o} across the crop rows to ensure that more leaf area was exposed to the light sensors. The PAR (MJm^{-2}) that was intercepted and recorded in percentage was expressed as follows:

$$\%\mathbf{PAR} = \frac{(\mathbf{PAR_a} - \mathbf{PAR_b})}{\mathbf{PAR_b}} \mathbf{x\ 100}$$

Where:

PAR_a = PAR intercepted above the canopy and PAR_b = PAR below the canopy.

4.5.4 Leaf Area Index

Leaf area index (LAI) was estimated from the second week after planting to physiological maturity using a leaf area meter at two (2) weeks interval which was sourced from UoN.

4.5.5 Light Extinction Coefficient

Light extinction coefficient was determined from the LAI and their corresponding PAR with intercept set at zero using the equation below.

$$\mathbf{Light\ extinction\ coefficient} = \frac{\mathbf{In(PAR_b)}}{\mathbf{PAR_a}}\ \mathbf{x}\ \frac{\mathbf{1}}{\mathbf{LAI}}$$

PAR $_a$ is the PAR above the canopy, PAR $_b$ is the PAR below the canopy, and LAI is the leaf area index.

4.5.6 Relationship between PAR and LAI

Was determined using an exponential regression model that fits best for a set of data using the equation below.

$$\mathbf{y = ab^x}$$

Where,

$a \neq 0$

The relative predictive power of an exponential model is denoted by R^2. The value of R^2 varies between 0 and 1. The more close the value is to 1, the more accurate the model is.

Where:

R^2 = Ratio of sum of squares

y = dependent variable (or output of the function)

a = initial value of the function (or the y-intercept)

b = change factor (or a constant)

x = independent variable (or input of the function)

4.5.7 Maize Stem Girth

The second internode from the bottom was measured in millimeters at every two (2) weeks interval from 45^{th} day up to 119 DAP using a Vanier caliper. The center part from where the Measurement of the girth was taken was determined by use of a ruler.

4.5.8 Yield

At dry maturity (when grains are dry and ready for harvesting) plants were hand harvested from each plot. Cowpea was harvested when the crops had reached their respective maturity stages. Grain shelling was then done by hands and grain weight per plot and moisture content recorded using grain moisture meter. The grain weight of maize was measured using a field weighing balance. Maize grain yield per plot was converted to t/ha.

$$\textbf{Yield (t/ha)} = \frac{\textbf{Plot weight (g)} * \textbf{1,000}}{\textbf{Plot area (m}^{\textbf{2}}\textbf{)} * \textbf{10,000}}$$

4.6 Statistical Analysis

The data collected were subjected to analysis of variance (ANOVA) using GENSTAT statistical package. Means were separated using Fisher's protected least significant difference LSD at 5% probability level. General linear model regression analyses was performed to establish the interactive relation of data on maize stem girth, height, leaf area index, leaf extinction coefficient, interception of photosynthetically active radiation, maize and cowpea grain yield.

4.7 Results

4.7.1 Effect of Intercropping on Maize Crop Height

The intercropping of maize and cowpea did not significantly affect maize plant height in all the treatments in both sites and were not significant at ($P \leq 0.05$). In Igoji, however, the tallest maize plants were observed under the maize-inoculated cowpea plots (T2) during the early stages of the crop growth (28, 42 and 56 DAP, with 64.7 cm, 134.23 cm and 169.18 cm, respectively) than in maize-non inoculated cowpea (T3) and sole maize (T1). In Magutuni, the tallest maize plants were observed in T2 during the early stages (28, 42 and 56 DAP, with 58.45cm, 125.08 cm and 150.85cm, respectively) compared to T3 and T1, but at the end of the season, (84 and 119 DAP) the sole maize crop had the tallest plants with 193.08 cm. Similar to Igoji, T1 also recorded the tallest maize plants at the end of the season with 198.20 cm (Table 4.1).

Table 4.1: Effect of Intercropping on Maize Plant Height (cm)

Site	CP	Plant Height (DAP)					Mean
		28	42	56	84	119	
Igoji	T1	61.20a	119.83b	167.73c	198.16cb	198.20cb	115.5
	T2	64.70a	134.23ab	169.18c	181.02bc	181.11bc	146.0
	T3	64.50a	118.20b	165.30c	194.45cb	194.53cb	147.4
CV		6.1	20.3	11.6	16.2	13.8	
LSD		12.71	20.65	19.97	26.16	26.14	
	T1	56.58a	118.88b	147.98cb	193.00cb	193.08cd	141.9
Magutuni	T2	58.45a	125.08b	150.85cb	179.88bc	179.88bc	138.8
	T3	55.23a	121.43b	151.13bc	177.13c	177.18cb	136.4
CV		8.4	23.5	16.1	19.9	14.2	
LSD		11.58	16.24	25.84	41.63	41.55	

Significant differences at $P \leq 0.05$. T1=pure maize stand, T2=maize intercropped with inoculated cowpea, and T3=maize intercropped with non-inoculate.

4.7.2 Stem Girth

There was a significant difference on maize stem girth ($P \leq 0.05$) that was observed in maize intercropped with inoculated cowpea (2.95 mm and 2.46 mm) compared to maize intercropped with non-inss1 oculated cowpea (2.88 mm and 2.35 mm) and pure maize stand (2.83 mm and 2.37 mm) at 119 DAP in Igoji and Magutuni respectively (Table 4.2). The improved maize stem girth in maize, intercropped with inoculated cowpea could be attributed to the reduced competition for nitrogen due to nitrogen fixation by cowpea.

Table 4.2 Maize Stem Girth (mm) under Sole Maize and Maize Cowpea Intercropping

		Maize stem (DAP)						
Site	CP	14	28	42	56	84	119	mean
Igoji	T1	2.59ab	2.63a	2.67a	2.71ab	2.79b	2.83a	2.70
	T2	2.65a	2.68a	2.72a	2.79a	2.85ab	2.95a	2.78
	T3	2.44b	2.64a	2.68a	2.70a	2.80a	2.88ac	2.69
CV		8.2	5.9	5.7	4.3	5.1	6.4	
LSD		0.15	0.05	0.05	0.09	0.06	0.12	
Magutuni	T1	1.54d	2.02a	2.04ab	2.10ca	2.24a	2.37ab	2.05
	T2	1.81c	2.16a	2.97b	2.21b	2.37a	2.46a	2.31
	T3	1.75c	1.91a	1.91a	2.00a	2.30ca	2.35b	2.05
CV		8.6	6.6	5.4	3.9	4.2	5.8	
LSD		0.19	0.17	0.16	0.18	0.16	0.15	

Means with different letters indicate significant differences ($P \leq 0.05$). T1=pure maize stand, T2=maize intercropped with inoculated cowpea, T3=maize intercropped with non-inoculated cowpea.

4.7.3 Leaf Area Index (LAI) Development Trend

Intercropping, significantly affected leaf area index ($P \leq 0.05$). The minimum peak LAI values across the sites and cropping patterns were recorded in controls (T1 and T4) at 63 to 70 DAP (figure 4.1).

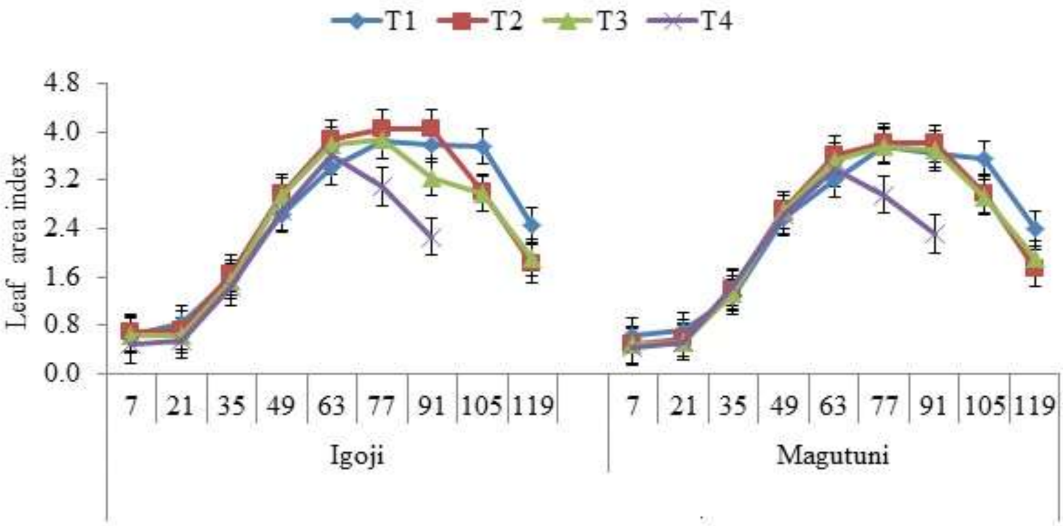


Figure 4.1: Leaf Area Index Development during the Experimental Period.

T1=pure maize stand, T2=maize intercropped with inoculated cowpea, T3=maize intercropped with non-inoculated cowpea and T4=pure non-inoculated cowpea stand. Key: Y axis- leaf area index and X axis- days after planting (DAP).

4.7.4 Response of Light Extinction Coefficient to Cropping Patterns

There was a significant difference on the light extinction coefficient at ($P \leq 0.05$) in the intercrops than in the sole crops, and ranged between 0.34 and 0.52 in Igoji and between 0.37 and 0.57 in Magutuni. T2 has the highest extinction coefficient with 0.52 and 0.57 (Table 4.3).

Table 4.3 Light extinction coefficient under sole crops and maize-cowpea intercropping patterns

Cropping pattern	Igoji	Magutuni
	Light extinction coefficient	
T1	0.34a	0.37a
T2	0.52ab	0.57ab
T3	0.49ab	0.52b
T4	0.39b	0.41b
LSD	0.18	0.2
CV	3.20	4.40

Means with different letters indicate significant differences ($P \leq 0.001$). T1=pure maize stand, T2=maize intercropped with inoculated cowpea, T3=maize intercropped with non-inoculated cowpea and T4=pure non-inoculated cowpea stand.

4.7.5 Effect of Cropping Pattern on the Interception of Photosynthetically Active Radiation (PAR)

Significant variations in PAR were observed during the growing season with a maximum PAR achieved on the 63 DAP in both sites. The PARs values in Igoji ranged from 88.35 millijoules per meter squared (MJ m^{-2}) in sole cowpea (T4) to 581.54 MJm^{-2} in maize inoculated with cowpea (T2). Sole cowpea (T4) intercepted less PAR than maize-cowpea intercrops (T2 and T3) ($P \leq 0.05$; Figure 4.2) whilst intercrops intercepted more PAR than sole maize (T1). This was more evident after silking (63 DAP) when maize leaves started senescing. In the initial stages of growth, however, the difference in intercepted PAR between the intercrops was not significant until cowpea and maize flowered.

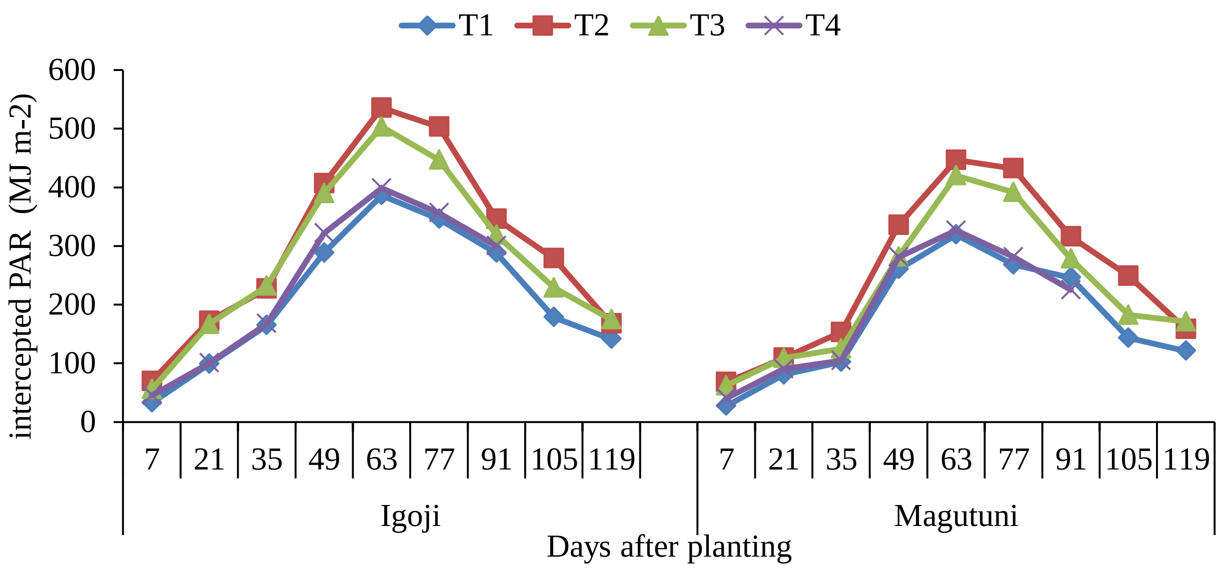


Figure 4.2: Amount of PAR intercepted under different cropping patterns throughout the study period in both sites.

T1=pure maize stand, T2=maize intercropped with inoculated cowpea, T3=maize intercropped with non-inoculated cowpea and T4=pure non-inoculated cowpea stand

4.7.6 Relationship between PAR and LAI

The PAR was positively and significantly ($P \leq 0.05$) correlated with LAI using an exponential model in Igoji ($0.83 \leq r^2 \leq 0.98$; $0.027 \leq$ SEE ≤ 0.047) and Magutuni ($0.81 \leq r^2 \leq 0.96$; $0.026 \leq$ SEE ≤ 0.057) across the four cropping patterns (Figure 4.3).

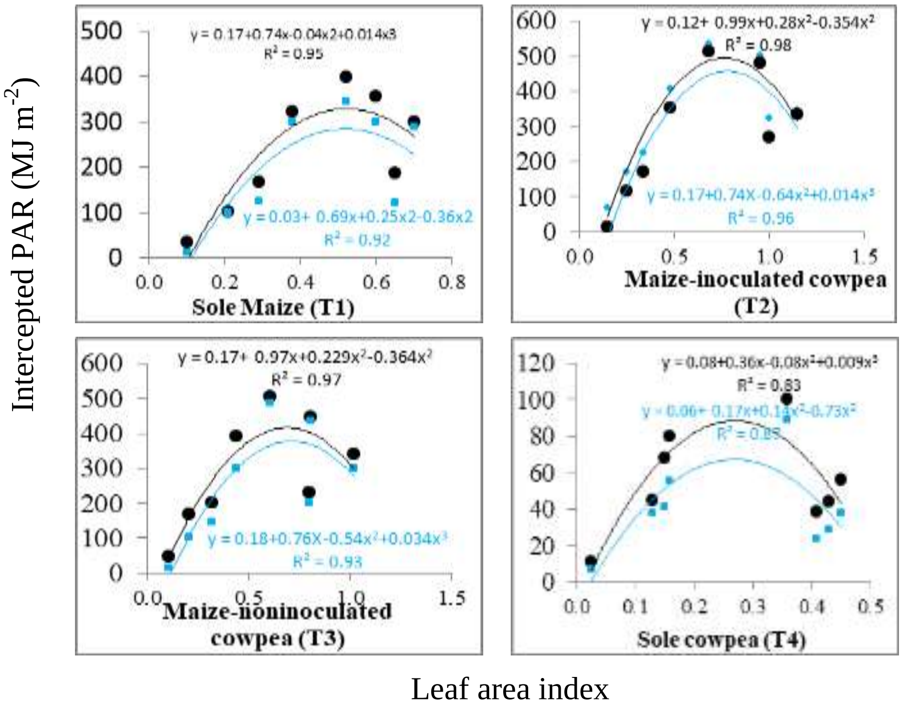


Figure 4.3: Relationship between intercepted PAR and LAIs for the four treatments.

Key: ● Igoji; ▪ Magutuni

Y axis – Intercepted PAR (MJ m^{-2})

X axis – Leaf Area Index

4.7.7 Effect of Maize-Cowpea Intercropping on Grain Yield

Grain yield was significantly different across the treatments ($P \leq 0.001$). Across the sites, maize yield (mean ± SE) was highest in pure maize stand (2.2±0.7 t/ha and 2.9±0.9 t/ha in Magutuni and Igoji, respectively) than when intercropped with cowpea

(T2, 2.1±0.6 t/ha and T3, 2.0±0.8 t/ha) Igoji and (T2, 1.7±0.5 t/ha and T3, 1.7±0.3 t/ha) Magutuni (Figure 4.4 a). Cowpea recorded yield ranging from 0.69 t/ha under (T2 and T3) to 1.3 t/ha under (T4) in Igoji and 0.8 t/ha under T2 and 0.67 t/ha under T3 in to 1.1 t/ha under (T4) in Magutuni (Figure 4.4 b).

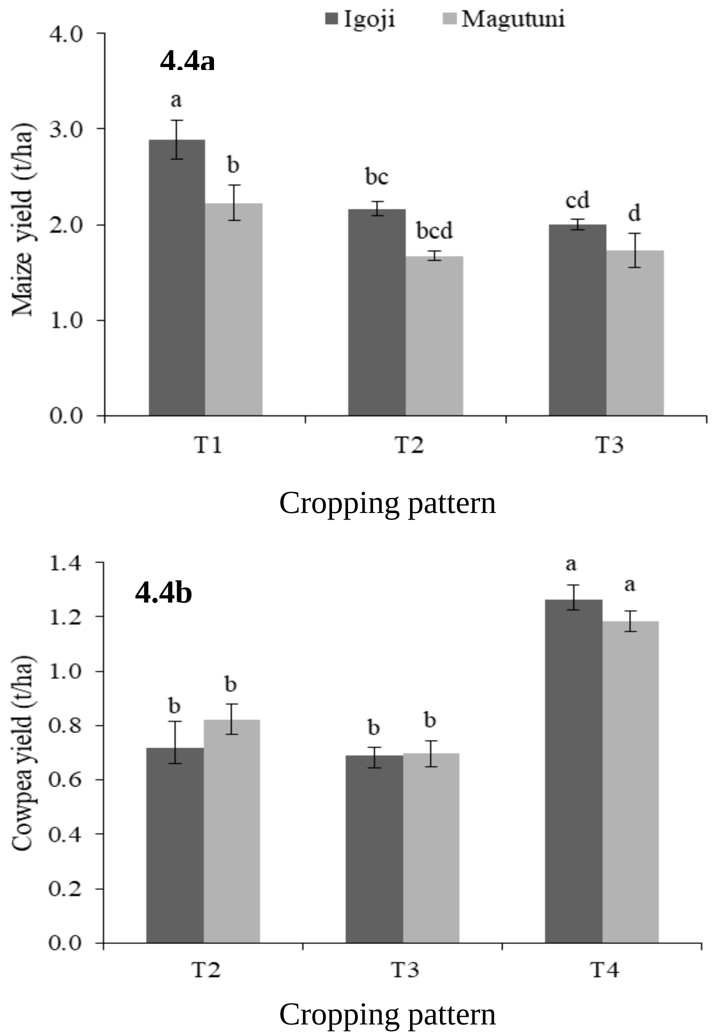


Figure 4.4: Maize grain yield (a) and cowpea grain yield (b) under different cropping patterns.

Vertical error bars represent standard error of mean. Different lowercase letters represent significant differences between treatments ($P \leq 0.001$). T1 = pure maize stand, T2 = maize intercropped with inoculated cowpea, T3 = maize intercropped with non-inoculated cowpea and T4 = pure non-inoculated cowpea stand.

4.8 Discussion

4.8.1 Effect of Intercropping on Maize Plant Height

The intercropping of maize and cowpea did not significantly affect maize plant height ($P \leq 0.05$) in both sites (Igoji and Magutuni), during the sampling periods. In Igoji, however, the tallest maize plants were observed under the maize-inoculated cowpea plots (T2) during the early stages of the crop growth (28, 42 and 56 DAP, with 64.7 cm, 134.23 cm and 169.18 cm, respectively) than in maize-non inoculated cowpea (T3) and sole maize (T1). In Magutuni, the tallest maize plants were observed in T2 during the early stages (28, 42 and 56 DAP, with 58.45cm, 125.08 cm and 150.85cm, respectively) compared to T3 and T1, but at the end of the season, (84 and 119 DAP) the sole maize crop had the tallest plants with 193.08 cm. Similar to Igoji, T1 also recorded the tallest maize plants at the end of the season with 198.20 cm (Table 4.1). These results, however, contradict with studies which reported that intercropping maize with soybean or cowpea did not have any effect on height of maize (Undie *et al.*, 2012; Akinyemi *et al.*, 2018; Pierre *et al.*, 2018). This was probably because the plant densities in the previous studies were higher than plant density in this study.

The high mean maize plant height that was observed from intercropped compared to sole maize implied that there was a positive interaction and competition among the companion crops due to two reasons. First the competition for light between maize and cowpea increased the efficiency of maize leaves to capture more light hence increasing the photosynthetic activities and thus the growth of maize. This assertion is supported by the high light extinction coefficient under the maize-cowpea intercropping plots compared to sole maize plots (Table 4.3). Competition for light among companion crops may have contributed to increase in the height of maize as an intercrop with cowpea than when planted as a sole crop. Secondly, cowpea may have also supplied additional nitrogen to the maize plants thus reducing the intraspecific competition for the limited N in soil.

4.8.2 Stem Girth

The improved maize stem girth in maize, intercropped with inoculated cowpea in both Igoji and Magutuni could be attributed to the reduced competition for nitrogen due to nitrogen fixation by cowpea. Maize intercropped with inoculated cowpea (2.95 mm and 2.46 mm) had a greater stem girth compared to maize intercropped with non-inoculated cowpea (2.88 mm and 2.35 mm) and pure maize stand (2.83 mm and 2.37 mm) at 119 DAP in Igoji and Magutuni respectively. This was in agreement with Akintoye *et al*., (2011) who reported a significant increase in stem girth of okra when intercropped with beans. Nweke (2015) reported that intercropping of both *Panicum maximum* and maize was found to yield more with better stem girth than maize on sole cropping, though some parameters assessed were not statistically significant. It was observed that Igoji had a greater stem girth than Magutuni. This could be attributed to inherent soil fertility at Igoji than in Magutuni, leading to increased N fixation that resulted to increased stem girth. Treatment and site interacted significantly in 28 DAP and 56 DAP to influence maize stem girth (Table 4.2). An increased stem girth is able to support the plant and also stores water that is used by the grains during grain filling and maturation stages.

4.8.3 Leaf Area Index Development during the Experiment Period

Intercropping, significantly affected leaf area index ($P \leq 0.05$). The minimum peak LAI values across the sites and cropping patterns were recorded in controls (T1 and T4) at 63 to 70 DAP (Figure 4.1). This implied that the total plant canopy under intercropping patterns (T2 and T3) was higher compared to sole cropping patterns. The trend of LAI development exhibited in this study was typical of most crops that increase their LAI to a peak value, after which the LAI reduces as the crop senesces. The observed reduction in LAI by maize and cowpea under the sole cropping patterns could be a strategy by the crops to reduce water loss and maintain the soil water uptake at satisfactory levels. Stomatal conductance and morphological modifications by maize and cowpea may have achieved this. Absorption of soil water decreases with reduction in LAI (Dermody *et al*., 2006).

Relative to sole cropping patterns (T1 and T4), maize intercropped with inoculated cowpea (T2) recorded the peak LAI of 3.75 at 70 DAP at Igoji and 3.16 at 63 DAP in Magutuni (Figure 4.1). There was a significant decline in the LAIs immediately after the maximum LAIs were reached in the two sites and in all the treatments, with the fastest decline being observed under sole non-inoculated cowpea stand (T4) (Figure 4.1). Attaining the peak LAI of different cropping patterns at different times suggests that the spatial distribution of LAI in this study was influenced by the cropping patterns and site (Belel *et al.,* 2014). However in this study, site did not exhibit significant variation in LAI (P=0.46). The modification of the time of leaf senescence in response to availability in soil moisture could explain this variability between sole crops and intercrops. It has been reported by Haworth *et al*. (2015) that reduced stomatal conductance under limited water conditions cause interruption in CO_2 assimilation. Under such conditions, plants may consume own water reserves and may lead to early death of the plants or leaf senescence. Nutrient and water deficit in crops may shorten leaf longevity leading to decrease in LAI.

A better LAI distribution was achieved when maize was intercropped with cowpea regardless of whether cowpea was inoculated or not. This was an indication that the integration of component crop increased the development of LAI that lead to an increased ground cover, which conserved soil moisture making the crop to utilize the moisture and increase surface area for $C0_2$ absorption to enhance the process of photosynthesis (Haworth *et al*. 2015). Lack of significant differences in the peak LAI between inoculated (T2) and non-inoculated cowpea (T3), suggested that intercropping cowpea without application of rhizobium inoculant was sufficient to achieve optimal canopy cover depending on the population of native rhizobium in the soil. The slightly higher rainfall in Igoji than in Magutuni during that experimental season could have contributed to a better LAI development as the improved moisture conditions could have led to enhanced assimilation of nutrients and accelerated leaf development.

4.8.4 Response of Light Extinction Coefficient to Cropping Patterns

The low light extinction coefficient observed in the sole maize (T1) and cowpea (T4) indicated that there were few vertical leaves in the cropping pattern, as compared to inoculated maize cowpea intercrop (T2) and non-inoculated maize cowpea intercrop (T3), probably as a result of the low soil moisture content due to the greater exposure to the ground surface. This therefore, implied that the sole cropping patterns had unequal distribution of light within the canopy leading to low radiation interception due to changes in inclination architecture foliage, probably as a result of soil moisture deficiency. This finding was in agreement with Belel *et al*. (2014), who reported that, the deficiency in soil moisture can change the position of leaf inclination, spatial distribution and leaf optical characteristics. The high light extinction coefficient in the maize-cowpea intercropping systems (T2 and T3) (Table 4.3) may indicate that penetration of light into the canopy was fairly uniform in these treatments. The observed light extinction coefficient values are consistent with those reported for maize and maize-legume intercropping systems within sub-Saharan Africa (Tsubo, 2000; Kanton and Dennett, 2008; Matusso *et al.*, 2014). This consequently, meant that photosynthesis was evenly distributed across the canopy and this facilitated improved maize growth rate.

4.8.5 Effect of Cropping Pattern on the Interception of Photosynthetically Active Radiation

There was a significant difference on PAR intercepted among different cropping patterns that was observed after 20th DAP with a maximum PAR being achieved on the 63rd DAP in both sites. This suggested that light penetration within the canopy was almost uniform at the initial stages of maize and cowpea development irrespective of the planting pattern when leaf area was not fully established. At this time the LAI was low. Varlet-Grancher (1989) reported that the efficiency of PAR interception depends on the leaf area of the plants population. There was a sharp decline of PAR in all the cropping patterns following attainment of peak LAI, perhaps due to the increased leaf senescence, which reduced canopy cover. This was in agreement with Bergamaschi *et al*., (2010) who reported that after maximum LAI of maize crop, the interception of PAR was almost constant, but showed lower values in comparison to the PAR observed at maximum LAI. However, the decline in intercepted PAR after attainment of peak LAI was rapid under the sole maize (T1) and cowpea (T4) (Figure 4.2) suggesting that extended water stress in the late stages of crop development accelerated leaf senescence. This was in agreement with Green *et al*., (2003) who reported that the efficiency of radiation interception is also influenced by the level of nutrients in plants and water absorbed. The high PAR variation exhibited at the beginning of the season can be linked to the low inter-row compactness of the crops at this stage thus causing low leaf area index.

4.8.6 Relationship between PAR and LAI

The strong and positive relationships between PAR and LAI across the cropping patterns (Figure 4.3) indicated that LAIs accounted for more than 81% of the variability in the PARs. This, therefore, meant that the interception and utilization of light by maize and cowpea was largely influenced by the variations in geometry and orientations of the leaves. Ali *et al.* (2003) and Pradhan *et al.* (2018), reported that LAI and PAR exhibited a positive relationship in that as LAI increased radiation, interception per unit surface area also increased. The results were consistent with Ali *et al.* (2003) who reported that lower LAI reduced the amount of radiation intercepted by leaves. Other studies reported that canopy structure exhibited a direct relationship with light interception efficiency (Cabrera-Bosquet *et al.*, 2016; Rahman *et al.*, 2018) and that radiation interception reduced exponentially from above to below the canopy (Medlyn *et al.*, 2003; Toyota *et al.*, 2017).

4.8.7 Effect of Maize-Cowpea Intercropping on Grain Yields

The low maize yield under maize-cowpea intercropping patterns compared to pure maize stand was attributed to the increased competition for resources such as water and nutrients between the component crops resulting in lower maize cowpeas yield. Similar results were reported when maize was intercropped with potatoes (Mushagalusa *et al.*, 2008). Similarly, Ngwira *et al.* (2012) reported a decrease in yield when maize was intercropped with pigeon pea (*Cajanus cajan*) and *Lablab purpureus* (*L.*).

On the other hand, the low cowpea yield in maize-cowpea intercrop relative to pure cowpea stand could be due to higher-lying canopy of maize at late maize growth stages which could have decreased light interception by cowpea plants, hence reducing the capacity of photosynthesis leading to low tuber yield. This collaborates with the findings by Fan *et al*. (2016), who reported that crop yield is highly dependent on the amount of intercepted solar radiation. In a maize-potato intercropping system study, Mushagalusa *et al.* (2008) reported up to 26% decrease in potato yield that was brought about by the shading effect of maize crops. The slightly higher cowpea yield in T2 compared to T3 suggested a positive effect of inoculating legumes. This could be explained by the differences in biological-nitrogen fixation between the two patterns. In T2, inoculation of cowpea with elite rhizobia bacteria increased the amount of available nitrogen, resulting in higher maize yields than in T3 (Figure 4.4a).

In Magutuni, maize yield was slightly lower 1.8 t/ha compared to 2.3 t/ha in Igoji. This could be attributed to the lower moisture amount received during that season with Igoji receiving 5% higher than Magutuni. Given that maize cultivation under monoculture requires 500−800mm of water in a growing season (Brouwer and Heibloem, 1986) the amount of soil moisture recorded in the Magutuni was inadequate to meet the crop's seasonal moisture requirement. This might have resulted in moisture-stress conditions, which might have resulted in reduced nutrient uptake and translocation of assimilates into the kernels leading to low yields (Zhang, and Li, (2003). This argument is consistent with findings by Steward *et al*. (2018) who reported that water stress reduced maize grain yield significantly. Under low soil moisture condition, crops close their stomata resulting in decreased transpiration (Matusso *et al* 2014).

4.9 Conclusion

Inoculation of cowpea had a significant effect on maize growth rate and yield. This probably was as a result of increased nitrogen fixed by the root nodules that was actively utilized by maize. In comparison with sole maize crops, intercropping did not increase the yield of maize probably due to competition for nutrients.

4.10 Recommendation

There is need to embrace intercrop of maize-cowpea since it improves the growth rate of maize and equivalent yield.

CHAPTER FIVE

SOIL MOISTURE RETENTION CAPACITY UNDER MAIZE COWPEAS INTERCROP AND SOLE CROPS

5.1 Introduction

Maize (*Zea mays* L.), a staple food in Kenya, is produced by mostly small scale farmers who have little capacity to produce it efficiently. The largest portions of small scale farmers constitute over 80% of the total Kenyan farmers (Booker, 2010). Intercropping of cereals and legumes plays an important role in subsistence food production in both developed and developing countries, especially in situations of limited water resources (Dahmardeh *et al.,* 2010). All the growth stages of crop plants are affected by moisture stress. The effect of moisture stress on maize grain yield is less severe when it occurs at vegetative stages than when it occurs at the kernel development and grain filling stages. Drought stress can reduce the final size and weight of maize kernels especially which occurs at grain filling. Drought stress is a major climatic factor limiting production of maize in the tropics (Ortiz *et al.,* 2008), Kenya included.

Water use by intercrops has mostly been studied in terms of water use efficiency (WUE). Intercrops of legume and cereals may use water more efficiently than monoculture of their species through exploring a large total volume of water in the soil especially if component crops have different rooting patterns (Willey 1979). Water use efficiency in maize cowpea intercrop was higher than in sole crops when soil water was not limiting (Hulugalle and Lal 1986). However under water limiting conditions WUE in the crop compared to sole maize can be higher hence will lead to retarded growth and decreased yield. The work which was done by Mao *et al* (2012) showed that when maize and sorghum was intercropped, they utilized resources more efficiently than their respective mono crops. Also Kanton and Dennette (2004) recorded higher WUE in maize cowpea intercrop compared to cropping of sole maize.

Agronomic interventions that aim at maximizing water availability at key growth stages are important (Qadir and Drechse, 2011). In order to reduce soil moisture shortage and loss from evaporation, it is important to use surface mulches and plant shelter belts to improve water use efficiency of a cropping system (Cheminingwa *et al.,* 2007). Inoculated cowpeas are quick in forming a canopy that cover the ground surface compared to non-inoculated cowpeas owing to their enlarged leaf area index. This maintains a good soil cover that prevents excessive evaporation and also preventing the soil from being exposed to agents of erosion. A good crop ground cover ensures less water is lost through evaporation, and such water is available for crop development. In Meru and Tharaka Nithi counties the soil moisture retention, leaf area index and percentage plant cover under maize cowpea intercrop, sole maize and cowpea crops have not been evaluated. Therefore, the objective of this study was to determine the soil moisture retention capacity under maize cowpeas intercrop and sole crops.

5.2 Materials and Methods

5.2.1 Description of the Experimental Sites

As described in chapter three section 3.2.1

5.2.2 Experimental Design and Crop Husbandry

As described in chapter three section 3.3

5.2.3 Data Collection

Data collected included; soil moisture content before planting and during the growth period, percentage plant ground cover and leaf area index.

5.2.4 Determination of Moisture Retention Capacity

The soil moisture retention capacity, leaf area index (LAI) and percentage plant cover were assessed at two weeks intervals. The *in situ* soil moisture was monitored weekly throughout the cropping season starting from the planting date up to 119th day after planting (DAP) when the maize was harvested. Measurements were taken using a neutron probe from 41.25 mm (inside diameter) pre-installed polyvinyl chloride (PVC) access tubes that were installed in each plot with calibration of the probe done in the field before each sampling event and measurements taken at three depths; 0-20, 20-40 and 40-60 cm.

Before establishing the experiment, a hole for the access tube was carefully prepared by means of a soil auger sourced from UoN while minimizing soil disturbance. The enlarged top hole was back-filled to avoid water running down from the outside of the access tube. The access tubes were closed at the bottom by a tapered plastic cap. The probe was calibrated gravimetrically in the field on each measurement event. One point was randomly allocated in each plot from where depth-wise soil samples (0-20, 20-40 and 40-60 cm) were obtained and immediately sealed in plastic bags following procedures described by Okalebo *et al*. (2002). The samples were then transported to the soil chemistry laboratory at the University of Nairobi where they were weighed using a precision balance, oven dried at 105°C for 48 hrs and soil moisture expressed as percent soil moisture content using the Equation below:

$$\textbf{Gravimetric moisture content}\ (\%) = \frac{(\textbf{wet weight} - \textbf{oven dry weight})\ (\textbf{g})}{\textbf{Oven dry weight}\ (\textbf{g})} * \mathbf{100}$$

Moisture readings were later converted to volumetric water content (θ_v) (%) using the Equation below:

$$Soil\ moisture\ content\ (mm) = \theta v\ \times SD$$

Where:

θ_v is the volumetric soil moisture content (%)

SD is the sampling depth (600mm).

5.2.5 Data Analysis

As described in chapter three section 3.6

5.3 Results

5.3.1 Effect of Cropping Pattern on Soil Moisture Content

The cropping patterns and maize development stages (MDS) exhibited significant differences on soil moisture content (SMC), with MDS having the greatest influence on soil moisture content than cropping patterns (Table 5.1). Significant interactions were observed between cropping patterns and maize development at ($P \leq 0.05$). The highest value of SMC (255.5 ± 3.7 mm and 253.0±1.9 mm) at Igoji and Magutuni respectively was observed at kennel development stage in T2 and lowest value recorded in T4, (96.6 ± 2.7 mm Igoji and 98.8±5.4 mm Magutuni) at maturation stage.

At kernel development stage, significantly higher SMC was observed under intercropping patterns (T2 and T3) than in pure maize stand (T1), in Igoji and Magutuni.

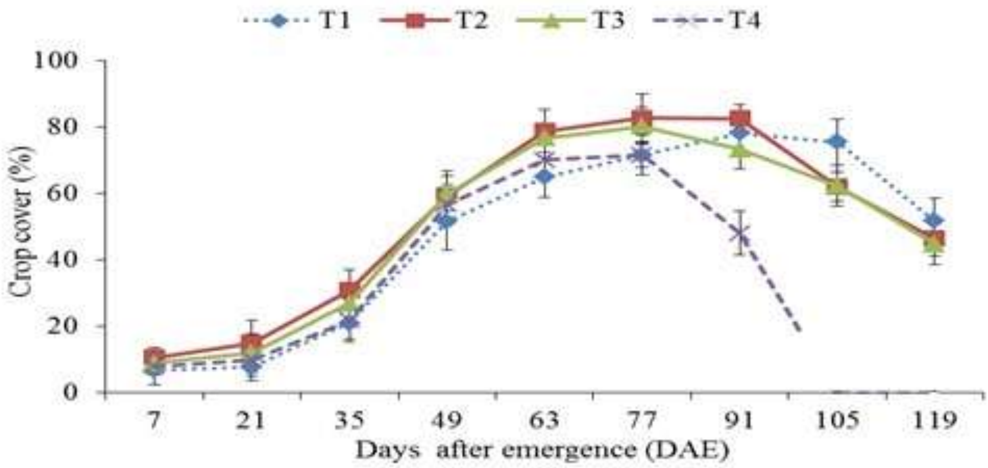
Table 5.1 Effect of Cropping Pattern on Soil Moisture Content (mm/m) at Different Maize Development Stages. (MDS)

Site	CP	Maize Development Stages					
		Planting	Post Emergence	Cob devpt	Kernel devpt	Grain filling	Maturation
Igoji	T1	230.3±1.2a	235.2± 2.9a	240.0±11b	245.3±40b	200.9±25.9b	117.8±3.9de
	T2	230.0± 1.5a	240.5± 2.6a	250.1±1.1a	255.5±37a	212.5±15.9cd	119.9±6.3d
	T3	232.2± 2.8a	238.7± 4.9a	245.9±1.5a	250.7±29a	205.2±14.8c	117.1±7.7de
	T4	229.2± 1.8a	235.5± 4.3a	243.8±1.8a	248.9±56a	190.2±9.7cd	96.6 ± 2.7e
CV		26.8	25.1	23.6	23.9	20.4	19.3
LSD		10.3	11.4	12.4	30.1	10.5	26.8
Magutuni	T1	228.5±1.8a	230.2±1.8a	231.3±2.8a	230.8±27b	152.3±1.1c	102.7±5.5e
	T2	227.8±1.9a	233.7± 2.1a	238.2±3.0a	253.0±19a	198.4±2.2b	118.9±8.2cde
	T3	225.7±0.8a	230.0±1.7a	235.2±0.7a	240.5±13a	185.2±22.5b	144.4±15.8cd
	T4	221.9±3.1a	228.4±2.1a	230.6±1.6a	233.7±37a	170.2±14.5b	98.8±5.4e
CV		30.6	24.6	23.4	22.3	18.2	17.7
LSD		11.4	15.9	20.3	12.6	7.1	30.9

Values are means ± standard error. Different lowercase letters within the same row and column represent significant differences between treatments and MDS respectively at $P \leq 0.001$. T1 = pure maize stand, T2 = maize intercropped with inoculated cowpea, T3 = maize intercropped with non-inoculated cowpea and T4 = pure non-inoculated cowpea stand.

Cropping pattern (CP) had significant effect ($P \leq 0.001$) on canopy cover in both sites (Figure 5.2). Despite the canopy cover in Igoji being slightly higher than in Magutuni, the differences between the two sites were not significant ($P \leq 0.001$). Across the maize development stages and sites, ground cover was significantly higher under inoculated maize cowpea intercrop T2 (51%) and lowest under sole maize T1 (31%). In both sites canopy cover at the kernel development (77 DAP) and grain filling stages (91 DAP) was significantly higher under T2 (82.7%), T3 (80.2%) and T4 (79.4%) than T1 (71.5%), although the difference between T2 and T3 was not significant. At maize maturation (105 DAP) and harvesting (119 DAP) stages, T2 and T3 had the highest percentage ground cover compared to T1 which had the lowest cover than T4 (Figure 5.2).

a



b

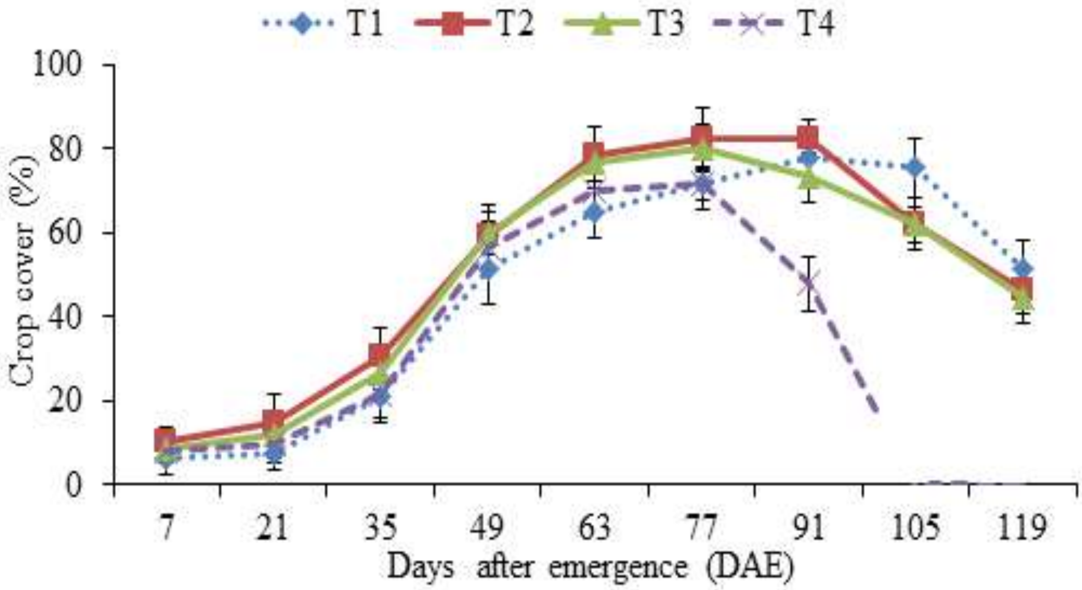


Figure 5.2: Development of maize and cowpea cover under different cropping patterns during the study period.

T1=pure maize stand, T2=maize intercropped with inoculated cowpea, T3=maize intercropped with non-inoculated cowpea and T4=pure non-inoculated cowpea stand. Vertical bars represent standard error of the mean.
Key – a- Igoji b- Magutuni

5.4 Discussion

5.4.1 Effect of Cropping Pattern on Soil Moisture Content

The similarity in soil moisture content during planting and post-emergence stages in both sites was attributed to the rainfall events that were experienced in the areas. Crops were in early stages of development and may not have formed enough ground cover to influence significant differences in soil moisture. However, at the later stages of maize development, the results indicated the potential role of intercropping in promoting soil moisture conservation in maize production systems. The contents of soil moisture contents have been reported to increase under other intercropping systems such as potato-maize (Mushagalusa *et al.*, 2008; Fan *et al.*, 2016), maize-bean (Tsubo *et al.*, 2003), maize-cowpea (Ghanbari *et al.*, 2010) and dolichos-sweet potato (Chepkemoi *et al.*, 2014). Conversely, pure maize and cowpea stands which had relatively less dense canopy cover than maize-cowpea intercropping probably experienced a greater loss of water through direct evaporation from the soil surface leading to lower soil moisture content.

Compared to sole maize plots (T1), the maize-cowpea intercropping plots had consistently higher soil moisture content T2, (239.5 mm, 232.7mm) and T3, (226.0mm, 218.2mm) at maize kernel development and pod formation (cowpeas) stage at both Igoji and Magutuni respectively (Table 5.1). This stage coincided with the period when the LAI in the intercropping plots was also higher than in sole maize plots (between 49 and 77 DAP) in both sites (Figure 5.2). Hence, low LAI in the sole maize plots exposed a greater surface area than the intercrop plots which could have increased direct evaporation of soil moisture from the surface. Maize-cowpea intercropping, therefore, increased soil water conservation by minimizing the losses due to surface evaporation. Moreover, the additional canopy cover provided by cowpeas in the intercropped plots could have helped in intercepting more rain water

(Karuma *et al.*, 2011; Neely *et al*., 2018; Nyawade *et al.*, 2018). This may have increased the amount of water infiltrating into the soil resulting in higher soil moisture content in intercropping patterns as compared to pure maize stand.

The results indicated the potential role of cowpea in promoting soil moisture conservation in maize production systems. The high ground cover in the two sites was attributed to high rainfall received during the cropping season in both sites. Crops used available soil water effectively, resulting in high canopy cover and eventually more biomass production. The higher ground cover in maize-cowpea intercropping relative to maize pure stand could be attributed to the ability of cowpea to provide a quick thick canopy. This may have increased the amount of water infiltrating into the soil resulting in higher soil moisture content in intercropping patterns as compared to pure maize stand. Additionally, the increased ground cover in maize-cowpea intercropping patterns could have created a microclimatic condition by preventing the escape of moist and cool air close, thereby reducing water loss through evaporation from the soil surface.

5.5 Conclusions

There was increased soil moisture that was retained under inoculated cowpea maize intercrop than non-inoculated maize cowpea intercrop and sole crops of maize and cowpeas. Increased ground cover under intercropping patterns could be a potential water conservation strategy of intercropping maize with legumes. Integration of cowpea into maize cropping patterns could be essential to improve crop water productivity. Increased crop water productivity in smallholder farmers who depend on rain-fed agriculture is essential for improving their livelihoods.

5.6 Recommendation

There is need to increase the ground cover through intercropping patterns in order to conserve soil moisture in Meru and Tharaka Nithi counties.

CHAPTER SIX

COST BENEFIT ANALYSIS AND EQUIVALENT YIELD OF MAIZE-COWPEA INTERCROP AND SOLE CROPPING PATTERNS

6.1 Introduction

Maize (*Zea mays* L.) is the major food crop in Kenya and a major source of income for smallholder farmers, accounting for about 14% of farm household income (Nyoro *et al*., 2009), and is wholly produced under rain fed conditions. Maize production is a key sub-sector in the agricultural sector in Kenya. The country's area under maize production stands at 2.3 million ha in 2016 with an annual production of approximately 3.3 million metric tons (FAOSTAT, 2015).

Olwande (2012), reported that maize productivity in Kenya was low (1.0–2.1 t/ha) compared to other sub-Saharan countries (1.1−4.9 t/ha). This has been attributed to the high cost, increased adulteration of inputs, declining soil fertility, decreasing land sizes, limited access to affordable capital and low absorption of modern technology (Chebet *et al*., 2018). The yield t/ha can considerably be increased if proper arrangements for cheaper inputs to reduce costs of production are made. In this regard a benefit cost analysis and equivalent yield of maize cowpea intercrop and sole cropping was conducted using cowpeas legume intercropping as a source of N. Higher maize equivalent yields have been reported under maize-lentil intercropping compared to pure maize stand (Akter *et al*., 2004). However, very little information have been documented on maize equivalent yield and cost benefit analysis on maize cowpea intercrop in Kenya. The present study was an attempt in this direction to fill in this gap in documenting the cost benefits for the maize cowpea intercrop and as sole crops.

6.2 Materials and Methods

6.2.1 Study Site

As described in chapter three section 3.2.1

6.2.2 Experimental Design

As described in chapter three section 3.3

6.2.3 Data Collection

Data collected included; maize yield, cowpea yield, maize equivalent yield and calculation for cost benefit analysis. Harvesting was carried out manually at 85 DAP for cowpea and 120 DAP for maize. For cowpea, the whole plant was uprooted, sun dried for three days and threshed to obtain the grains. For maize, plants were cut at the base, grains shelled from the comb and measured in kilograms per plot then converted to t/ha. The maize and cowpea grain yields were expressed in t/ha then converted into maize equivalent yield (MEY) terms to evaluate the economic returns of the cropping patterns (Gitari *et al*., 2018). The Equation below was used:

$$MEY = CY(kg/ha) + MY(kg/ha) + \frac{CY(kg/ha) \times CP(Ksh/kg)}{MP\ (Ksh/kg)}$$

Where;

MEY = maize equivalent yield,

MY = maize yield,

CY = cowpea yield,

MP = market price of maize (36 ksh/kg) and

CP = market price of cowpea (90 ksh/kg).

For economic analysis, net income for each intercrop and sole cropping was estimated using the Equation below:

$$\text{Net income} = \text{Gross income} - \text{Total cost of production.}$$

The total cost of production included the cost of inputs and labor. The cost of inputs included seed, inoculants and pesticides. This study was in agreement with Gitari *et al*., (2018) who recommended labor to be valued by recording the time taken to carry out various agronomic activities (land preparation, planting, weeding, pest control and harvesting) and paid at the rate of ksh 485 per man-day of 8 h. Gross income was taken as the total value of economic yield (grains) per intercrop and sole cropping.

6.2.4 Data Analysis

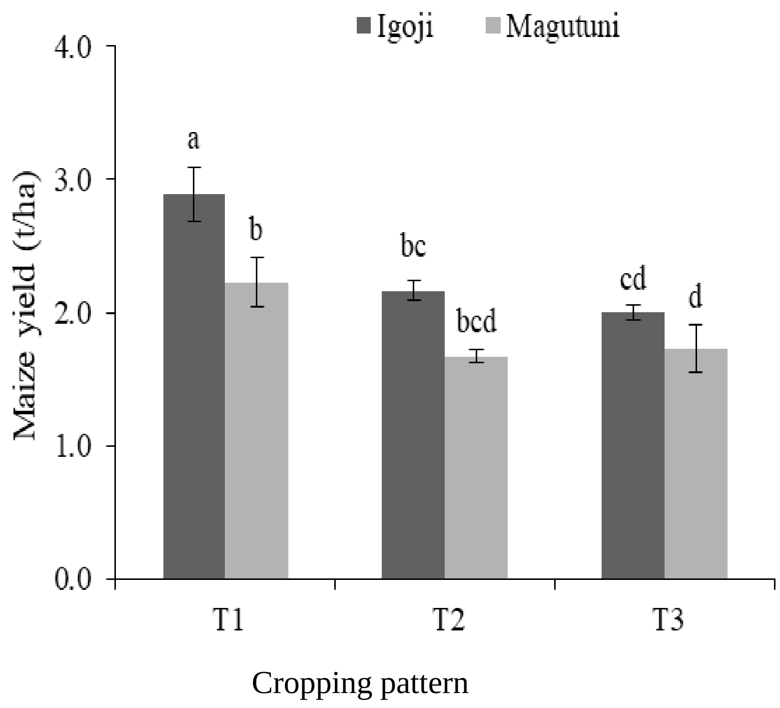
The data on maize yield, cowpea yield, maize equivalent yield and cost benefit analysis were subjected to analysis of variance (ANOVA) using GENSTAT statistical package. Means were separated using Fischer's protected least significant difference (LSD) at 5% probability level. General linear model regression analyses were performed to establish the interactive relation of data on maize yield, cowpea yield, and maize equivalent yield and calculation for cost benefit analysis.

6.3 Results

6.3.1 Effect of Maize-Cowpea Intercropping on Grain Yield

Maize yield had a significant difference between the treatment at ($P \leq 0.05$). Across the sites, maize yield was highest in pure maize stand T1, (2.9 t/ha and 2.2 t/ha) than when intercropped with cowpea T2, (2.1 t/ha, 1.6 t/ha) and T3, (2.0 t/ha, 1.7 t/ha) at Igoji and Magutuni respectively (Figure 6.1 a). Cowpea recorded yield of T2, (0.7 t/ha, 0.81 t/ha) and T3, (0.68 t/ha, 0.68 t/ha) T4, (1.3 t/ha, 1.18 t/ha) at Igoji and Magutuni respectively (Figure 6.1 b).

6.1 a



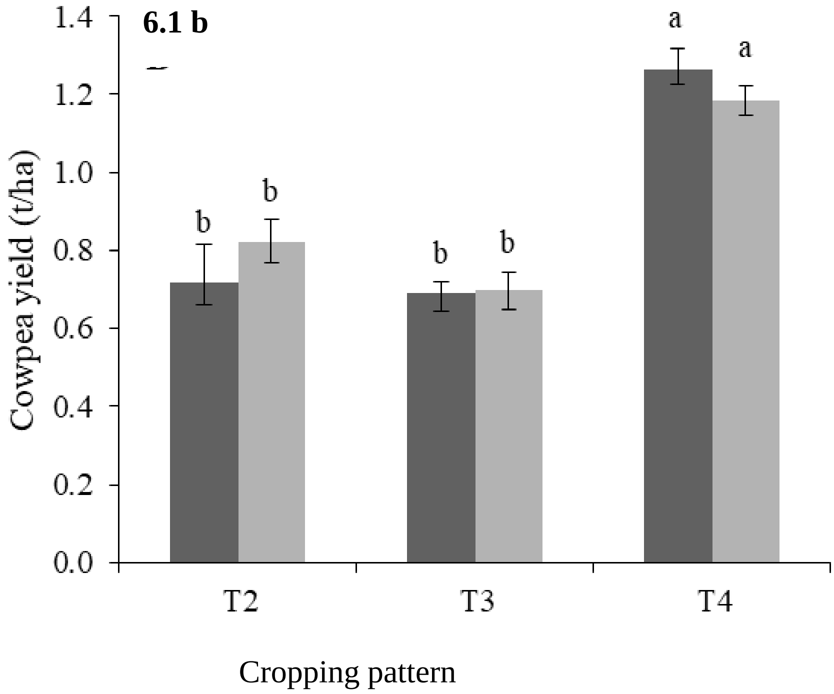


Figure 6.1: Maize grain yield (a) and cowpea grain yield (b) under different cropping patterns.

Vertical error bars represent standard error of mean. Different lowercase letters represent significant differences between treatments (*P*≤0.001). T1 = pure maize stand, T2 = maize intercropped with inoculated cowpea, T3 = maize intercropped with non-inoculated cowpea and T4 = pure non-inoculated cowpea stand.

When all economic yields (maize and cowpea) were expressed in terms of maize equivalent yield which expresses the total income received, the highest values were observed in T2, (4.70 t/ha, 4.58 t/ha) and T3, (4.44 t/ha, 4.19 t/ha) at Igoji and Magutuni respectively (Table 6.1). The highest cost of production was incurred under maize-cowpea intercropping patterns ranging from Ksh 40,700 /ha to Ksh 48,210 /ha compared to as low as Ksh 37,110 /ha in maize pure stand. However, the maize-legume intercropping patterns were the most profitable with net income of Ksh 86,730 /ha and 93,490 /ha for T3 and T2, respectively compared to T1 Ksh 48,260 /ha. This resulted in higher benefit cost ratios in T2, (2.14) and T3, (2.08) compared to (1.13) in T1.

6.3.2 Effect of Cropping Patterns on Maize Equivalent Yield (MEY), Gross, Net Income and Benefit: Cost Ratio

Cropping patterns significantly influenced maize yield, maize equivalent yield, gross and net income at ($P \leq 0.001$) (Table 6.1), but only yield and gross income varied with site at (P=0.002 and 0.039, respectively).When all economic yields (maize and cowpea) were expressed in terms of equivalent yield, the highest values were observed in T2 and T3 (intercropped) across the sites (Table 6.1). Even though the highest cost of production was incurred under maize-cowpea intercropping patterns, the maize-legume intercropping patterns were the most profitable with net incomes of Ksh 8,673 and ksh 9,349 /ha for T3 and T2, respectively compared to T1 Ksh 4,826 /ha. This resulted in higher benefit cost ratios in T2, (2.14) and T3, (2.08) compared to (1.13) in T1. Sole cowpea (T4) was not included in determining the MEY, since it was used as a control. Pure cowpea T4 yielded (1.3 t/ha, 1.18 t/ha more than intercrops T2, (0.7 t/ha, 0.18 t/ha) and T3, (0.68 t/ha, 0.68 t/ha) at Igoji and Magutuni respectively.

Table 6.1: Maize Equivalent Yield (MEY), Gross, Net Income and Benefit: Cost Ratio of Different Cropping patterns at Different Sites

Site	Cropping patterns	MEY t/ha	Cultivation cost	Gross Income Ksh /ha	Net Income	Benefit: Cost Ratio
Magutuni	T1	2.23^{b}	371.1	792^{c}	420.5^{b}	1.13^{c}
	T2	4.58^{a}	407.0	1335^{a}	928.1^{a}	2.28^{a}
	T3	4.19^{a}	396.5	1240^{ab}	843.9^{a}	2.13^{ab}
Igoji	T1	2.88^{b}	460.7	1025^{b}	544.7^{a}	1.13^{c}
	T2	4.70^{a}	482.1	1414^{a}	941.6^{a}	1.99^{b}
	T3	4.44^{a}	472.3	1331^{a}	890.7^{a}	2.02^{b}
LSD		2.47	-	993.5	507.5	1.15

Means with different letters indicate significant differences at $P \leq 0.001$. T1=pure maize stand, T2=maize intercropped with inoculated cowpea, T3=maize intercropped with non-inoculated cowpea.

6.4 Discussion

6.4.1 Effect of Maize-Cowpea Intercropping on Grain Yields

There was a lower maize grain yield from an intercrop of maize and cowpea compared to pure maize stand. This was attributed to increased competition for resources like nutrients between component crops that led to lower maize cowpeas yield. Similar results were reported when maize was intercropped with potatoes (Mushagalusa *et al.*, 2008). Rashid *et al.* (2006) also reported the viability of intercropped legumes with sorghum and discussed that intercropping of legume crops affect plant height as well as lowering grain yield of sorghum crop and on the same way the leaf area index of intercropped sorghum is lower than sole growing sorghum. In contrast the results of Shahid *et al.* (2017) showed that grain yield of maize in intercropping system was higher than maize planted as sole.

On the other hand, the low cowpea yield in maize-cowpea intercrop as compared to pure cowpea stand could be due to effects of the higher-lying canopy of maize at late maize growth stages which could have decreased light interception by cowpea plants, thus reducing their photosynthetic capacity and hence low yield. This collaborated with the findings by Fan *et al*. (2016) and Gitari *et al.* (2018), who reported that crop yield was highly dependent on the amount of intercepted solar radiation. In a maize-potato intercropping system, Mushagalusa *et al.* (2008), reported up to 26% decrease in potato yield, which was attributed to the shading effect of maize crops. The slightly higher cowpea yield in T2 compared to T3 suggested a positive effect of inoculating legumes. This could be explained by the differences in biological-nitrogen fixation between the two systems. In T2, inoculation of cowpea with elite rhizobia bacteria increased the amount of available nitrogen, resulting in higher maize yields (Figure 6.1 a).

6.4.2 Effect of Cropping Pattern on Maize Equivalent Yield (MEY), Gross, Net Income and Benefit: Cost Ratio

The higher maize equivalent yield under intercropping pattern compared to pure maize cropping pattern could mainly be attributed to the additional cowpea yield. In addition, the increased nutrient uptake and translocation of assimilates into maize and legume seeds as observed by Gitari *et al.* (2018), could have contributed to the high MEY under intercropping patterns. Higher maize equivalent yields have been similarly reported under maize-lentil intercropping compared to pure maize stand (Bhat *et al.*, 2018). Although lower cowpea yield was recorded in the intercropped patterns, the maize equivalent yield was still high due to the high market price of cowpea (Ksh 90 /kg). In other similar studies, higher gross income has also been reported under maize-okra-cowpea intercropping systems compared to the respective pure stands (Sharma *et al.*, 2017).

The higher productivity observed under intercropping patterns relative to a pure stand of maize implied that a higher proportion of soil moisture was taken up by the plants and used for transpiration instead of being lost through direct evaporation from the soil surface. This suggested an effective utilization of soil water (Blum, 2012). With the high density of roots under the intercropping patterns, it was expected that water uptake was enhanced resulting in high transpiration and consequently high yield (Chimonyo *et al*., 2016). Karanja *et al*. (2014), reported higher productivity when sorghum was intercropped with cowpea compared to the pure stand of sorghum. This study, therefore, emphasizes the potential of maize-cowpea intercrop that can easily be adopted by smallholder farmers to increase their incomes. Moreover, cowpea shows the potential of being successfully incorporated into the maize production patterns without necessarily compromising maize grain yield. Cowpea is also a good and essential source of proteins for most families in Meru and Tharaka Nithi counties.

6.5 Conclusion

This study established that returns are highest when all economic yields in a maize cowpea intercrop are expressed in terms of maize equivalent yield compared to a pure stand of maize. The higher productivity under intercropping patterns relative to a pure stand of maize implied that a higher proportion of soil moisture and other resources are efficiently used by the improved crop productivity. Therefore the most profitable cropping pattern is the intercrop of inoculated maize cowpeas.

6.6 Recommendation

There is need to intercrop maize with inoculated cowpea since the returns are highest when all economic yields are expressed in terms of maize equivalent yield compared to a pure stand of maize.

CHAPTER SEVEN
SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS
7.1 Summary of Findings

Intercropping significantly affected maize growth rate parameters which included; stem girth, leaf area index, leaf extinction coefficient, photosynthetically active radiation and grain yield. A greater stem girth was observed in maize intercropped with inoculated cowpea compared to maize intercropped with non-inoculated cowpea and pure maize stand. A larger leaf area index was observed under inoculated cowpea maize intercrop than in non-inoculated intercrops and sole crops. The leaf extinction coefficient was significant in the intercrops than in the sole crops, with the sole crops having a greater extinction coefficient than the intercrops. Significant variations in PAR were observed during the growing season with a maximum PAR being achieved on the 63 DAP in both sites. Across the sites, maize yield was highest in pure maize stand than when intercropped with cowpea due to competition for nutrients in intercrops.

Cropping patterns had a significant effect on the canopy cover which was greater under intercrops than sole crops. Across the maize development stages and sites, ground cover was significantly higher under inoculated maize cowpea intercrop and lowest under sole maize. Despite the canopy cover in Igoji being slightly higher than in Magutuni, the differences between the two sites were not significant. The cropping patterns and maize development stages (MDS) exhibited significant differences on soil moisture content (SMC), with MDS having the greatest influence on soil moisture content than cropping patterns.

Site had no significant effect on total nitrogen fixed in the soil before planting and after harvesting. Across the cropping patterns, there was a difference in amount of nitrogen fixed by T2 being greater than T3 and T4 but the difference was not significant, probably because the experiment was done in two sites per season leading to fewer residue N accumulation. The slightly higher amount of N fixed in T2 due to inoculation led to an increase of yield compared to T3 (non-inoculated) and sole crops. Across the sites, mean maize yield was highest in pure maize stand than when intercropped with cowpea because there was no competition for resources.

Grain maize yield had a significant difference between the treatments. Across the sites, maize yield was highest in pure maize stand than when intercropped with cowpea. When all economic yields (maize and cowpea) were expressed in terms of maize equivalent yield which expresses the total income received, the highest values were observed under maize-cowpea inoculated intercrop then followed by non-inoculated maize cowpea intercrop, with the sole crops having the lowest values in t/ha. Cropping patterns significantly influenced maize yield, maize equivalent yield, gross and net income but only yield and gross income varied with site.

7.2 Conclusion

The amount of nitrogen fixed in the soil under inoculated cowpeas-maize intercrop was slightly higher than in non-inoculated maize cowpea intercrops and sole crops. This led to increased yield in T2 (inoculated) than T1, T3 and T4. This study demonstrated that the productivity in these soils can be improved by intercropping using rhizobium inoculant since the soils are deficient of N. Thus there is need for inoculation of cowpea with commercial rhizobium strain to enhance BNF in both sites for increased maize production. Inoculation of cowpea had a significant effect on maize growth rate and yield. This probably was as a result of increased nitrogen fixed by the root nodules that was actively utilized by maize. In comparison with sole maize crops, intercropping did not increase the yield of maize probably due to competition for nutrients. There was increased soil moisture that was retained under inoculated cowpea maize intercrop than non-inoculated maize cowpea intercrop and sole crops of maize and cowpeas. Increased ground cover under intercropping patterns could be a potential water conservation strategy of intercropping maize with legumes. Integration of cowpea into maize cropping patterns could be essential to improve crop water productivity. Increased crop water productivity in smallholder farmers who depend on rain-fed agriculture is essential for improving their livelihoods. This study established that returns are highest when all economic yields in a maize cowpea intercrop are expressed in terms of maize equivalent yield compared to a pure stand of maize. The higher productivity under intercropping patterns relative to a pure stand of maize implied that a higher proportion of soil moisture and other resources are efficiently used by the improved crop productivity. Therefore the most profitable cropping pattern is the intercrop of inoculated maize cowpeas.

7.3 Recommendation

There is need to;

i. Study methods and strategies that increase the efficacy of final product under Rhizobium performance in maize-cowpea intercrop since inoculation increases the percentage of nitrogen fixation.
ii. Embrace intercrop of maize-cowpea since it improves the growth rate of maize and equivalent yield.
iii. Increase the ground cover through intercropping patterns in order to conserve soil moisture in Meru and Tharaka Nithi counties.
iv. Intercrop maize with inoculated cowpea since the returns are highest when all economic yields are expressed in terms of maize equivalent yield compared to a pure stand of maize.

7.4 Suggestions for Further Research

Further studies in this line could include;

i. Identification of indigenous elite rhizobia strains for cowpeas to avoid possibilities of inoculation failure. Indigenous strains could be highly adaptive and more effective than exotic ones.
ii. Several intercropping patterns including more crops species can also be studied.
iii. Since the study was limited to lower regions of Meru and Tharaka Nithi counties, there is need for a replication of this study in other agro ecological zones that have different situations which can elicit different responses.

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APPENDIX 1
PLATES

APPENDIX 2

CHUKA UNIVERSITY ETHICS REVIEW COMMITTEE CLEARANCE LETTER

CHUKA UNIVERSITY

Telephones: 020 2310512
020 2310518

P.O. Box 109
Chuka

CHUKA UNIVERSITY

OFFICE OF THE CHAIRMAN
INSTITUTIONAL ETHICS REVIEW COMMITTEE

Our Ref: CU/IERC/NCST/18/5

6th March, 2018

THE CHIEF EXECUTIVE OFFICER
NATIONAL COMMISION FOR SCIENCE, TECHNOLOGY AND INNOVATION
P.O. BOX 30623-00100
NAIROBI

Dear Sir/Madam,

RE: RESEARCH CLEARANCE AND AUTHORIZATION FOR IAN MWENDA KIRIMI REG NO NM17/29139/17

The above matter refers:

The Institutional Ethics Review Committee of Chuka University met and reviewed the above MED Research Proposal titled **Effects of Inoculated Cowpeas Intercrop on Maize Performance and Soil Moisture Retention in Lower Eastern Kenya)"** The Supervisors are. **Dr. Munyiri Sehelmith and Dr. Haggai O. Ndukhu**

The committee recommended that after candidate amends the issues highlighted in the Attached research clearance and authorization check list, the permit be issued.

Attached please find copies of the minutes, research clearance and authorization check list for your perusal. Kindly assist the student get the research permit.

Yours faithfully,

Prof. Adiel Magana
CHAIR
INSTITUTIONAL ETHICS REVIEW COMMITTEE
cc: BPGS

APPENDIX 3
MINISTRY OF EDUCATION AUTHORIZATION LETTER

REPUBLIC OF KENYA

MINISTRY OF EDUCATION
STATE DEPARTMENT OF EDUCATION

Telegrams: "Elimu", Chuka
Telephone: Chuka 630353
FAX: 064 630166
Email: *tharakanithicountyedu@gmail.com*
When replying please quote:

TNC/ED/GC/GEN/5. VOL.111/18

COUNTY DIRECTOR OF EDUCATION
THARAKA NITHI
P.O. BOX 113-60400
CHUKA

30th October, 2017

Ian Mwenda Kirimi
Chuka University,
P.O BOX 109-60400
CHUKA.

RE: RESEARCH AUTHORIZATUION

Your letter referenced **NACOSTI/P/18/76158/23299** from the National Commission for Science Technology and Innovation dated 8th October 2018 refers.

I am pleased to inform you that your request for research Authorization to carry out research on ***"Effects of inoculated cowpeas intercrop on maize performance and soil moisture retention in lower Eastern Kenya"*** (THARAKA NITHI COUNTY) has been granted.

This permission is granted on the understanding that you shall deposit a hard copy and a soft copy of your final research report to the office of the County Director of Education within one year of completion of your research.
Kindly note that this permission is given for the period ending 8th October 2019.

FOR:- COUNTY DIRECTOR OF EDUCATION
George Nderitu
For: County Director of Education
THARAKA NITHI COUNTY
THARAKA NITHI
P. O. Box 113 CHUKA

APPENDIX 4
NACOSTI AUTHORIZATION

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone:+254-20-2213471,
2241349,3310571,2219420
Fax:+254-20-318245,318249
Email: dg@nacosti.go.ke
Website : www.nacosti.go.ke
When replying please quote

NACOSTI, Upper Kabete
Off Waiyaki Way
P.O. Box 30623-00100
NAIROBI-KENYA

Ref. No. **NACOSTI/P/18/76158/23299**

Date: **8th October, 2018**

Ian Mwenda Kirimi
Chuka University,
P. O. Box 109-60400
CHUKA.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Effects of inoculated cowpeas inter-crop on maize performance and soil moisture retention in Lower Eastern Kenya"*** I am pleased to inform you that you have been authorized to undertake research in **Tharaka Nithi County** for the period ending **8th October, 2019.**

You are advised to report to **the County Commissioner and the County Director of Education, Tharaka Nithi County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

BONIFACE WANYAMA
FOR: DIRECTOR-GENERAL/CEO

COUNTY COMMISSIONER
30 OCT 2018
THARAKA NITHI COUNTY

Copy to:

The County Commissioner
Tharaka Nithi County.

The County Director of Education
Tharaka Nithi County.

APPENDIX 5

NACOSTI PERMIT

THIS IS TO CERTIFY THAT:
MR. IAN MWENDA KIRIMI
of CHUKA UNIVERSITY, 0-60401 CHOGORIA,has been permitted to conduct research in *Tharaka-Nithi County*

on the topic: *EFFECTS OF INOCULATED COWPEAS INTER-CROP ON MAIZE PERFORMANCE AND SOIL MOISTURE RETENTION IN LOWER EASTERN KENYA*

for the period ending:
8th October,2019

Permit No : NACOSTI/P/18/76158/23299
Date Of Issue : 8th October,2018
Fee Recieved :Ksh 1000

……………………………
Applicant's Signature

……………………………
Director General
National Commission for Science, Technology & Innovation

APPENDIX 6

ANALYSIS OF VARIANCE TABLES

Analysis of variance: Soil Moisture

Variate: Soil moisture_mm

Source of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Block Stratum	2	1311.2	655.6	2.02	
Block.*Units* Stratum					
Site	1	146.3	146.3	0.45	0.503
Treatment	3	12140.2	4046.7	12.45	<.001
MDS	3	407587.3	135862.4	418.07	<.001
Site.Treatment	3	184.7	61.6	0.19	0.904
Site.MDS	3	2872.4	957.5	2.95	0.034
Treatment.MDS	9	7657.5	850.8	2.62	0.007
Site.Treatment.MDS	9	17918.6	1991.0	6.13	<.001
Residual	206	66945.6	325.0		
Total	239	516763.6			

Analysis of variance: Plant cover %

Variate: Plant cover %

Source of variation	d.f	s.s	m.s	v.r	F pr
Site	1	472.28	472.28	26.74	0.324
DAP	16	248762.13	15547.63	880.19	<.001
Treatment	3	29568.39	9856.13	557.98	<.001
Site DAP	16	434.75	27.17	1.54	0.086
Site Treatment	3	171.34	57.11	3.23	0.023
DAP Treatment	48	45852.52	955.26	54.08	<.001
Site DAP Treatment	48	957.04	19.94	1.13	0.272
Residual	272	4804.62	17.66		
Total	407	331023.07			

Analysis of variance: LAI

Variate: LAI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Site	1	2.149	2.149	1.27	0.261
Treatment	3	66.547	22.182	13.10	<.001
Site.Treatment	3	0.357	0.119	0.07	0.976
Residual	400	677.363	1.693		
Total	407	746.416			

Analysis of variance: stem_girth

Variate: stem_girth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Site	1	59.1516	59.1516	314.50	<.001
Treatment	2	0.1916	0.0958	0.51	0.601
Week	1	4.8503	4.8503	25.79	<.001
Site.Treatment	2	1.9432	0.9716	5.17	0.006
Site.Week	1	1.5153	1.5153	8.06	0.005
Treatment.Week	2	0.4019	0.2010	1.07	0.344
Site.Treatment.Week	2	0.9206	0.4603	2.45	0.088
Residual	420	78.9950	0.1881		
Total	431	147.9696			

Analysis of variance: Cowpea yield kg

Variate: Cowpea yield kg					
Source of variation	d.f	s.s	m.s	v.r	F pr
Block stratum	2	0.00061	0.00030	0.03	
Block.*Units* stratum					
Site	1	0.00055	0.00055	0.05	0.835
Treatment	2	0.97905	0.48952	40.53	<.001
Site Treatment	2	0.02550	0.01275	1.06	0.384
Residual	10	0.12079	0.01208		
Total	17	1.12649			

Analysis of variance: Maize yield t/ha

Variate: maize yield t/ha					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.14568	0.07284	1.33	
Block.*Units* stratum					
Site	1	1.00431	1.00431	18.37	0.002
Treatment	2	1.77332	0.88666	16.21	<.001
Site.Treatment	2	0.11427	0.05713	1.04	0.387
Residual	10	0.54684	0.05468		
Total	17	3.58441			

Analysis of variance: Net Income USD

Variate: Net income USD					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.4233	0.2116	1.25	

Block.*Units* stratum					
Site	1	0.5243	0.5243	3.10	0.109
Treatment	2	15.1169	7.5584	44.63	<.001
Site.Treatment	2	0.2387	0.1193	0.70	0.517
Residual	10	1.6934	0.1693		
Total	17	17.9965			

Analysis of variance: MEY t/ha

Variate: MEY_t/ha					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.4233	0.2116	1.25	
Block.*Units* stratum					
Site	1	0.5243	0.5243	3.10	0.109
Treatment	2	15.1169	7.5584	44.63	<.001
Site. Treatment	2	0.2387	0.1193	0.70	0.517
Residual	10	1.6934	0.1693		
Total	17	17.9965			

Analysis of variance: Benefit cost ratio

Variate: Benefit cost ratio					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.004238	0.002119	0.23	
Block.*Units* stratum					
Site	1	0.079956	0.079956	8.62	0.015
Treatment	2	3.795895	1.897947	204.67	<.001
Site. Treatment	2	0.064061	0.032030	3.45	0.072
Residual	10	0.092733	0.009273		
Total	17				