EFFECTS OF LEGUME INTERCROPS AND MINERAL NITROGEN ON NUTRIENT UPTAKE AND YIELD OF MAIZE (*Zea mays* L.) IN MALAWI

INNOCENT MALUNGA

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DECLARATION AND APPROVAL

Declaration

I declare that this thesis is my original work and has not been submitted in this or any other University for the award of a Degree, Diploma or Certificate.

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Recommendation

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DEDICATION

I dedicate this thesis to my sisters Ivy and Nancy; Brother Vincent and my grandmother for their genuine love and moral support. Sincerely, I love you guys, God bless you.

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ABSTRACT

Nitrogen (N) is the critical plant nutrient. Low maize (*Zea mays* L.) yields in smallholder farms of Malawi are attributable to declining N fertility, aggravated by the ever increasing price of fertilizer. Maize, the country's staple, has a high nitrogen demand. Little effort has been made to establish the best nitrogen rate in a maize- cowpea and maize-bean intercrop under variable soil conditions as a way of improving production, and was the objective of the current study. Field experiments were conducted at Chitedze Agricultural Research Station in Lilongwe and Makoka Agricultural Research Station in Zomba during the 2016/17 growing season. A split plot layout in a randomized complete block design, with three replicates was used. The main plots were; sole maize, sole bean, sole cowpea, bean/maize and cowpea/maize intercrop systems. The sub plots were N fertilizer rates (0, 52.5, 78.75 and 105 kg N ha^{-1}), applied as urea. Measured parameters included plant height, leaf area index, and N uptake by the maize plant, dry matter and grain yield, legume biomass and yield, land equivalent ratio, weight and number of nodules and nutrient use efficiency. The data was subjected to analysis of variance using SAS software version 9.3 (SAS Institute Inc.) at $P<0.05$. Means were separated using Duncan Multiple Range (DMRT) test at 95% significance level. The results showed that application of N fertilizer and legume integration increased maize grain yield and that 105 kg N ha^{-1} was optimal mineral N fertilizer rate for maximum maize grain yield per unit area. Maximum maize Nitrogen use efficiency (NUE) (48.63 kg/kg) was obtained at application rate of 78.75 kg N ha^{-1} and the minimum value (44.86 kg/kg) was recorded at the highest N rate (105 kg N ha^{-1}). Application of mineral N fertilizer increased N uptake by maize while legume intercrops did not have any significant ($P<0.05$) effect on uptake. Maize grain and dry matter yield were significantly ($P<0.05$) affected by the application of mineral N fertilizer but not by legume intercrops. The effect of cropping system × N level interaction was significant ($P<0.05$) on N uptake by maize, maize DM (Dry matter) yield but not on maize grain yield, higher values were obtained under bean/maize intercropping x 105 kg N ha^{-1}. Maize planted at Chitedze had significantly taller maize plants, higher maize grain yield, cob weight and 100 maize seed weight than Makoka. The land equivalent ratio (LER) values obtained for intercropping were higher than one and confirm the advantage of intercropping over sole cropping system.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
BNF	Biological Nitrogen fixation
FAO	Food and Agriculture Organization
N2	Nitrogen gas
SAS	Statistical Analysis Software
SSA	sub-Sahara Africa
Mt	Metric tons
DM	Dry Matter
LER	Land Equivalent Ratio
NUE	Nutrient Use Efficiency
LAI	Leaf Area Index

CHAPTER ONE
INTRODUCTION

1.1 Background Information

Soil fertility has been defined as the soil`s capacity to hold in reserve water, oxygen, and plant essential nutrients and to supply them in adequate amounts and in suitable proportions for plant growth and reproduction. The soil's inherent ability to supply plants with resources for growth and development decreases with an increase in soil cropping or continuous cropping such as monocropping. This happens when the essential nutrients taken up by crops are not replenished (Gachene and Kimaru, 2003).

Nitrogen (N) is among the most important nutrient which limits crop production. It promotes vigorous vegetative growth. Chemically it is the main constituent of plant proteins, enzymes, alkaloids and cell-organelles. Nitrogen occurs in gaseous state in the atmosphere in its free state. In fact, about 79% of air is nitrogen (N) only and thus nature provides us with the non-exhaustible supply of nitrogen. Plants are not capable of absorbing atmospheric elemental nitrogen. They mainly absorb it in the form of nitrate (NO_3^-) or ammonium (NH_4^+) form. Hence, all the nitrogenous fertilizers which are being manufactured contain nitrogen either in nitrate or in ammonium forms or in any form which has to transform into ammonium or nitrate form, before it can be taken up by plant roots (Havlin *et al*., 2008; Paul, 2008).

Nitrogen is the most frequently deficient plant nutrient in Malawian soils (Munthali and Mazuma, 2010) as a result of continuous cropping without adequate replenishment of nutrients lost through harvesting. The deficiency of N has resulted into low maize yields, which is the country's staple food. Nitrogen (N) is one of the essential nutrients affected by increased soil cropping (Gachene and Kimaru, 2003; Mbewe, 2011). Alternative ways of improving nitrogen fertility of soil and subsequently increase maize yield should be identified.

Studies conducted on legumes have reported that legumes have the potential to significantly contribute to soil nitrogen, through biological nitrogen fixation, and increase yields of either subsequent or associated non-nodulating crops such as cereals through biological nitrogen fixation (Hayat *et al.,* 2008). Cowpea ((*Vigna unguiculata L*) is a legume of African origin and one of the most ancient crops ever domesticated by man. It is an important source of food and income (FAO, 2004) and Africa produces 96% of the more than 5.4 million tons of the annual global cowpea production. Cowpea is highly adaptable to grow in different soil types and intercropping systems. It also has the following advantages; it is drought resistant and has the ability to improve soil fertility through biological nitrogen fixation and also reduces the risk of soil erosion (IITA, 2016). In Malawi cowpea is an important legume crop for small holder farmers and the crop is adapted to grow in a wide range of local condition (Nkongolo *et al.*, 2009). The production of cowpea in Malawi is estimated to be 50 249 million tons on average from the year 2000 to 2013 (FAOSTAT, 2013). Common bean (*Phaseolus vulgaris* L*)* is the most important food legume for direct consumption in the world and it is a major source of dietary protein in Malawi. It is also an important cash crop for smallholder farmers in Malawi (FAO, 1999; Magreta and Jambo, 2012). ICRISAT (2013) estimated the production of beans in Malawi to be about 111 889 million tones on average between 2000-2011.

Intercropping is an agricultural practice of growing two or more crops simultaneously on the same piece of land (Mbewe, 2011). A lot of studies which have been conducted on intercropping have reported that this cultivation practice is more efficient than monocropping, the reason being that cultivation of two or more crops results in increased productivity per unit of land. This has led researchers to conclude that intercropping system of farming efficiently uses the limited resources in the soil to maximize crop production. Other advantages of intercropping include: higher nutrient uptake and better water use efficiency, improvement and maintenance of soil fertility, pest and disease management, and labour use efficiency and erosion control (Geno and Geno, 2001; Yilmaz *et al*., 2008; Mbewe, 2011; Gebru, 2015).

Determination of nutrient requirements of cowpea/maize and bean/maize intercropping systems will contribute towards judicious use of fertilizers for increased maize yield in Malawi. This is in view of the ever- increasing price of this commodity (fertilizer) (Munthali and Mazuma, 2010).

1.2 Statement of the Problem

Malawian soils are facing a serious problem of declining soil fertility through an increase in soil cropping and poor soil management. Maize monocropping is one of the most serious challenges to soil fertility in Malawi and most smallholder do not meet the nitrogen requirement by maize, hence low yields. This is due to the rising cost of fertilizers and the removal of government fertilizer subsidies. It is suggested that intercropping is more efficient than monocropping, in use of resources to maximize crop production. Little effort had been made to establish the best nutrient management strategies in a maize- cowpea and maize-bean intercrop under variable soil conditions as a way of improving production. Therefore there is a need to establish the best nutrient management strategies under variable soil conditions so as to improve maize production.

1.3 Objectives

1.3.1 General Objective

To contribute towards food security by increasing maize yield through integration of legumes and application of nitrogen fertilizer in Malawi.

1.3.2 Specific Objectives

The specific objectives were:

1. To determine the effect of legume intercrops and nitrogen levels on N uptake by maize
2. To determine the effect of legume intercrops and nitrogen levels on maize grain and dry matter yield.
3. To determine the effect of legume intercrops and nitrogen levels on N maize growth.

1.4 Hypotheses

1. Legume intercrops and nitrogen levels have no significant effect on N uptake by maize.
2. Legume intercrops and nitrogen levels have no significant effect on maize grain and DM yield.
3. The effect of nitrogen levels and legume intercrops has no significant effect on maize growth.

1.5 Justification of the study

Soil fertility in Malawian soils is generally low. Integration of legumes in tropical cropping systems is now being highly emphasized among smallholder farmers in the tropics as a way of reducing production cost and improving soil and crop productivity (Odhiambo *et al.*, 2010). Cowpea and beans are important sources of dietary proteins and income among the small holder farmers in Malawi. Experimental evidence supporting claims of beneficial effects of legume crop integration in tropical agriculture is provided by a number of studies conducted largely in humid or sub-humid regions. These studies have shown that legumes have the potential to enhance yields of subsequent or associated non-nodulating crops through biological nitrogen fixation of the atmospheric nitrogen as well as enhanced mineralization of soil organic nitrogen during legume residues decomposition (Nwaogu *et al*., 2013). Studies on land equivalent ratio have also indicated that there is a yield advantage in intercropping system over monocropping system (Darish *et al*., 2006).Little is known about effects of fertilizer rates on soil N fertility in maize-cowpea and maize-common beans intercropping system in the low fertility soils of Malawi. This study will document information on judicious use of inorganic fertilizer and legume intercrops for optimal maize yields.

CHAPTER TWO

LITERATURE REVIEW

2.1 Maize Production in Malawi

Maize (*Zea mays L.*) also referred to as the queen of cereals is the most important cereal in the world. It is called the queen of cereals because its physiology makes it one of the most efficient crop species domesticated by man with high yield potential (Naidu *et al*., 2006). Maize is the most important grain crop in Malawi as it forms the basic staple food for the country (Munthali and Mazuma, 2010).

Maize production requires warm weather and the production is highly suitable when the mean temperature is between 21–32^{o}C. However, production is not suitable when the mean temperatures are either greater than 40^{o}C or less than 15^{o}C. The extremely higher temperatures of greater than 40^{o}C lead to poor grain formation as they have damaging effect on the leaves and desiccate the pollen during the flowering stage hence interfering with pollination. The maize crop requires the following rainfall distribution and soil conditions for proper growth and development: a well distributed rainfall of 750- 900 mm during the growth cycle, well drained sandy loam soils and the moisture availability in the soil should last more than 100 days of the growing period. Maize production is successful when the soil pH is in the range of 5.5-7.5, the Cation exchange capacity is greater than 20 Cmol/kg of soil, the organic matter content of soil is high and when the soil is non sodic and non-saline (Naidu *et al*., 2006).

2.2 Cowpeas Production in Malawi

Cow pea (*Vigna unguiculata* L.) also known as black eyed pea, field pea, southern pea and Crowder pea is regarded as one of the most ancient crops ever domesticated and used as food source by man. It has been suggested that cowpeas originated from Africa in general and Ethiopia in particular .Cowpea is grown as a nutritious and palatable food source and animal feed crop for semi-arid tropics of Africa, Asia, Europe, the United States, Central and South America. Cowpea is mostly grown for its seed but both flowers and leaves may also be consumed (FAO, 2004; Sheahan, 2012).

In 2012, Food and Agriculture Organization (FAO) reported that cowpea seed contains 24% crude oil, 53% carbohydrates and 2% fat. United States is both the largest producer and exporter of cowpea, followed by East Asia and then Africa. The United States exports 2000 tons per year of cowpea. In Africa cowpea is most grown in West and Central Africa and more than 8 million hectares of cowpea are grown every year (FAO, 2004).

Cowpea is a fast growing cover crop that is able to produce 1134 – 2041kg/acre/year of dry matter, at the same time providing 45-68 kg/acre/year of nitrogen to the subsequent crop. Cowpea thrives in hot climates and can be intercropped with cereals as it contributes to nitrogen fixation and sustainable cropping system in marginal lands. Production of cowpea requires proper planning because the crop is attacked by insects and pests such as Mexican bean beetles, aphids, grasshoppers, weevils, and stem borers, and diseases such fusarium wilt, bacterial canker, cowpea mosaic virus at seedling stage (Sheahan, 2012).

In Malawi cowpea is an important legume crop for small holder farmers and the crop is adapted to grow to a wide range of local condition (Nkongolo *et al*., 2009). The production of cowpea is estimated to be 50 249 million tons on average 2000 – 2013 (FAOSTAT, 2013).

2.3 Common bean production in Malawi

Common bean (*Phaseolus vulgaris* L.) is also referred to as common dry bean is the most important food legume for direct consumption in the world and it is a major source of dietary protein in Malawi (FAO, 1999). Common bean is known to be largely a self-pollinated plant though some studies have suggested that cross-pollination is a possibility if the stigma comes into contact with a pollen coated bee when extended from the flower. Common bean is grown for consumption of its green pods, green leaves, and immature/ dry seeds and provides a major source of dietary proteins, complex carbohydrates, and valuable micronutrients for more than 300 million people in the tropics (FAO, 1999; Katungi *et al*., 2009).

Over 200 million people in the Sub-Sahara Africa (SSA) rely on common bean as a primary source of staple food and are the second most important source of calories after maize (CIAT, 2012). Globally, about 12 metric tons of common bean are produced per year. Latin America is the leading producer (about 5.5 million metric tons) and consumer, with Brazil and Mexico being by far the major producers of common beans. The Great Lakes region of Africa is the second most important producer and consumer of common bean, producing about 2.5 million metric tons, with Uganda, Burundi, Kenya, Rwanda, Tanzania and Congo being major contributors (FAO, 1999; CIAT, 2012).

Common bean can be grown in a wide range of soils of average fertility and pH up to 9.0. It requires mean temperature in the growing season of about 20 -35^{o}C and temperatures of less than 15^oC or more than 45^oC are not suitable for bean production. Bean production requires a total rainfall in the range of 500- 900 mm, but not less than 500 mm, and during the growing period soil moisture should be available for more than 120 days. The production of common bean is highly suitable when the soil is well drained/ moderately well drained and when both soil salinity and sodicity is low (Naidu *et al*., 2006).

2.4 Intercropping

Intercropping is defined as an agricultural practice of growing two or more crops simultaneously on the same piece of land (Andrew and Kassam, 1976; Sanchez, 1976). It is suggested that intercropping is more efficient than monocropping, the reason being that growing two or more crops results in increased productivity per unit of land. In intercropping system there is efficient use of limited resources to maximize crop production (Ofori and Stern, 1987). It is also suggested that crops which are grown under intercropping systems have higher nutrient uptake and better water use efficiency than crops growing under monocropping system. Biological efficiency of intercropping is due to exploration of large soil mass compared to monocropping (Francis, 1986).

Various studies conducted on intercropping have reported that maize-bean intercrop exhibited lower attacks of fall army-worm (*Spodeptera frugiperda*) than in sole maize (*Zea mays*) system (Francis and Sanders, 1978).There are some socio economic (Ofori and Stern, 1987), biological and ecological advantages (Wiley, 1985) in intercropping over monocropping. And most studies on intercropping have focused on the cereal based intercropping (Ofori and Stern, 1987) and proved the success of intercropping. Successful intercropping needs several considerations before and during cultivation.

2.5 Element Nitrogen: In Soil and in Plants

Nitrogen is regarded as the most important macronutrient limiting crop growth and development in the tropics (Sanchez, 1976). Nitrogen plays important roles in crop production; it is the critical component of organic molecules such as amino acids, proteins and nucleic acids (Walworth, 2013) and it also promotes vigorous vegetative growth (Havlin *et al*., 2008). Nitrogen in the soil takes many forms and most of these transformations are facilitated by micro-organisms. Dinitrogen gas (N_2) is the most predominant form of Nitrogen in the soil; however it is relatively inert and unusable by plants. It is only used by plants when it is transformed to organic Nitrogen through a process called Nitrogen fixation (Paul, 2008; Havlin *et al*., 2008).

There are two forms of nitrogen fixation; one is called the biological nitrogen fixation which is mediated by microbes and the other one is the industrial nitrogen fixation also called the Haber-Bosch process which is regarded as the primary source of nitrogen in fertilizers. Organic soil nitrogen is another form of nitrogen in the soil through mineralization process. This form of nitrogen is the product of decomposition of tissues of dead plants, animals and micro-organisms. Just like dinitrogen gas, organic soil nitrogen is also unavailable for plant uptake. In the soil micro-organisms feeding on the dead organic matter convert these organic forms of nitrogen to inorganic forms, which are available for plant uptake. This process, whereby organic nitrogen is converted into inorganic nitrogen is called mineralization and the reverse of this process is called immobilization (Paul, 2008).

These two processes are mediated by soil micro-organisms and are affected by the carbon: nitrogen ratio. When the ratio is greater than 25:1 immobilization takes places and when it is less than 25:1 mineralization takes places. The products of mineralization are Ammonium and Nitrate which make up the bulk of the soil inorganic nitrogen and the principle forms of nitrogen for plant uptake. Hence plants mainly absorb nitrogen in forms of nitrate and ammonium ions. Nitrate is negatively charged and can easily be transported by water through the soil as it is repelled by the negatively charged soil colloids. Ammonium, on the other hand, is positively charged and can be held on the Cation exchange sites associated with organic matter, clay surfaces and variable charge minerals. As a consequence of their antagonistic properties, nitrate is subject to leaching in the soil while ammonium is not subjected to leaching as it is trapped or held by soil colloids (Paul, 2008; Walworth, 2013).

2.6 Factors affecting nitrogen availability in soil

2.6.1 Soil pH

A pH greater than 7.5 is known to increase the rates of nitrogen loss from the soil in the process of volatilization. This takes place because of the following reason; the high pH increases the concentration of ammonia by converting ammonium to ammonia in the solution thereby making it volatile. Urea fertilizer has the potential to increase the soil pH. When soil pH is less 7.0 losses of nitrogen from the soil are low because there is absence of calcium carbonate (Jones *et al.*, 2013).

Soil pH also affects the soil processes of nitrogen mineralization and immobilization as it directly influences the kinds, amounts and activities of micro-organisms which mediate these processes. Studies have shown that the optimum pH range for microorganisms to mediate the process of mineralization is slightly on the alkaline side, high pH and low in neutral (Abdelmagid, 1980). The loss of nitrogen from the soil through the process of denitrification is affected by soil pH. Bacteria involved in the process of denitrification are sensitive to low pH and N_2 loss from the soil is observed at a neutral or greater pH (Havlin *et al*., 2008).

2.6.2 Soil moisture

Soil moisture plays a very important role in the availability of nitrogen in the soil. The process of volatilization whereby nitrogen is lost from the soil in form of ammonia gas increases linearly as the soil water content increases. The rate of volatilization increases until the soil attains saturation (Jones *et al*., 2013).

Soil moisture also has a direct influence on soil nitrogen mineralization. Soil moisture determines the types, number and activity of microbes which mediate nitrogen mineralization. It is suggested that when soil moisture is low, i.e. dry soil, there is a reduction in both microbial activity and population size. This is a direct response to the decreased access to nutrients and organic materials dissolved in soil water. However, when the soil saturated with water the micro-organisms are oxygen starved due to the fact that the water completely fills up the water spaces. Therefore, mineralization of nitrogen requires the optimum soil moisture for the microbes, and the soil should not be dry and neither be saturated (Paul, 2008).

Soil moisture also plays a critical part in the loss of nitrate-nitrogen from the soil through a process called Denitrification. During the process of denitrification nitrate is converted into Dinitrogen gas (N_2) and this process is very fast when the soil moisture is high so much so that oxygen supply is too low to meet aerobic microbial requirements. Loss of nitrogen from the soil through denitrification is optimum when the oxygen level decreases to 8-10% (Havlin *et al*., 2008).

2.6.3 Soil temperature

When soil temperature is high, it triggers the loss of nitrogen from the soil in the form of ammonia gas, the process called volatilization. Soil surfaces on which all ammonia and ammonia based fertilizers have been applied are more vulnerable to volatilization. When the soil temperatures are high, the warm soil water cannot hold a lot of ammonia gas and eventually loss of ammonia gas takes place. The rate at which hydrolysis of urea and conversion of ammonia gas from ammonium, which leads to volatilization, takes places is affected by temperature. The higher the temperatures the higher rate at which hydrolysis of urea and ammonium conversion to ammonia gas takes place (Jones *et al*., 2013).

At least 95 % of Nitrogen which is in the soil is in organic form, which is in unavailable form for plant uptake. Temperature plays an important role in converting this organic form of Nitrogen to in-organic form for plant uptake in a process called mineralization. The rate of mineralization is high when soil temperatures are high and is lower when soil temperatures are lower. This is so because nitrogen mineralization and its reverse process of immobilization are mediated by micro-organisms which are markedly influenced by temperature. Micro-organisms work best at their optimum temperature. Studies have illustrated that the rate of mineralization is very slow at or near freezing point (5^{o}C), this is due to restricted micro-organisms activity and the rate is maximum at 37^{o}C. When the temperature is 55^{o}C mineralization completely comes to a halt (Abdelmagid, 1980; Paul, 2008).

Temperature also plays a crucial in loss of nitrogen through denitrification. Nitrogen loss from the soil by denitrification takes place at slightly higher rates when soil temperature increases from $2\text{-}10^{o}$C range to $25\text{-}60^{o}$C range. However, it is inhibited when by temperatures which are greater than 60^{o}C. The observed rates of denitrification at higher temperatures suggest that this loss of nitrogen from the soil is mediated by thermophilic microbes (Havlin *et al*., 2008).

2.6.4 Management practices

Studies have indicated that management practices affect the availability of nitrogen in the soil. Researchers have suggested that conservation tillage which involves crop residues incorporation leads to the building up of organic matter at or near the surface of soil. The buildup of organic matter increases the rate of Nitrogen mineralization because decomposition happens faster when crop residues are incorporated than when they are left on the soil surface. This is so because micro-organisms carrying out the work of decomposition have an increased availability of nitrogen hence mineralization takes place (Hargrove *et al*., 1991).

The loss of nitrogen from the soil through volatilization is much greater with broadcast method of applying fertilizer compared to subsurface or surface band applications. This is like that because ammonia formed through subsurface placement or incorporation of urea or urea-containing N solutions must diffuse over a greater distance before escaping into the atmosphere (Havlin *et al.*, 2008).

2.6.5 Crop residue

The presence of crop residues in the soil increases the rate at which nitrogen is lost from the soil by volatilization. The crop residues achieve this by enhancing the rate of urea hydrolysis which eventually leads to volatilization. The crop residues achieve this because of the following reasons: firstly, the microorganisms which produce the urea hydrolyzing enzymes, urease, are 40 times more active in the surface residues than in the mineral soils. Secondly, these crop residues have a pH which is higher than that of soils. The higher pH is a favourable condition for the increased concentration of ammonia in solution. Thirdly, the crop residues have a potential to increase soil moisture which tends to increase the presence of ammonia in the solution hence making it available for volatilization (Jones *et al.*, 2013).

The crop residues quality in the soil determines whether the form of soil Nitrogen is organic (unavailable for plant uptake) or in-organic (available for plant uptake). The crop residue release nitrogen during the process of decomposition which is mediated by soil microbes. The rate of decomposition is affected by the carbon: nitrogen ratio of the crop residue. When the ratio is greater than 25: 1 the conversion of organic nitrogen forms from in organic form predominates (immobilization). Conversely, when the ratio is less than 25:1 the reverse of immobilization (mineralization) takes place. This happens because the microbes which mediate the process of decomposition, mineralization and immobilization require carbon as an energy source and Nitrogen to maintain their bodies by forming proteins, nucleic acids and enzymes from the residue. So when the ratio is less than 25:1 all the nitrogen from the crop residue is incorporated into the microbes' tissues and when it is greater than 25:1 some nitrogen is mineralized into the soil (Abdelmagid, 1980; Paul, 2008).

2.6.6 Clay Mineral

Clay minerals such as vermiculite and mica are negatively charged and have the potential to fix ammonium ion through Cation exchange whereby the ammonium ion replaces the cations which initially occupied the lattice. The fixation of ammonium ion is defined as the adsorption or absorption of ammonium ions by clay minerals of the soil in such a manner that they are relatively unexhangeable by the usual methods of Cation exchange. The availability of fixed ammonium ranges from negligible to relatively high (Paul, 2008; Havlin *et al.*, 2008).

2.7 Biological Nitrogen Fixation (BNF)

Biological nitrogen fixation is the process whereby plants in the legume family, through the aid of prokaryotes of the domains Archaea and Bacteria, transform atmospheric nitrogen (which is inert) to reactive Nitrogen species. Traditionally legumes have been used in rotational systems to improve soil fertility because of the ability to form unique symbiotic relationship with nitrogen fixing rhizobia bacteria (Paul, 2008).

The amount of nitrogen fixed varies with yield level, effectiveness of rhizobia inoculation, the nitrogen obtained from the soil, either from the decomposition of organic residues or from residual nitrogen or from the environmental conditions. The amount of nitrogen fixed also varies with type of legume grown, some legumes are better at nitrogen fixation than others. For example common bean are poor nitrogen fixers and they tend to fix less nitrogen than their nitrogen needs(less than 23 kg per acre). On the other hand cowpeas, groundnuts, soy-beans and fava beans are good nitrogen fixers (113kg per acre) and will fix all their nitrogen needs other than that absorbed from the soil and they do not require fertilizer (Havlin *et al*., 2005; Flynn and Idowu, 2015).

The process of Biological nitrogen fixation begins with development of a mutualistic partnership between the legume-host and the rhizobia bacteria via a series of developmental stages. Rhizobia invade the roots of the legume-host and then initiate the development of structures called nodules on the root surface. The process of establishing a symbiotic relationship is species specific, which means that a bacterial species has a limited spectrum of legumes with which they can form a symbiotic relationship. Within the nodules the rhizobia convert the atmospheric nitrogen into forms which the plant can absorb. Rhizobia fix nitrogen in the nodules through the use of an enzyme called nitrogenase. Nitrogen fixation is an energy demanding process so the rhizobia obtain energy in form of photosynthetic products; sugars, carbohydrates and ATP (adenosine triphosphate) from the legume-host (Havlin *et al*., 2008; Paul, 2008).

The nitrogen fixed is mostly used by the legume host, although at times it is secreted into the soil from the nodule and used by other crops intercropped with the legume and also when the rhizobia die they release nitrogen into the soil environment. Apart from rhizobia there are other nitrogen fixing bacteria which establish a similar type of symbiosis as rhizobia, but only associate with a small group of non-leguminous plant species. It is estimated that the annual biological nitrogen fixation worldwide ranges from 130 to 180×10^6 Mt, with about 50% fixed by rhizobia. This is in contrast with the world N fertilizer use of about 132 x 10^6 Mt in 2008 and it was projected to be about 146 x 10^6 Mt in 2012 (FAO, 2008; Havlin *et al*., 2008; Paul, 2008).

Apart from grain legumes, there are also woody leguminous trees which form associations with microbes and fix appreciable amounts of nitrogen. These leguminous trees include; *Gliricidia sepium, Leucaena leucocephala, and Sesbania bispinosa*-they are used as green manure to restore and improve soil fertility (Havlin *et al*., 2008). Even though there is a wide range of organisms and microbial-plant symbiotic relations that are capable of fixing nitrogen from the atmosphere, the symbiotic partnership between rhizobia and legumes is responsible for fixing the largest amount of fixed nitrogen to agricultural soils. It is estimated that grain legumes contribute at least 20 million tons of fixed nitrogen to agricultural soils annually (Herridge *et al*., 2008).

2.8 Nitrogen Uptake Efficiency and Utilization

Nitrogen use efficiency of a cropping system is defined as the ratio between the amount of nitrogen removed from the field by the cropping system and the amount of nitrogen supplied. The subject of nitrogen use efficiency is very important in the study of cereal production because cereals such as maize (Z*ea mays*), rice (*Oryza sativa*) and wheat (*Tritium aestivum*) have been reported to provide more than 60% of the human dietary calories either as cereals for direct human consumption or indirectly from livestock products or by-products (Cassman *et al*., 2002; Brentrup and Palliere, 2010).

Studies have indicated that not all the nitrogen which is applied to the soil is taken up by the plant. This nitrogen which is not taken up by the plant is immobilized in soil organic nitrogen pools which encompass both microbial biomass and soil organic matter. The immobilized nitrogen is subject to loss from the soil through processes of volatilization, denitrification and leaching (Brentrup and Palliere, 2010).

2.9 Nodulation

Nodulation is the formation and development of root invaginations also known as nitrogen-fixing root nodules as a result of a symbiotic relationship involving soil bacteria called rhizobia and leguminous plants. Studies have shown that application of fertilizers to legumes has the ability to suppress the formation of nodules. This is so because application of fertilizer may lead to an increase in soil acidity. Acidic soils constrain symbiotic nitrogen fixation by limiting the survival of rhizobia hence reducing nodulation. Phosphorus is highly dependent on soil pH, and in acidic soils, P usually fixed by Al, Mn or Fe, thus unavailable to plants. This limits nodulation because nodule development depends on phosphorus (Erker and Brick, 2014).

Aluminum is soluble at low soil pH, and the more the soil is acidic the more soluble aluminum becomes hence causing aluminum toxicity in the soils. The presence of available aluminum in acid soils will inhibit nodulation directly and indirectly by stunting root growth and tends to compound the effects of low-level calcium by inhibiting its uptake. Soils of pH below 6.0 have low molybdenum (Mo) availability (Erker and Brick, 2014), as Mo solubility and availability is pH dependent. Molybdenum is an important micronutrient in nitrogen fixation, since it is an essential component of one of the two proteins, which together form nitrogenase (Paul, 2008). Biederbeck *et al.*, (2013) suggested that an increase in the levels of Nitrogen fertilizer has a capacity to reduce Nitrogen fixation by legumes.

2.10 Land Equivalent Ratio (LER)

Land Equivalent Ratio has been defined as the sum of the fractions of intercropped yields divided by sole crop yield. It is calculated as follows; LER = $\sum$ (Ypi/Ymi), where Yp is the yield of each crop in the intercrop and Ym is the yield of each crop in the sole crop. According to the formula above a LER value of 1.0 indicates that there is no significant difference between the intercropping system and the collection of monocropping systems and a value of greater than 1.0 indicates that there is a yield advantage for the intercrop. The advantages of Land Equivalent Ratio include the following: (1) LER provides a basis of farming system which a farmer can choose. This basis helps the farmer to add crops so as to form combined yields. (2) LER also provides a platform for comparison between individual LERs which can indicate some comparative effects. (3) The total LER can be used as a measure of the relative yield advantage (Darish *et al.*, 2006; Yilmaz *et al.*, 2008).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study sites

Field experiments were conducted in two sites in 2016/17 growing season. The first site was located at Chitedze Agricultural Research Station, near Lilongwe Central part of Malawi (Figure 1). It is located at about 13^{o} 59` S longitude and 33$^{o}$ 38 ` E latitude at an elevation of 1146 m above sea level. Chitedze Research Station has a mean annual temperature of 20^{o}C and annual rainfall averages from 800 to 900 mm, 85% of which falls from November to April. The station is a representative of Lilongwe plain, which is a major maize producing agro-ecology of the country. The terrain is flat to gently undulating. The soils are chromic Luvisols. They have a well-developed structure with a dark, reddish brown top soil. The pH ranges from 4.5 to 6.0.

The second site was located at Makoka Agricultural Research Station near Zomba, the southern region of Malawi (Figure 1). The soil is classified as Ferric Lixisol (FAO/UNESCO) or Oxic Hapleustalf (USDA). It is situated at about 15^{o} 30'S longitude and 35^{o} 15'E latitude at an elevation of 1030 m above sea level. The soil texture is 73.84% sand, 19.33% clay and 6.83% silt. Total annual rainfall ranges from 560 to 1600 mm, with a mean of 1024 mm. The site experiences unimodal type of rainfall with most of the rains falling from November to April. Rainfall and temperatures were recorded during the 2016/17 growing season at Chitedze and Makoka by means of an automatic weather station (Table 1 below).

Table 1 : Monthly rainfall and temperatures during 2016/17 growing season at Chitedze and Makoka research stations

Location	Climate data	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Chitedze	Rainfall(mm)	13.5	3.3	81.6	246.1	489.1	138.0	70.9	13.5
	Max T (˚C)	30.7	32.2	28.9	26.1	27.5	20.8	26.1	26.1
	Min T (˚C)	15.5	19.0	19.3	16.7	18.1	17.4	16.1	14.3
Makoka	Rainfall(mm)	0.7	112.6	176.6	308.9	152.7	200.9	9.8	1.4
	Max T (˚C)	31.6	31.2	28.8	27.4	28.2	26.2	25.7	25.4
	Min T (˚C)	17.9	19.4	19.6	19.2	18.9	17.3	16.1	14.3

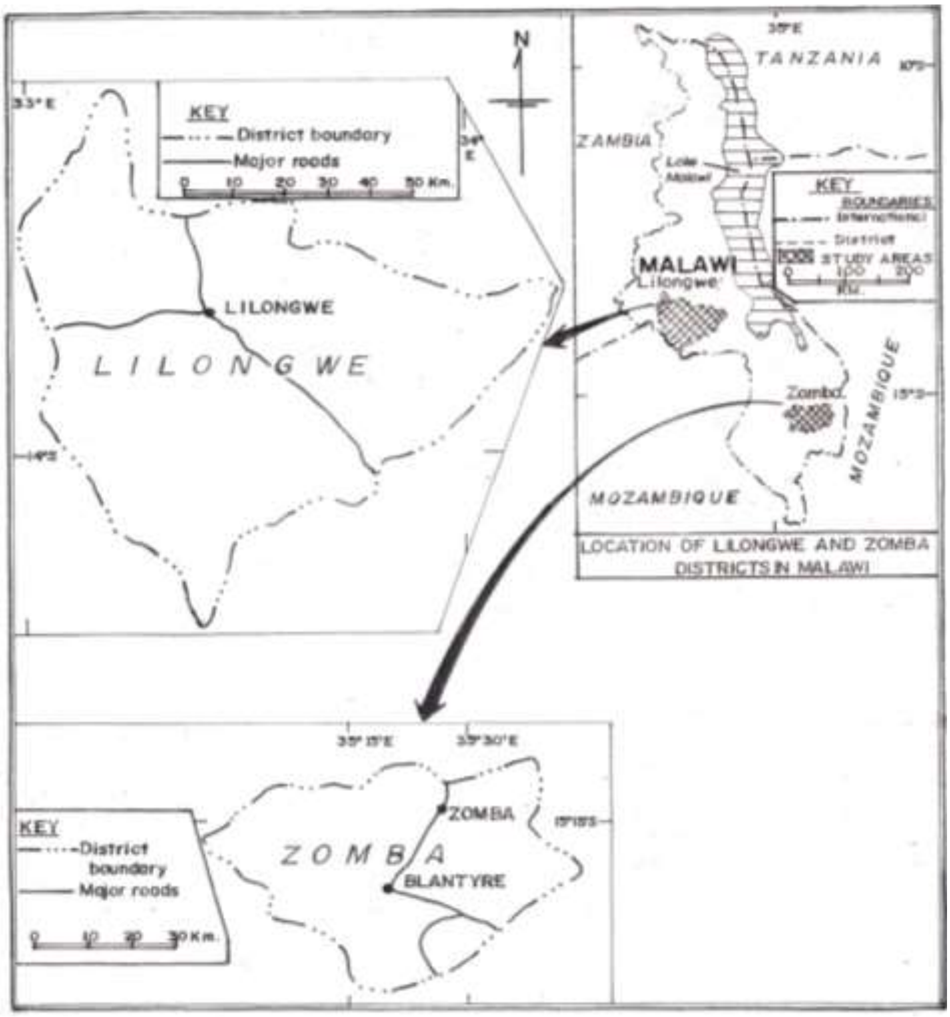


Figure 1: Map of Malawi Showing Study Sites

Source: Geography Department, Egerton University.

3.2 Experimental Design and Treatments

The experiment was set up as a split plot in a randomized complete block design (RCBD) replicated three times (Figure 2). The main plots were: (i) cropping system (sole maize, sole bean, sole cowpea, bean/maize and cowpea/maize intercrop). The sub plots were four rates of N (0, 52.5, 78.75 and 105 kg N ha^{-1}) applied as inorganic fertilizer rates correspond to zero, one-half (50%), 75% and 100% of the recommended national fertilizer rate for maize. The recommended N rate for Malawi is 105 kg N ha$^{−1}$ by side dressing (MAIFS, 2004). Urea fertilizer was used as a source of N. The seeds for maize, cowpeas and common bean were purchased from Agricultural Trading Company located in Lilongwe, Malawi.

Rep. I

C1				C2				C3				C4				C5			
N1	N3	N0	N2	N2	N0	N1	N3	N3	N1	N2	N0	N0	N2	N3	N1	N1	N2	N3	N0

Rep II

C4				C3				C5				C1				C2			
N0	N2	N3	N1	N3	N1	N2	N0	N1	N2	N3	N0	N1	N3	N0	N2	N2	N0	N1	N3

Rep. III

C5				C1				C2				C3				C4			
N1	N2	N3	NO	N1	N3	N0	N2	N2	N0	N1	N3	N3	N1	N2	N0	N0	N2	N3	N1

Figure 2: Experimental Layout

Key:

C1 = Maize monocropping

C2 = bean/maize intercrop

C3 = Cowpea/maize intercrop

C4 = Cowpea monocropping

C5 = Bean monocropping

N0 = 0 kg N ha^{-1}

N1 = 52.5 kg N ha^{-1}

N2 = 78.75 kg N ha^{-1}

N3 = 105 kg N ha^{-1}

The gross plot size was ten (10) ridges and each ridge was 6 meters long. The net plot comprised eight middle ridges, a ridge on each side of the plot was discarded, and each ridge was 4 metres long, one meter on each side of the ridge was discarded.

The treatment combinations were as follows:

1. C1N0= sole maize + 0 kg N ha^{-1}
2. C1N1 =sole maize + 52.5 kg N ha^{-1}
3. C1N2 = sole maize + 78.75 kg N ha^{-1}
4. CIN3 = sole maize + 105 kg N ha^{-1}
5. C2N0= bean/ maize intercrop + 0 kg N ha^{-1}
6. C2N1 = bean/ maize intercrop +52.5 kg N ha^{-1}
7. C2N2 = bean/ maize intercrop +78.75 kg N ha^{-1}
8. C2N3 = bean/ maize intercrop + 105 kg N ha^{-1}
9. C3N0= cowpea/ maize intercrop + 0 kg N ha^{-1}
10. C3N1 = cowpea/ maize intercrop + 52.5 kg N ha^{-1}
11. C3N2 = cowpea/ maize intercrop + 78.75 kg N ha^{-1}
12. C3N3 = cowpea/ maize intercrop + 105 kg N ha^{-1}
13. C4N0 = sole cowpea + 0 kg N ha^{-1}
14. C4N1 = sole cowpea + 52.5 kg N ha^{-1}
15. C4N2 = sole cowpea + 78.75 kg N ha^{-1}
16. C4N4 = sole cowpea + 105 kg N ha^{-1}
17. C5N0 = sole bean + 0 kg N ha^{-1}
18. C5N1 = sole bean + 52.5 kg N ha^{-1}
19. C5N2 =sole bean + 78.75 kg N ha^{-1}
20. C5N3 = sole bean + 105 kg N ha^{-1}

3.3 Agronomic practices

3.3.1 Land Preparation and Planting

Land was prepared manually using hoes. Maize was planted at spacing of 75cm between rows and 25 cm between planting stations. Two seeds were planted per hill and later thinned to 1 when plants were 10 cm tall (53,000 plants/ha). The maize variety SC 403, an early maturing variety, was planted. In the intercropping system, the legume seeds were sown between two maize rows, at spacing of 75 cm between rows and 25 cm between planting stations. Two seeds were planted per station, and then thinned to one plant. A medium duration common bean variety was planted (Mwaiwathu alimi). The cowpea variety planted was IT82E-16, a medium duration variety. Sole legumes were sown at a spacing of 75 cm between rows and 25 cm between planting stations.

3.3.2 Fertilizer Application and Field Management

Urea fertilizer was applied as a source of nitrogen, in two equal splits, 7 days and 30 days after planting, to minimize potential leaching losses. Triple superphosphate (TSP) was applied at a rate of 40 kg P ha^{-1} as a source of phosphorus as basal dressing fertilizer. Careful and superficial manual weeding was done three times, after crop emergence. Pesticides (Dimethoate and Cypermethrin) were applied twice, first when the plants were two weeks old and second when the maize was tasseling and the legumes were flowering. The pesticides were applied at a rate of 3litres/hectare.

3.4 Data Collection

3.4.1 Soil Sampling and Analysis

Pre-plant soil characterization was determined by randomly collecting 10 sub-samples per plot, using Edelman soil augers, from 0 to 30cm top soil layer. They were mixed for a composite, representative sample. Samples were air dried to constant weight, for at least 96 hours, ground to pass through a 2mm sieve and analyzed for total N, organic C, available P and exchangeable Ca, Mg and K, following standard procedures stipulated by Anderson and Ingram (1993). Exchangeable cations were determined by using 1N ammonium acetate. Soil pH was read in a suspension of 1:2.5 soils: distilled water. Texture was determined using a hydrometer in a dispersant solution of 3% sodium hexametaphosphate (Anderson and Ingram, 1993). Chemical and physical characteristics of the Chitedze and Makoka Agricultural research stations are tabulated in table 2.

Table 2: Initial physical and chemical characteristics of soils at Chitedze and Makoka Agricultural Research Stations

		Chitedze		**Makoka**	
Property	**units**	**Value**	**Interpretation**	**Value**	**Interpretation**
PH	-	6.09	Medium	4.91	Deficient in Ca
Organic Carbon	%	1.58	Medium	0.32	Low
Organic Matter	%	2.75	Adequate	0.53	Low
Total N	%	0.20	Medium	0.10	Low
Available P	ppm	39.54	High	72.98	High
K	cmolkg^{-1}	0.11	Low	0.11	Low
Ca	cmolkg^{-1}	0.45	Low	0.16	Low
Mg	cmolkg^{-1}	0.05	Low	0.04	Low
Zn	ppm	0.31	Low	0.10	Low
Clay	%	19.20		19.33	
Silt	%	13.00		6.83	
Sand	%	67.80		73.84	
Textural class		Sandy clay loamy		Sandy clay loamy	

Chemical characteristics of soil were classified according to Landon (1991).

3.4.2 Determination of Nitrogen Uptake by Maize

To determine the nitrogen taken up by the plant, the leaf opposite the ear was taken from five maize plants per plot at tasseling stage. The plants were selected randomly from the plot border rows. The samples collected were chopped into small pieces and sub-samples oven dried at 65°C for 72 hours. The weights of the oven dry sub-samples were recorded. The dried samples were ground and digested in sulphuric acid- selenium extractant and analyzed for total nitrogen according to standard procedures stipulated by Anderson and Ingram (1993). Nutrient uptake was calculated using the following formulae (Peterburgski, 1986);

$$\text{Total nutrient uptake} = \text{nutrient contration x dry matter yield} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

3.4.3 Yield Determination

Grain and dry matter yields of both legumes and maize were determined at physiological maturity. The net plot harvested was made up of 8 ridges which were 4 metres long. The aboveground biomass of plants per net plot was harvested. Biomass fresh weights were determined in the field. Sub samples were taken to the laboratory and dried at 65^0C to constant weight. Dry weights were determined and used to calculate above ground dry matter yield. Maize grain yield was expressed at 13% moisture content. The moisture content was determined by moisture meter. The weight of grains and dry matter were measured by an analytical balance and yield calculated using the following formulae:

$$\text{Grain (dry matter) yield } (\text{kgha}^{-1}) = \text{kg grain yield m}^{-2} \text{ x } 10,000\text{m}^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The 100 seed mass of maize was also determined, using a weighing balance.

3.4.4 Measurement of nodules

At harvest of legumes, shoots were cut using a clean, sharp knife at the first node after the soil surface and soil was washed gently to isolate the roots. Nodulation (number of nodules and fresh weight) was recorded

3.4.5 Land Equivalent Ratio Determination

The Land Equivalent Ratio (LER) was calculated from the formula:

$$\text{LER} = \sum (\text{Ypi/Ymi}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where Yp is the yield of each crop in the intercrop and Ym is the yield of each crop in the sole crop (Darish *et al.*, 2006).

3.4.6 Nutrient Use Efficiency

Using treatment yield, nutrient use efficiency (NUE) was calculated using the following formula (Brentrup and Palliere, 2010):

$$\text{NUE} = \frac{\text{yield with nitrogen} - \text{ yield without nitrogen}}{\text{Total Nitrogen added}}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

3.4.7 Leaf Area Index

Leaf area per plant was measured by length (L) and width (W) corrected to 0.75, as described by Saxena and Singth (1965).

$LA = 0.75 (L \times W)$ --- (5)

Where: L = leaf length, cm

W = width of widest portion of leaf, cm

LA = leaf area, cm^2

Leaf area index (LAI) was calculated using the following formulae (Addo-Quaye *et al*., 2011):

$LAI = LA/P$ Where: P = the ground area, cm^2…………………………………………… (6)

3.4.8 Maize Plant Height

Plant height readings were taken 4 weeks after planting, using a ruler, until the maize plants reached physiological maturity. Plant height of three plants per subplot in each of the middle rows randomly selected was taken and marked. The mean height was calculated and recorded.

3.5 Statistical Analysis

Data was subjected to analysis of variance (ANOVA). Data entry was done in excel and analysis was conducted using statistical package SAS version 9.3. The treatment means were compared using Duncan’s Multiple Range Test (DMRT) tests at $P<0.05$. In the plots with legume/maize intercropping, the mean data on grain yield, biomass and nutrient uptake by maize was subjected to correlation.

3.6 Statistical Model

$$Y_{ijklm} = \mu + \beta_i + C_j + \beta C_{(ij)} + N_k + CN_{(jk)} + L_l + LC_{(lj)} + LN_{(lk)} + CLN_{(jlk)} + \varepsilon_{ijklm}$$

Where;

Y_{ijklm}: Yield

μ: Overall mean

β_i : Effect of the ith block

C_j: Effect of jth cropping system

$\beta C_{(ij)}$: Effect of interaction between ith replicate and jth cropping system

N_k: Effect of kth nitrogen level

$CN_{(jk)}$: Effect of interaction between jth cropping system and kth Nitrogen level

L_l: Effect of lth location

$LC_{(lj)}$: Effect of interaction between lth location and jth cropping system

$LN_{(lk)}$: Effect of interaction between lth location and kth Nitrogen level

$CLN_{(jlk)}$: Effect of interaction between jth cropping system, lth location and kth nitrogen level

ε_{ijklm} :Random error term

Where; **i** = 1, 2, 3. **j =** 1, 2. , **k** = 1, 2, 3, 4. **l** = 1, 2, 3.

CHAPTER FOUR

RESULTS

4.1 Effect of cropping system, nitrogen level, location and their interaction on maize yield, dry matter yield weight of cobs and 100 seed weight

The main effects of nitrogen levels and locations on maize grain yield, dry matter (DM) yield weight of cobs and 100 seed weight were significant (Table 3). Significantly higher values ($P<0.05$) were obtained with application of 105 kg N ha^{-1} (N3), followed by 78.75 kg N ha^{-1} (N2), N1 (52.5kg N ha $^{-1}$) and N0 (0 kg N ha^{-1}) in that order (Table 3). Maize grain yield, weight of cobs and 100 seed weight were significantly ($P<0.05$) higher at Chitedze Research Station than at Makoka (Table 3). Effect of cropping system was significant for DM yield only. Significantly ($P<0.05$) higher means were observed in bean/maize intercropping and maize monocropping systems (Table 3).

The effect of interaction between cropping systems and levels of nitrogen on maize DM yield, weight of cobs and 100 seed weight was significant (Table 4). Cob weight was significantly higher ($P<0.05$) when bean/maize intercropping system was combined with inorganic fertilizer at N3. DM yield was significantly higher when maize monocropping was combined with N3 level and 100 seed weight was significantly higher when cowpea/maize intercropping was combined with N3 fertilizer level. The effect of interaction between cropping systems and levels of nitrogen was, however, not, significant ($P<0.05$) for maize grain yield (Table 4).

The nitrogen levels, cropping systems and location interactions effects were significant for weight of cobs and weight of 100 maize seeds but were not significant for maize yield grain and DM yield (Table 5). Cob weight was significantly higher in bean/cowpea intercropping system, N3 nitrogen level, followed by N2 and N1 at Chitedze research station. It was significantly lower in N0 under bean/maize intercropping at Makoka research station. On the other hand significantly higher values for weight of 100 maize seeds were obtained under the following treatment combinations; cowpea/maize intercropping, N3 and Chitedze research station, followed by bean/maize intercropping system, N3 and Chitedze research station (Table 5).

The interactive effect of cropping system and location on weight of cobs and DM yield was significant. Significantly higher values were observed under bean/maize intercropping system at Chitedze research station. Cob weight was significantly lower under the same cropping system at Makoka research station while DM yield was significantly lower under the treatment combination of cowpea/maize intercrop and Makoka research station (Table 6). The effect of interaction between nitrogen levels and location was significant on weight of cobs but was not significant on maize grain, DM yield and 100 seed weight (Table 6). The weight of cobs was significantly higher under N3 nitrogen level at Chitedze research station and was significantly lower when nitrogen level was N0 at Makoka Research Station.

Table 3: Effect of nitrogen level, cropping system and location on maize grain yield, DM yield and weight of cobs

Treatment	**Maize grain Yield(Mt/ha)**	**Maize DM yield (Mt/ha)**	**Cob weight (Mt/ha)**	**100 maize seed weight (g)**
Nitrogen Level				
N0	1.54d	1.17d	0.96d	31.72c
N1	3.99c	2.20c	1.43c	37.39b
N2	5.37b	3.08b	1.59b	39.50ab
N3	6.25a	4.54a	1.94a	40.97a
Cropping system				
Maize-monocropping	4.47a	2.75ab	1.46a	36.85a
Bean/maize-intercropping	4.16a	2.95a	1.51a	37.62a
Cowpea/maize-intercropping	4.23a	2.56b	1.47a	37.71a
Location				
Chitedze	5.04a	2.83a	1.56a	39.44a
Makoka	3.54b	2.67a	1.40b	35.35b

Means with the same letter within a treatment category are not significantly different ($P<0.05$) according to Duncan test

Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}

Table 4: Effect of the interaction between cropping systems and levels of nitrogen on maize grain yield, DM yield, weight of cobs and weight 100 maize seed (means ± std. error)

Cropping system	**Nitrogen level**	**Maize grain yield (Mt/ha)**	**DM yield (Mt/ha)**	**Cob weight (Mt/ha)**	**100 maize seed weight (g)**
Maize monocropping	N0	1.77±0.36	1.23±0.11	1.00±0.07	30.33±1.71
	N1	4.49±0.54	2.30±0.23	1.40±0.09	36.83±1.51
	N2	5.62±0.90	2.97±0.24	1.51±0.11	40.08±1.97
	N3	6.02±0.35	4.47±0.18	1.93±0.12	40.17±1.19
Bean/maize intercropping	N0	1.27±0.41	1.11±0.11	0.85±0.09	31.17±1.57
	N1	3.53±0.92	2.57±0.32	1.54±0.07	38.58±2.31
	N2	5.84±0.51	3.49±0.26	1.68±0.12	40.92±1.92
	N3	6.03±0.81	4.63±0.37	1.96±0.15	39.83±1.94
Cowpea/maize intercropping	N0	1.59±0.50	1.15±0.11	1.02±0.11	33.67±1.67
	N1	3.95±0.41	1.76±0.13	1.33±0.07	36.75±1.39
	N2	4.67±0.44	2.79±0.11	1.58±0.06	37.50±1.43
	N3	6.71±0.33	4.53±0.37	1.93±0.08	42.92±2.03

Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}

Table 5: Effect of interaction between cropping system, nitrogen level and location on maize grain yield, DM yield and weight of cobs (means ± std. error)

Cropping system	Nitrogen level	Location	Maize Yield (Mt/ha)	Dry matter yield(Mt/ha)	Cob weight (Mt/ha)	100 maize seed weight (g)
maize monocropping	N0	Chitedze	2.24±0.48	1.12±0.07	1.00± 0.13	32.33±1.45
		Makoka	1.30±0.43	1.35±0.21	1.00± 0.08	28.33±2.92
	N1	Chitedze	5.41±0.61	2.21±0.27	1.50± 0.13	38.33±0.88
		Makoka	3.57±0.46	2.39±0.42	1.31± 0.11	35.33±2.91
	N2	Chitedze	7.10±1.00	2.81±0.17	1.54± 0.11	44.00±0.58
		Makoka	4.14±0.95	3.13±0.49	1.47± 0.23	36.17±1.92
	N3	Chitedze	6.03±0.77	4.56±0.29	1.85±0.26	42.00±1.73
		Makoka	6.00±0.14	4.38±0.27	2.01±0.06	38.33±0.88
bean/maize intercropping	N0	Chitedze	2.01±0.35	1.00±0.18	0.88±0.10	34.33±0.88
		Makoka	0.52±0.42	1.21±0.15	0.81±0.16	28.00±1.26
	N1	Chitedze	4.97±1.37	2.76±0.66	1.65±0.06	41.00±4.16
		Makoka	2.10±0.55	2.37±0.17	1.44±0.12	36.17±1.88
	N2	Chitedze	6.90±0.12	3.76±0.49	1.87±0.10	44.67±1.45
		Makoka	4.77±0.40	3.22±0.15	1.49±0.15	37.17±1.48
	N3	Chitedze	7.03±0.93	5.17±0.63	2.24±0.06	42.00±2.00
		Makoka	5.03±1.18	4.10±0.07	1.67±0.18	37.67±3.17

Table 5 continued

cowpea/maize intercropping	N0	Chitedze	1.82±0.71	0.94±0.11	0.99±0.09	32.67±0.88
		Makoka	1.35±0.85	1.37±0.03	1.05±0.22	34.67±3.49
	N1	Chitedze	4.44±0.70	1.82±0.26	1.45±0.07	37.67±2.91
		Makoka	3.46±0.31	1.69±0.10	1.21±0.06	35.83±0.67
	N2	Chitedze	5.17±0.83	3.00±0.11	1.67±0.09	39.33±1.67
		Makoka	4.16±0.21	2.58±0.04	1.49±0.07	35.67±2.03
	N3	Chitedze	7.38±0.25	4.82±0.67	2.05±0.13	45.00±3.46
		Makoka	6.05±0.13	4.24±0.40	1.82±0.06	40.83±2.09

Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}.

Table 6: Effect of the interactions between cropping systems and location, nitrogen levels and location on maize grain yield, DM yield and weight of cobs (means ± std. error**)**

Treatment	**Location**	**Maize grain yield (Mt/ha)**	**DM yield (Mt/ha)**	**Cob weight (Mt/ha)**	**100 maize seed weight (g)**
Cropping system					
maize monocropping	Chitedze	5.19±0.63	2.67±0.39	1.47± 0.12	39.17±1.44
	Makoka	3.75±0.56	2.82±0.37	1.45± 0.12	34.54±1.50
bean/maize intercropping	Chitedze	5.23±0.71	3.17±0.51	1.66±0.15	40.50±1.55
	Makoka	3.11±0.64	2.73±0.33	1.35±0.12	34.75±1.48
cowpea/maize intercropping	Chitedze	4.71±0.66	2.65±0.46	1.54±0.12	38.67±1.69
	Makoka	3.75±0.54	2.47±0.35	1.39±0.10	36.75±1.22
Nitrogen level					
N0	Chitedze	2.02±0.27	1.02±0.07	0.96± 0.06	33.11±0.63
	Makoka	1.06±0.33	1.31±0.08	0.95± 0.09	30.33±1.74
N1	Chitedze	4.94±0.50	2.26±0.26	1.53± 0.05	39.00±1.57
	Makoka	3.04±0.33	2.15±0.18	1.32± 0.06	35.78±1.02
N2	Chitedze	6.39±0.48	3.19±0.21	1.69±0.07	42.67±1.07
	Makoka	4.35±0.32	2.98±0.18	1.48±0.08	36.33±0.94

Table 6 continued

N3	Chitedze	6.82±0.41	4.85±0.29	2.05±0.10	43.00±1.35
	Makoka	5.69±0.38	4.24±0.15	1.83±0.08	38.94±1.22

Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}

4.2 Effect of cropping system, nitrogen level, location and their interaction on nitrogen uptake by maize.

There were significant (P<0.05) main effects of nitrogen levels and location on N uptake by maize. The highest amount of nutrient uptake was observed in N3 nitrogen level, followed by N2.The lowest amounts of nutrient uptake were recorded when in N0 and N1 nitrogen levels. Significantly higher uptake was observed at Chitedze Research Station than at Makoka. Cropping systems did not have any significant effect on nutrient uptake (Table 7).

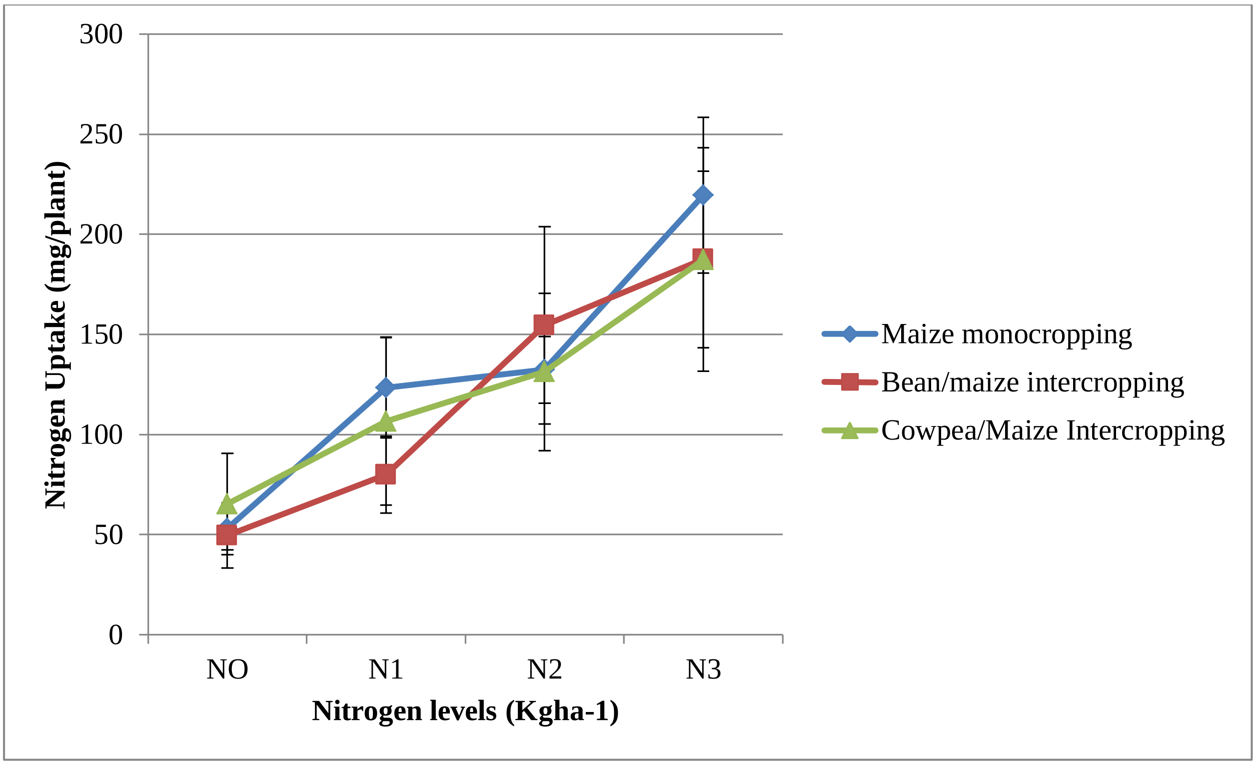
Table 7: Effects of cropping systems, nitrogen levels and locations on nutrient uptake in maize

Treatments	Nutrient uptake (mg-N/plant)
Cropping system	
maize monocropping	132.13a
bean/maize intercropping	117.92a
cowpea/maize intercropping	122.68a
Nitrogen level	
N0	56.05c
N1	103.36bc
N2	139.41b
N3	198.15a
Location	
Chitedze	163.03a
Makoka	85.45b

Note: Means with the same letter within a treatment category are not significantly different (P<0.05) according to Duncan test.

Key: N0 = 0 kg N ha^{-1}, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}.

The interaction effect between cropping systems and nitrogen levels on N uptake by maize was significant (P<0.05) (Table 8). The uptake was significantly higher in bean/maize intercropping system followed by cowpea/maize intercropping under N3 level of nitrogen in both cropping systems and in maize monocropping when the nitrogen levels were N1 and N2 (Figure 4).



Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}.

Figure 3: Effect of interaction between nitrogen levels and cropping system on nutrient uptake in maize

The effect of cropping systems and location interaction on N uptake in maize was significant only under maize monocropping system. The uptake was significantly higher at Chitedze research station than at Makoka research station in maize monocropping system at both sites (Figure 5). The interaction between nitrogen levels and location on N uptake by maize was not significant ($P<0.05$) (Table 6).

The interaction effects of nitrogen level, cropping system and location on N uptake by maize was significant ($P<0.05$) (Figure 7). Uptake was significantly higher under maize monocropping system combined with N3 level of nitrogen at Chitedze research station. The values were significantly lower under cowpea/maize intercropping system combined with N0 level of nitrogen at Makoka research station.

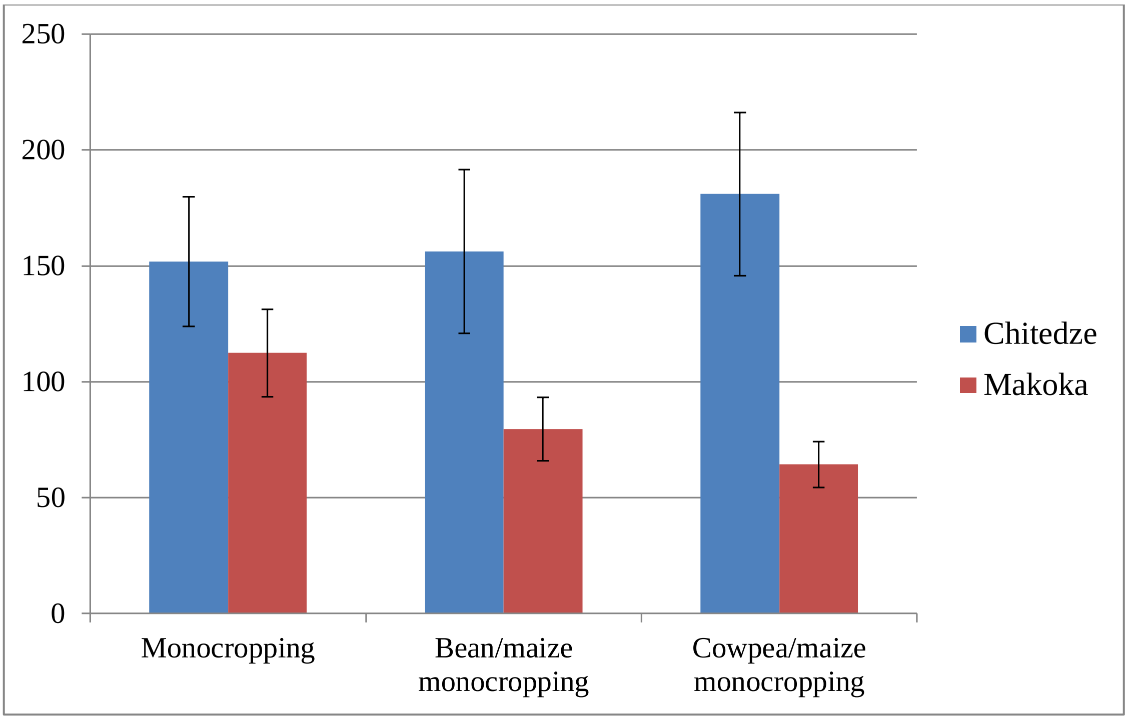
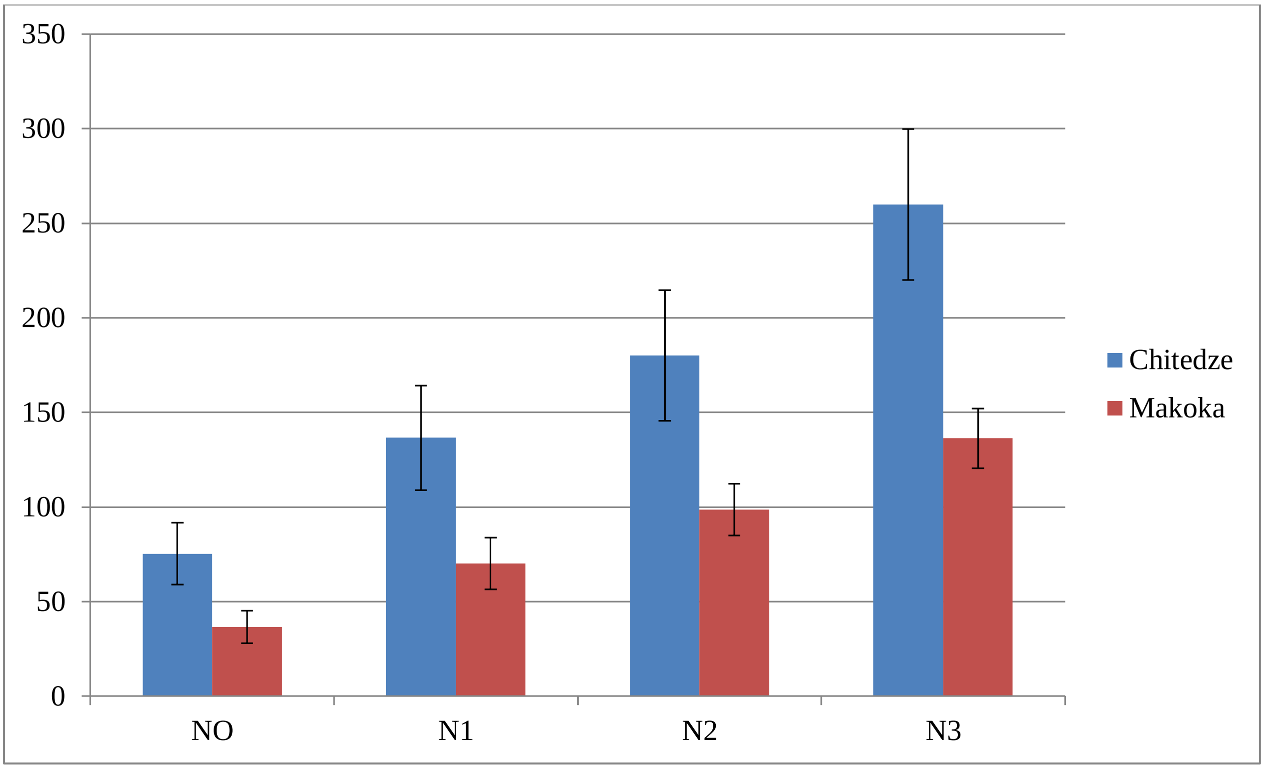


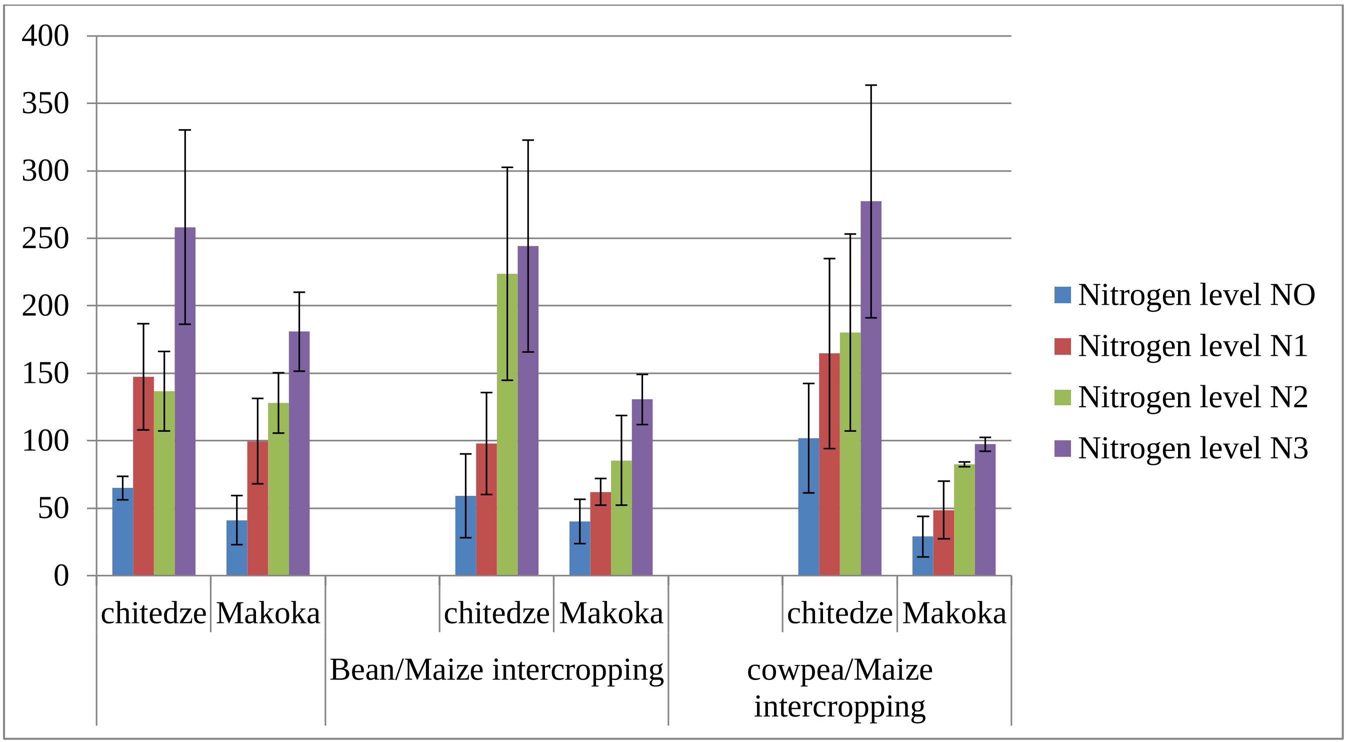
Figure 4: The interaction effects of Cropping system and Location on N uptake in mgplant^{-1}



Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}.

Figure 5: The interaction effects of nitrogen levels and location on nutrient uptake in maize in mgplant^{-1}

Figure 6: Effect of the interaction between nitrogen levels, cropping system and location on nutrient uptake in maize in mgplant^{-1}



Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}.

Figure 7: Effect of the interaction between nitrogen levels, cropping system and location on nutrient uptake in maize in mgplant^{-1}

4.3 Correlation coefficients for agronomic traits of maize grown under both monocropping and intercropping systems

Maize grain yield showed strong positive correlations with cob weight (r^2 = 0.87, P < 0.001), maize DM yield (r^2 = 0.83, P < 0.001) and weight of 100 maize seeds (r^2 = 0.83, P < 0.001) (Table 8). A positive but weak correlation was observed between maize grain yield and N uptake (r^2 = 0.62, P < 0.001). From the same table N uptake showed weak positive correlations with weight of 100 maize seeds (r^2 = 0.62, P < 0.001), maize DM yield (r^2 = 0.61, P < 0.001) and cob weight (r^2 = 0.56, P < 0.001). Cob weight showed strong positive correlation with maize DM yield (r^2 = 0.85, P < 0.001). Weight of 100 maize seeds showed a fairly strong positive correlation with cob weight (r^2 = 0.72, P < 0.001) but a weak positive correlation with maize DM yield (r^2 = 0.66, P < 0.001).

Table 8: Correlation coefficients for agronomic traits of maize grown under both monocropping and intercropping systems

	Grain yield	**N uptake**	**DM yield**	**Cob Weight**	**Weight of 100 seeds**
Maize grain yield	1.00				
N uptake	0.62***	1.00			
Maize DM yield	0.83***	0.61***	1.00		
Cob Weight	0.87***	0.56***	0.85***	1.00	
Weight of 100 maize	0.83***	0.62***	0.66***	0.72***	1.00

Note: ***correlation is significant (P < 0.001) Pearson Correlation

4.4 Effect of cropping system, nitrogen level, location and their interaction on maize height and leaf area index

The main effect of nitrogen levels was significant (P<0.05) for both height and leaf area index (LAI) of maize (Table 9). Significantly (P<0.05) higher values of maize height were obtained under N3 nitrogen level followed by N2, then N1 and lastly N0 nitrogen level. For LAI significantly higher means were obtained under N3, N2 and N1 than N0. On the other hand the main effect of location was only significant for maize height. Maize planted at Chitedze Research Station site were significantly (P<0.05) taller than at Makoka. The main effect of cropping systems was, however, not significant for both maize height and LAI (Table 9).

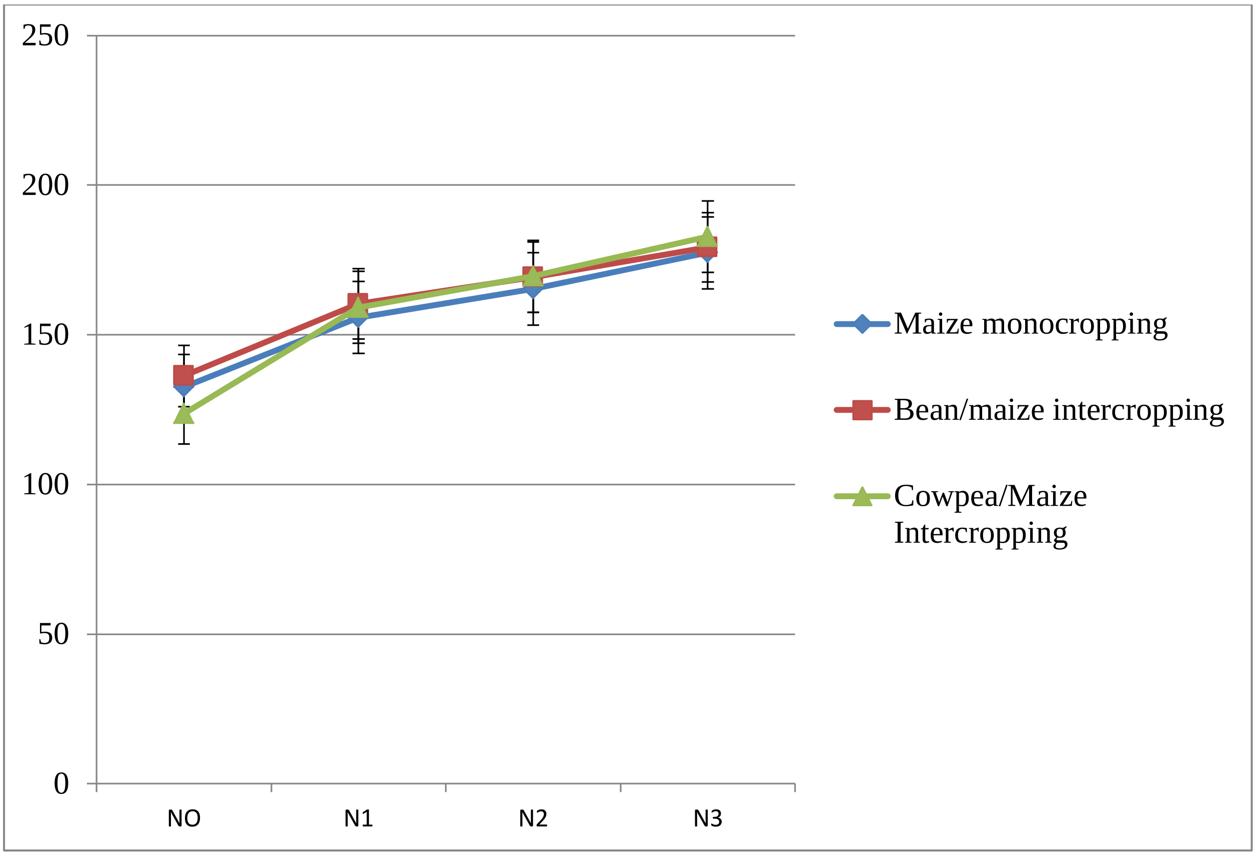
Table 9: Effects of nitrogen level, cropping system and location on maize height and leaf area index of maize

Treatments	**Height (cm)**	**Leaf Area Index**
Cropping System		
maize monocropping	157.78a	2.47a
bean/maize intercropping	161.25a	2.54a
cowpea/maize intercropping	158.77a	2.35a
Nitrogen Levels		
N3	179.78a	2.66a
N2	168.06b	2.58a
N1	158.41c	2.56a
N0	130.82d	1.92b
Location		
Chitedze	173.50a	2.41a
Makoka	145.04b	2.44a

Note: Means with the same letter within a treatment category are not significantly different (P<0.05) according to Duncan test

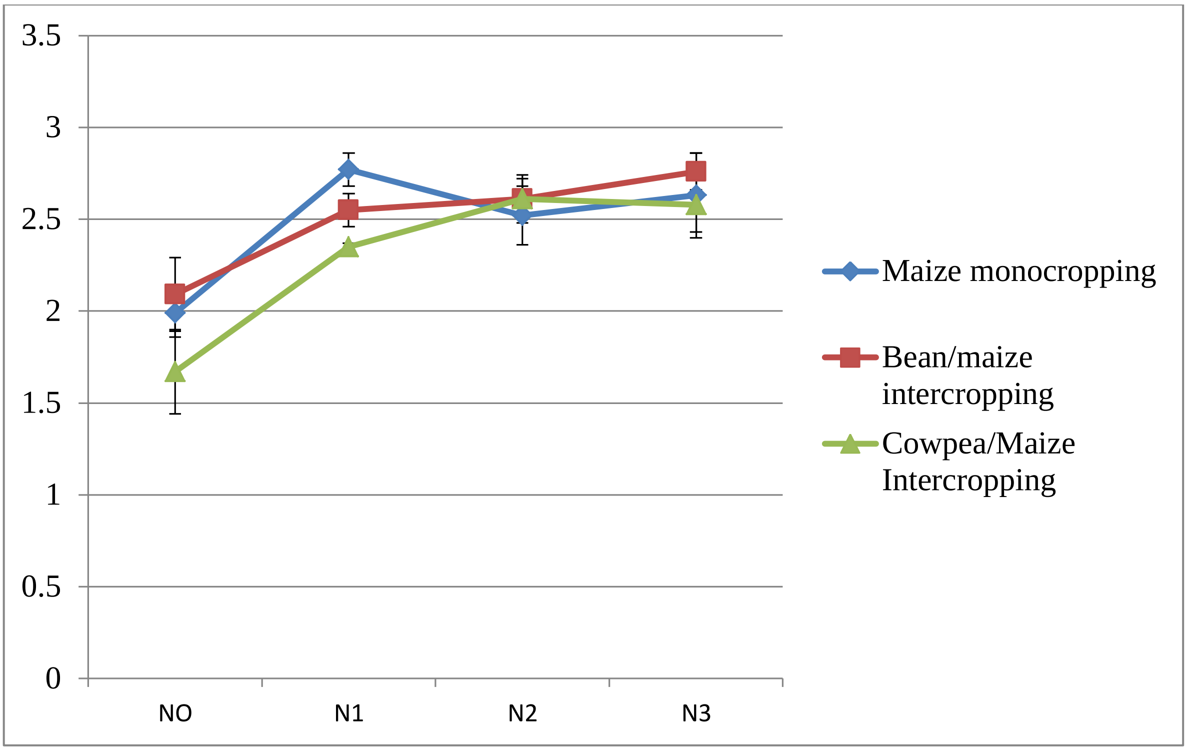
Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}.

The interactive effect of nitrogen levels and cropping systems was significant (P<0.05) for both maize height and LAI (Figure 8 and 9, respectively). It was observed that maize height was significantly higher under cowpea/maize intercropping system and N3 nitrogen and on the other hand lower under the same cropping system with N0 nitrogen level.



Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}.

Figure 8: Effect of interaction between nitrogen levels and cropping system on maize height in cm



Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}.

Figure 9: Effect of interaction between nitrogen levels and cropping system on maize leaf area index

The effect of interaction between cropping system and location was significant for LAI (Figure 10), but was not significant for maize plant height (Figure 11). It was significant under intercropping systems (bean/maize intercropping and cowpea/maize intercropping) and all levels of nitrogen. The interaction was, however, not significant in maize monocropping and all levels of nitrogen.

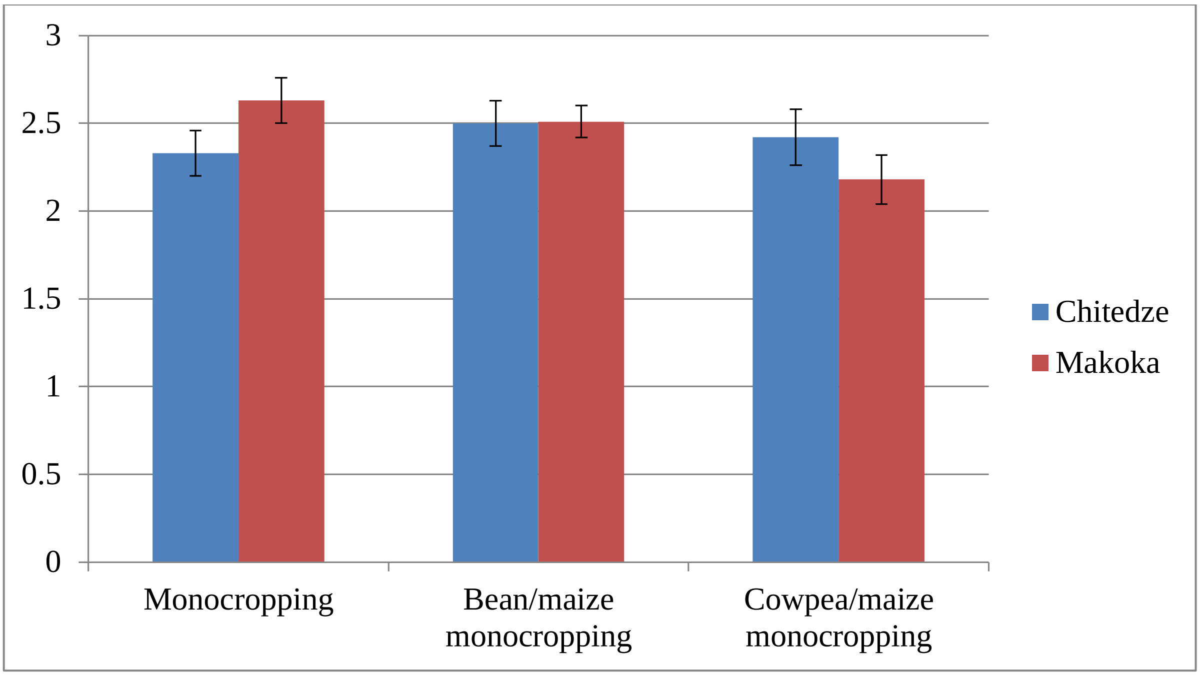


Figure 10: Effect of the interaction between cropping systems and location on leaf area index

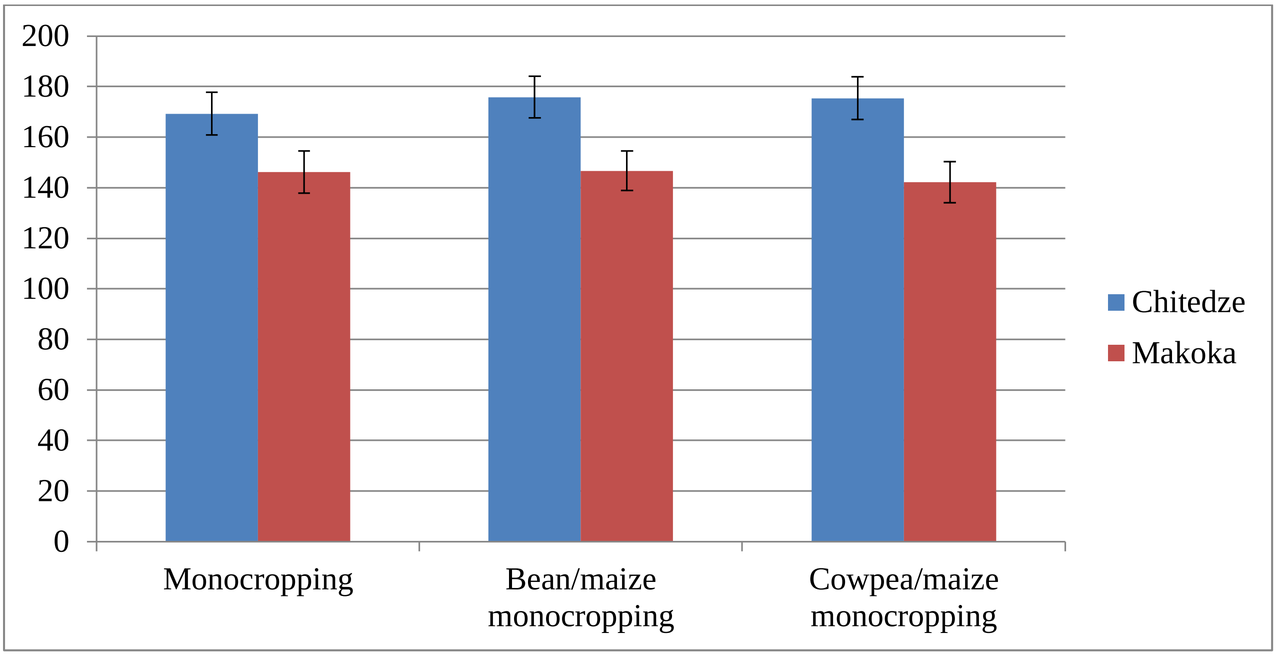
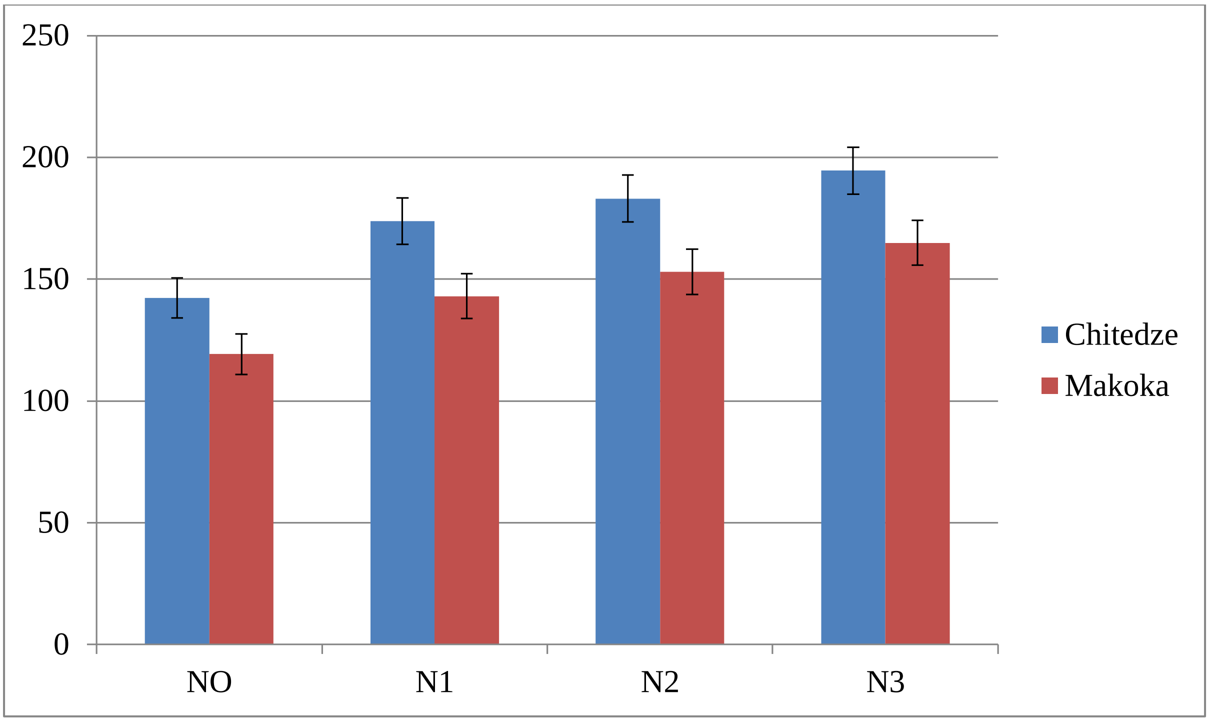


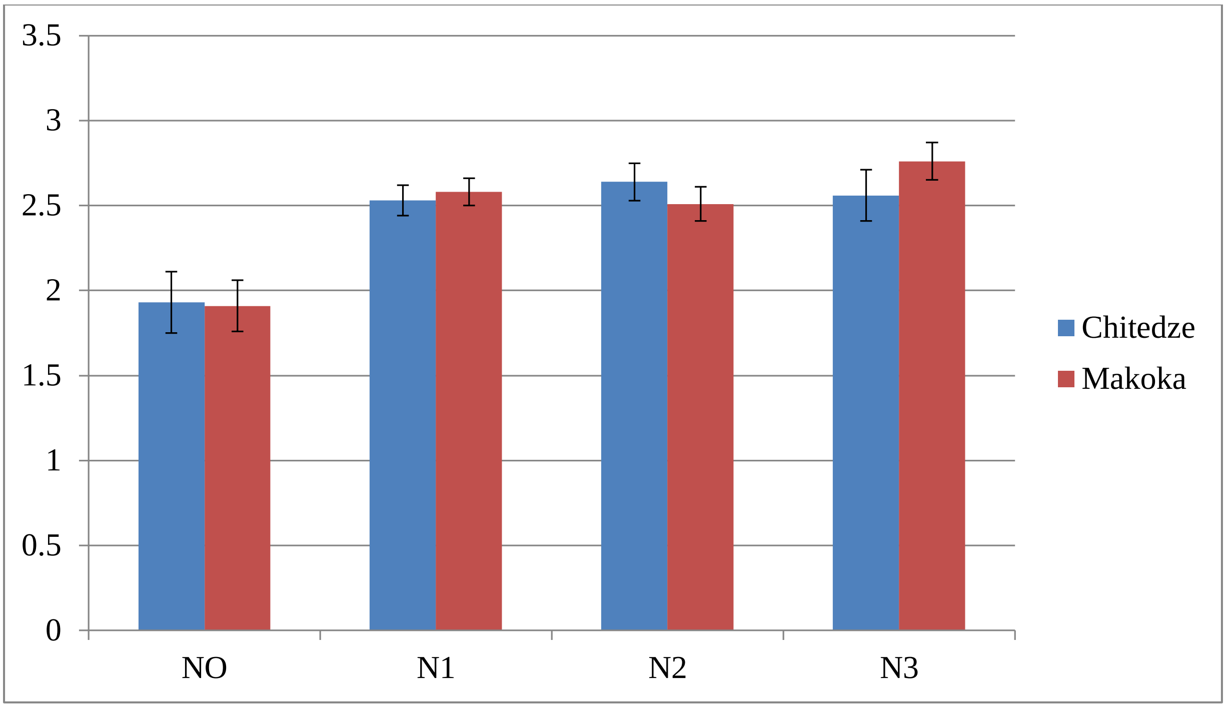
Figure 11: Effect of the interaction between cropping systems and location on maize height in cm

The effect of interaction between nitrogen levels and location was not significant for maize height (Figure 12) but was only significant for LAI (Figure 13). Significantly higher values were obtained in the combination between N3 level of nitrogen and Makoka Research Station site.



Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}.

Figure 12: Effect of the interaction between nitrogen levels and location on maize height in cm



Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}.

Figure 13: Effect of the interaction between nitrogen levels and location on maize leaf area index

The interactive effect of cropping system, level of nitrogen and location was significant ($P<0.05$) for both maize height (Figure 14) and LAI (Figure 15). Significantly higher values were observed under the treatment combination of cowpea/maize intercropping system, N3 level of nitrogen and Chitedze Research Station site while significantly lower values were obtained under the treatment combination of cowpea/maize intercropping system, N0 level of nitrogen and Makoka research station site. On the other hand significantly higher LAI values were observed under the treatment combination of maize monocropping system, N3 level of nitrogen and Makoka research station site. Significantly lower values were recorded under the treatment combination cowpea/maize intercropping system, N0 level of nitrogen and Makoka Research Station. The effects of interactions between time and location, time and nitrogen levels, time and cropping systems on maize height were not significant ($P<0.05$) (Table 10).

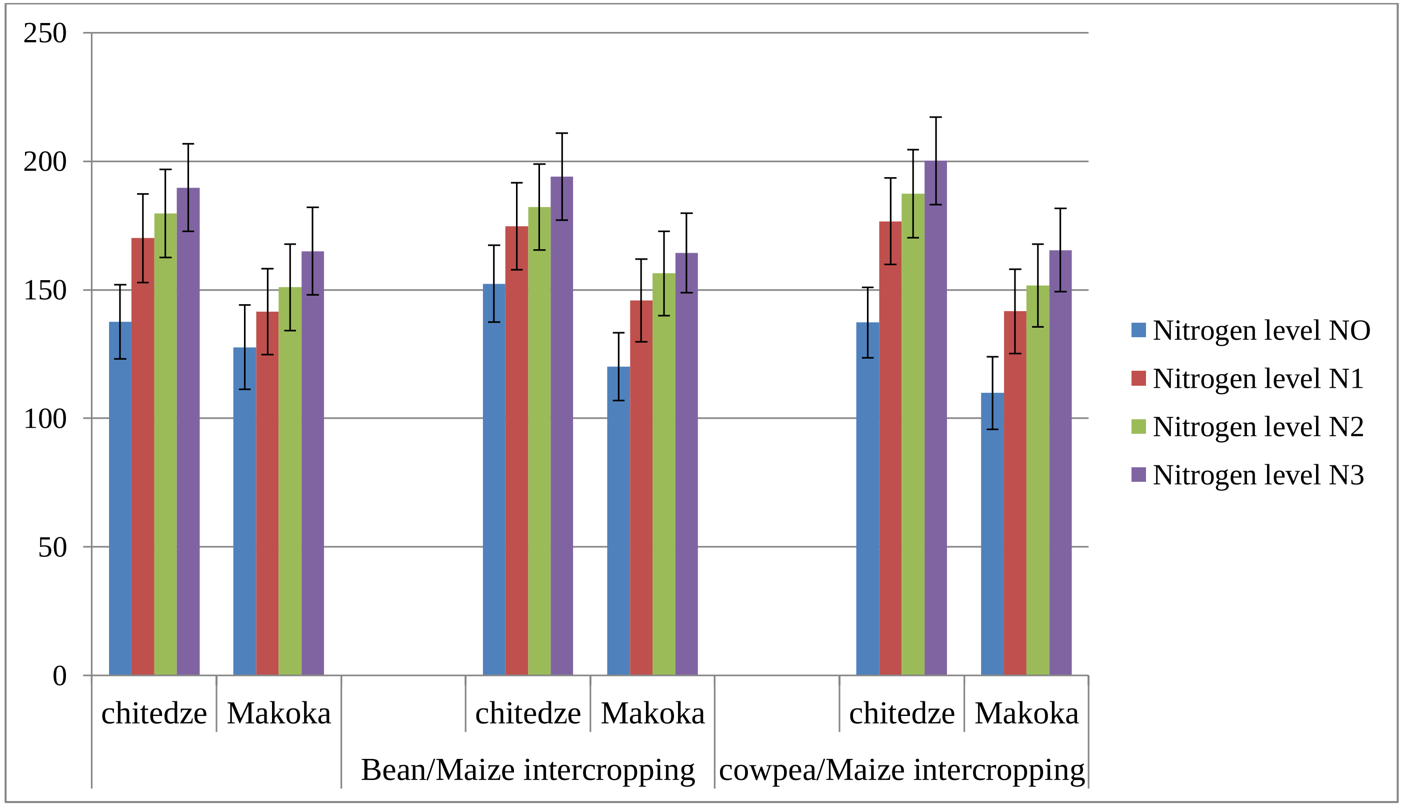
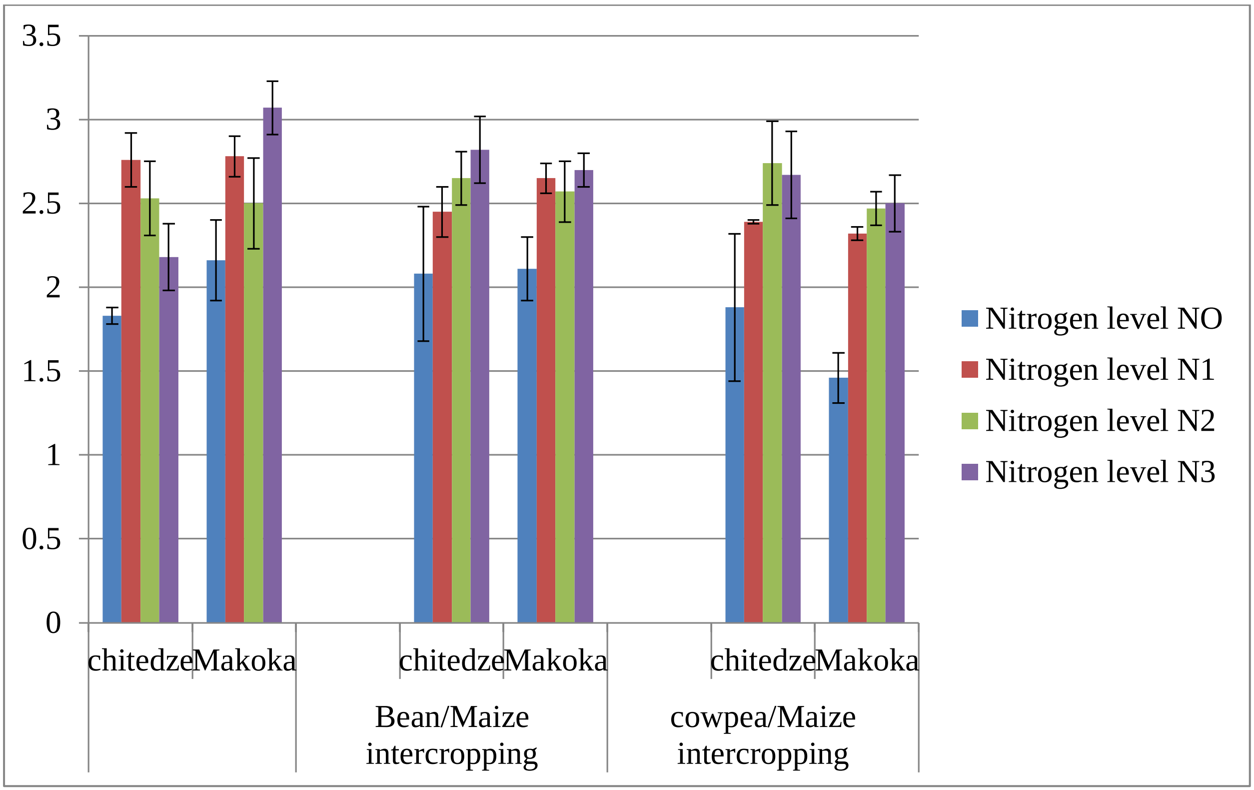


Figure 14: Effect of interaction between cropping system, nitrogen level and location on maize height in cm



Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}.

Figure 15: Effect of interaction between cropping system, nitrogen level and location on leaf area index

Table 10: Interactive effect of time and location nitrogen levels and cropping systems on maize height (means ± std. error)

N level	Weeks	Height(cm)	Cropping system	Weeks	Height(cm)	Location	Weeks	Height(cm)
N0	4	41.69±2.49	**maize monocropping**	4	50.44±2.85	Chitedze	4	61.03±2.24
	6	107.11±6.85		6	131.80±6.93	Makoka		50.44±2.07
	8	148.63±4.76		8	185.71±5.64	Chitedze	6	161.28±3.81
	10	171.35±5.30		10	207.29±4.56	Makoka		107.05±3.75
	12	185.30±5.59		12	213.67±4.29	Chitedze	8	204.05±4.38
N1	4	51.65±2.07	**bean/maize intercropping**	4	58.94±2.42	Makoka		168.89±4.46
	6	130.78±7.63		6	137.50±6.49	Chitedze	10	217.30±4.36
	8	185.86±5.75		8	187.33±6.37	Makoka		194.12±3.88
	10	206.20±3.63		10	206.81±5.22	Chitedze	12	223.83±4.21
	12	217.57±2.89		12	215.65±5.04	Makoka		204.68±3.73
N2	4	59.82±1.95	**cowpea/maize intercropping**	4	57.82±3.02			
	6	141.09±7.67		6	133.19±8.37			
	8	198.48±5.14		8	186.36±7.56			
	10	216.20±3.42		10	203.03±6.84			
	12	224.72±3.44		12	213.46±6.34			
N3	4	69.77±2.36						
	6	157.68±6.88						

Table 10 continued

8	212.90±4.22
10	229.08±3.29
12	229.44±5.51

Key: N0 = 0 kg N ha^{-1}, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1}, N3 = 105 kg N ha^{-1}**.**

4.5 Effect of cropping system, nitrogen level, location and their interaction on legume grain yield, legume biomass, weight of nodules and number of nodules.

The main effect cropping systems on legume grain yield, DM yield, and weight of nodules and number of nodules was significant ($P<0.05$). The results in Table 11 indicate that significantly higher values of legume grain yield DM yield and weight of nodules were obtained under sole cowpea while significantly higher values of number of nodules were recorded under sole bean and bean/maize intercropping. On the other hand significantly lower values of legume yield, and DM yield were recorded under bean/maize intercropping system while significantly lower values of number of nodules were recorded under sole cowpea.

From the same table the main effect of location was significant ($P<0.05$) for DM yield, and number of nodules. It was, however, not significant for legume yield and nodule weight. Significantly higher number of nodules were reported at Chitedze Research Station. On the other hand significantly higher values of DM yield were recorded under Makoka Research Station site (Table 11).

The interactive effect between cropping systems and levels of nitrogen was significant ($P<0.05$) on legume grain yield, DM yield, weight and number of nodules (Table 12). Significantly higher values were obtained under the following treatment combinations: cowpea/maize intercropping and N0, cowpea/maize intercropping and N3, cowpea/maize intercropping and N3, and bean/maize intercropping and N1, respectively. On the other hand significantly lower values were obtained under the following treatment combinations; bean/maize intercropping system and N0, bean/maize intercropping system and N2, bean/maize intercropping system and N0, and cowpea/maize intercropping and N2 for legume yield, DM, weight and number of legumes, respectively (Table 12).

The effect of interaction between cropping system, nitrogen level and location was significant ($P<0.05$) on legume yield, dry matter and weight of nodules (Table 13). From the same table it was observed that the interaction was significant under cowpea/maize intercropping and it was not significant under bean/maize intercropping system. The interactions that produced significantly higher values of legume yield, DM, weight and number of nodules were observed under the following treatment combinations; cowpea/ maize intercropping, N0 and Makoka Research Station site, cowpea/ maize intercropping, N3 and Makoka Research

Station site, bean/maize intercropping, N3 and Chitedze research station site, and cowpea/ maize intercropping, N3 and Chitedze Research Station site

The effect of the interaction between cropping system and location was significant for legume grain and DM yield (Table 14). The results indicated that significantly higher values of legume yield and number of nodules were obtained under the treatment combination of cowpea/maize intercropping system and Chitedze Research Station site and sole cowpea and Makoka Research Station site respectively (Table 14). From the same table significantly higher values for weight of nodules and number of nodules were obtained under the following treatment combinations; sole cowpea and Makoka research station site and cowpea/maize intercropping and Chitedze Research Station site respectively.

The interaction between nitrogen levels and location was significant for legume yield, DM yield and weight of nodules (Table 14). Significantly higher values were obtained under the following treatment combinations; N0 level of nitrogen and Chitedze Research Station site, N3 level of nitrogen and Makoka Research Station site and N3 level of nitrogen and Chitedze Research Station site.

Table 11: Effect of Nitrogen level, cropping system and location on legume yield, dry matter, weight of nodules and number of nodules

Treatments	Legume grain yield (Mt/ha)	Legume DM yield (Mt/ha)	Weight of nodules (g/plant)	Number of nodules/plant
Nitrogen Level				
N0	1.12abc	1.00a	7.08a	14.58a
N1	0.89bc	1.05a	7.77a	12.08a
N3	0.78bc	1.16a	8.96a	13.75a
N2	0.68c	0.93a	7.24a	9.08a
Cropping system				
Sole cowpea	1.76a	2.66a	25.88a	5.66c
Sole bean	1.42ab	1.75b	10.72b	26.33a
cowpea/maize intercropping	1.07bc	1.26c	8.12b	7.33bc
bean/maize intercropping	0.66c	0.81d	7.41b	17.41ab
Location				
Chitedze	0.97a	0.98b	9.74a	19.40a
Makoka	1.05a	1.56a	10.00a	6.80b

Note: Means with the same letter within a column are not significantly different ($P<0.05$) according to Duncan test

Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1} , N2 = 78.75 kg N ha^{-1} , N3 = 105 kg N ha^{-1},

Table 12: Effect of the interaction between cropping systems and levels of nitrogen on legume yield, dry matter and weight and number of nodules (means ± std. error)

Cropping System	Nitrogen Level	Legume Yield (Mt/ha)	Dry Matter Yield(Mt/ha)	Weight of Nodules(g/plant	Number of Nodules/plant
bean/maize intercropping	N0	0.59±0.13	0.83± 0.08	6.48±0.48	18.83±6.54
	N1	0.80±0.09	0.87± 0.17	7.29±1.17	19.00±6.10
	N2	0.59±0.15	0.65± 0.09	7.21±1.39	13.67±2.74
	N3	0.68±0.09	0.88±0.16	8.65±1.18	18.17±10.84
cowpea/maize intercropping	N0	1.66±0.80	1.17± 0.24	7.69±1.15	10.33±1.36
	N1	0.99±0.16	1.4± 0.22	8.25±1.16	5.17±0.65
	N2	0.77±0.16	1.21± 0.31	7.27±1.82	4.50±0.89
	N3	0.87±0.13	1.45± 0.29	9.28±1.27	9.33±5.94

Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1} , N3 = 105 kg N ha^{-1},

Table 13: Effect of interaction between cropping system, nitrogen level and location on legume yield, dry matter weight and number of cobs (means ± std. error)

Cropping System	**Nitrogen Level**	**Location**	**Legume Yield (Mt/ha)**	**Dry matter(Mt/ha)**	**Weight of nodules (Mt/plant)**	**Number of nodules/plant**
bean/maize intercropping	N0	Chitedze	0.53±0.05	0.94±0.04	6.48±0.29	31.00±7.94
		Makoka	0.64±0.27	0.72±0.13	6.47±1.03	6.67±1.67
	N1	Chitedze	0.77±0.14	0.86±0.15	7.38±0.58	32.00±4.04
		Makoka	0.83±0.14	0.88±0.34	7.19±2.55	6.00±1.00
	N2	Chitedze	0.69±0.28	0.76±0.09	9.06±0.97	19.67±0.88
		Makoka	0.49±0.14	0.55±0.15	5.37±2.31	7.67±0.88
	N3	Chitedze	0.82±0.07	0.83±0.19	10.73±1.58	31.33±20.34
		Makoka	0.55±0.14	0.94±0.31	6.57±0.29	5.00±0.58
cowpea/ maize intercropping	N0	Chitedze	0.50±0.07	0.89±0.23	6.48±1.76	10.33±1.86
		Makoka	2.82±1.36	1.44±0.41	8.89±1.43	10.33±2.40
	N1	Chitedze	0.98±0.36	0.85±0.19	7.94±1.96	5.00±1.15
		Makoka	1.00±0.03	1.62±0.26	8.55±1.69	5.33±0.88
	N2	Chitedze	0.71±0.33	0.66±0.06	8.50±3.28	3.33±0.67
		Makoka	0.83±0.12	1.75±0.44	6.04±2.07	5.67±1.45
	N3	Chitedze	0.90±0.20	1.10±0.15	8.16±1.17	14.67±12.17
		Makoka	0.85±0.22	1.79±0.53	10.39±2.34	4.00±0.00

Key: N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1}, N2 = 78.75 kg N ha^{-1} , N3 = 105 kg N ha^{-1}

Table 14: Effect of the interactions between cropping systems and location, nitrogen levels and location on legume yield, dry matter, number and weight of nodules (means ± std. error)

Treatments	**Location**	**Legume Yield(Mt/Ha)**	**Dry matter (Mt/Ha)**	**Weight of nodules(Mt/plant)**	**Number of Nodules/plant**
Cropping System					
bean/maize intercropping	Chitedze	0.70±0.08	0.84±0.06	8.41±0.65	28.50±4.98
	Makoka	0.63±0.09	0.77± 0.12	6.40±0.79	6.33±0.56
cowpea/maize intercropping	Chitedze	0.77±0.13	0.88± 0.09	7.77±0.96	8.33±2.97
	Makoka	1.37±0.39	1.65± 0.18	8.47±0.94	6.33±0.96
cowpea monocropping	Chitedze	1.97±0.22	1.84± 0.39	17.67±2.42	5.67±3.18
	Makoka	1.54±0.33	3.47±1.00	34.10±22.99	5.67±1.76
bean monocropping	Chitedze	1.85±0.24	1.11±0.08	14.98±1.94	41.00±13.89
	Makoka	0.99±0.05	2.39±0.83	6.46±0.65	11.67± 2.40
Nitrogen level					
N0	Chitedze	1.97±0.22	0.92±0.11	6.48±0.80	20.67±5.89
	Makoka	1.54±0.33	1.08±0.25	7.68±0.96	8.50±1.54
N1	Chitedze	1.85±0.24	0.86±0.15	7.66±0.92	18.50±6.32
	Makoka	0.99±0.05	1.25±0.25	7.87±1.40	5.67±0.61
N2	Chitedze	0.52±0.04	0.71±0.05	8.71±1.53	11.50±3.69
	Makoka	1.73±0.79	1.15±0.34	5.70±1.39	6.67±0.88
N3	Chitedze	0.88±0.18	0.97±0.18	9.45±1.05	23.00±11.24
	Makoka	0.91±0.07	1.36±0.33	8.48±1.36	4.50± 0.34

Key: N0 **=** 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha^{-1} , N2 = 78.75 kg N ha^{-1} , N3 = 105 kg N ha^{-1},

4.6 Yield advantages

The relative yield advantage of intercropping as expressed by Land Equivalent Ratio (LER) was 56% in maize-cowpea and 39% in maize-beans over their relative sole crops (Table 15). The partial LER of legume was lower in maize/bean intercropping system as compared to maize/cowpea intercropping system.

Table 15: Land Equivalent Ratio (LER) of the cropping systems

Cropping system	Yield (Mt/ha)	LER
Sole cropping		
Sole maize	4.47	
Sole cowpea	1.76	
Total	6.23	
Maize/Cowpea intercropping		
Maize	4.23	0.95
Cowpea	1.07	0.61
Total	5.3	1.56
Sole cropping		
Sole maize	4.47	
Sole bean	1.42	
Total	5.89	
Maize/ Bean intercropping		
Maize	4.16	0.93
Bean	0.66	0.46
Total	4.82	1.39

4.7 Nutrient Use Efficiency (NUE) of Maize

The results in table 16 indicate that N2 (78.75 kg N ha^{-1}) has the highest nitrogen use efficiency followed by N1 (52.5 kg N ha^{-1}) and N3 (105 kg N ha^{-1}) in that order.

Table 16: Nutrient Use Efficiency of maize at different nitrogen levels

Nitrogen level	Maize yield(Mt/ha)	NUE (kg/kg)
N0	1.54	
N1	3.99	46.67
N2	5.37	48.63
N3	6.25	44.86

CHAPTER FIVE

DISCUSSION

5.1 Main effects of cropping system, nitrogen level, location on maize yield, dry matter yield, weight of cobs and weight of 100 maize seeds.

N fertilizer application (52.5, 78.75 and 105 kg N ha^{-1}) resulted in significant increases in maize grain and DM yield and cob weight compared to control (no fertilizer). Nitrogen is a critical macronutrient for the growth of maize and its application enhances vigorous vegetative growth (Havlin *et al*., 2008). Many authors including Sebetha (2015), Abayomi *et al*. (2006), Mahdi and David (2005), Morgado and Willey (2003) and Muchow (1988), similarly reported that application of N fertilizer generally resulted in increases in maize grain yield. Significant increases in maize and DM grain yields and cob weight occurred with increase in N level, from 0 to 105 kg N ha^{-1}, an indication that application of 105 kg N ha^{-1} was optimal for maximum yield per unit area. Elevated N concentration results to healthier plant growth (Legg *et al*., 1979; Meisinger *et al*., 1985). The reduction in maize grain and DM yield under maize without N fertilizer is in agreement with the findings of Ding *et al.* (2005) and Lucas (1986).

The effect of cropping system was significant for maize DM yield. Higher means were obtained in bean maize intercropping and maize monocropping system. The high DM yield under sole maize could be attributed to absence of competition for resources such as light, nutrients and water (Ndakidemi, 2006). Legwaila *et al*. (2012) similarly reported that sole maize produced significantly higher DM yield than maize intercropped with cowpeas. Higher maize DM yield in bean intercropping than cowpea intercropping might have been due to differences in the depth of roots, lateral root spread and root densities, factors that affect competition between the component crops in an intercropping system for nutrients (Eskandari and Ghanbari, 2009).

Maize grain yields were not significantly increased by inclusion of bean and cowpea. Maize has a C4 carbon assimilation pathway and may have had a competitive edge over legumes, which are C3 plants (Kitonyo *et al.*, 2013; Sage and Zhu, 2011). In addition, maize was more competitive for soil nitrogen because its roots are distributed in both shallow and deeper layers (Carruthers *et al*., 2000). This is in contrast to the root systems of legumes which are smaller and confined to the upper layers (Hauggaard-Nielsen *et al*., 2001). Contrarily, most studies report that intercropped systems yield more than maize monocropping due to the ability of intercropped legumes to fix most of their nitrogen from the atmosphere (Chabi-Olaye *et al*., 2005; Hauggaard-Nielson, 2001). Common beans are, however, poor N fixers, in comparison to other legumes; hence they do not contribute significantly towards the N requirement by maize (Westermann *et al*., 1981, Bliss, 1993; Martinez-Romero, 2003). Mineral nitrogen may have reduced the rate of nitrogen fixation by cowpea in this study (Houwaard, 1979).

Results showed significantly higher maize grain yield, weight of cobs and 100 seeds weight at Chitedze than Makoka research site. This may be attributed to lower rainfall amounts and higher temperature at Makoka. The optimal temperature for warm season maize is 15−20 °C for planting and 20−30 °C for the regular growing season (Bird *et al*., 1977). The temperature range for Makoka during the growing season was 17.84- 28.06 ^{0}C (Table 1). The higher temperature led to higher rates of evapotranspiration and therefore increased competition for moisture (Ben-Asher *et al*., 2008). Water forms an integral part of plant body and plays an important role in growth initiation, maintenance of developmental process of plant life and hence has pivotal function in crop production (Aslam *et al*., 2013).

5.1.1 Interaction effects of cropping system, nitrogen level, location on maize yield, dry matter yield, weight of cobs and weight of 100 maize seeds

The interaction effect of cropping system × N level on maize DM yield, weight of cobs and weight of 100 seeds was significant. Significantly higher values were observed with application of N3 fertilizer level in maize monocropping, bean/maize intercropping system and cowpea/maize intercropping systems, respectively. The optimum values of the above mentioned yield parameters were observed with application of 105 kg N ha^{-1} than 78.75 and 52.5 kg N ha^{-1}. The increase in DM yield, weight of cobs and weight of 100 seeds with increasing N levels might be attributed to the fact that nitrogen plays a significant role in various physiological operations of maize. It extends the leaf area effectively, delays senescence and is essential for initiation of ear and kernel. Further, proper nitrogen supply also defines maize sink capacity (Torbert *et al*., 2011). It maintains functional kernels throughout grain filling and affects the number of developed kernels and final size of kernel (Hopf *et al*., 1992; John and Schmitt, 2007). The influence of N availability on essential agronomic traits of maize has been described by several investigators (McCullough *et al*., 1994; Evans, 2008). Among the various major nutrients required for proper plants, nitrogen has a key role and particularly it has been proven for maize by various experiments (Subramanian *et al*., 2006; Carpici *et al*., 2010).

On the other hand, studies have shown that common bean is a poor fixer of N and that there is usually a positive yield response when N fertilizer is applied (Henson and Bliss, 1991; Martinez-Romero, 2003). The high N requirement under cowpea/maize intercropping might be attributed to the competition for resources between maize and cowpea.

The interaction effect of cropping systems × N level was not significant for maize grain yield. This may possibly have been due to inhibition of symbiotic nitrogen fixation by the legumes due the application of N fertilizer (Erker and Brick, 2014). This is in agreement with Omokanye *et al*. (2013) who reported that the interaction effect of cropping system x nitrogen levels on maize grain yield was not significant.

The weight of cobs and DM yield were significantly affected by cropping system × location interaction. Significantly higher cob weight and DM yield was observed under bean/maize intercropping system at Chitedze than Makoka research station because of better climatic conditions and soil structure. Maize DM yield was significantly lower under the treatment combination of cowpea/maize intercrop and Makoka research station because there was more competition from cowpea for resources such moisture due to lower rainfall received than at Chitedze.

The results also indicated that maize grain and DM yield and 100 seed weight were not significantly affected by the interaction between cropping system × location because maize faced stiff competition for resources from legumes. These findings are contrary to the findings of Sebetha (2015) who reported that the interaction had a significant effect on maize DM yield and 100 seed weight.

Weight of cobs was significantly higher under N3 level at Chitedze because of its good climatic conditions and soil structure. The significantly lower cob weight when nitrogen level was N0 at Makoka research station was because of the poorer climatic conditions and soil structure and low soil nitrogen.

Weight of cobs and weight of 100 seeds of maize were significantly affected by the interaction effect of nitrogen levels × cropping systems ×location. Cob weight was significantly higher in bean/maize intercropping system, N3 nitrogen level, followed by N2 and N1 at Chitedze research station. Good climatic factors, N availability from fertilizer and better soil structure might be the contributing factors to these findings. It was significantly lower in N0 under bean/maize intercropping at Makoka research station. This was due to poor soil structure at Makoka and that N is a critical macronutrient for plant growth, development and yield. The significantly higher values for weight of 100 maize seeds were obtained under cowpea/maize intercropping, N3 and Chitedze Research Station followed by bean/maize intercropping system, N3 and Chitedze research station was because of the good climatic and soil factors at Chitedze and that N is a critical macronutrient for plant growth, development and yield. The interaction effect of cropping system x location x nitrogen level on both maize grain yield and DM matter was not significant. These findings suggest that cropping system did not influence dry matter accumulation. This finding is not in agreement with Sebetha (2015), who reported the significance of the interaction on maize grain yield.

5.2 Main effects of cropping system, nitrogen level, and location on nitrogen uptake by maize.

The results indicated that an increase in N uptake by maize occurred with increasing rates of N fertilizer applied. The maximum value (198.15 mg-N/plant) was recorded with the highest N fertilizer level (105 kg N ha^{-1}) while the lowest (56.05 mg-N/plant) at zero fertilizer rate. Rahman (2011) and Morgado and Willey (2003) similarly reported that N uptake by maize plant was influenced significantly by N fertilizer application rate. They reported lowest uptake in control (no N fertilizer) treatment. Chirnogeanu *et al.*, (1997) also documented that high levels of soil nitrogen had a significant positive influence on the nutrient uptake and translocation in leaves. Thus, the N content in maize plants increased in variation with high fertilizer rates.

The results of this study indicated that there were no significant differences in nutrient uptake by maize in the different cropping systems. Common bean being a poor N fixer did not supply enough N to be taken up by both the legume and the cereal crop involved. Application of nitrogen fertilizer might have hindered symbiotic nitrogen fixation by cowpea (Henson and Bliss, 1991; Erker and Brick, 2014). Contrarily, Eskandari and Ghanbari (2009) reported significantly greater nitrogen uptake in intercropping than sole maize. They reported that intercropping was more efficient at exploiting a larger soil total volume if component crops have different rooting habits, especially depth of rooting.

Nitrogen uptake by maize was significantly greater at Chitedze than at Makoka research station. This difference may be attributed to the differences in total soil N at the sites. The levels at Chitedze and Makoka were medium (0.20%) and low (0.10%), respectively (Table 1), according to the nutrient classification of Landon (1991).

5.2.1 Interaction effects of cropping system, nitrogen level, location on nitrogen uptake by maize

The effect of cropping system × N level interaction on N uptake by maize was significant. Significantly higher N uptake by maize was observed in the bean/maize intercropping system than cowpea/maize intercropping under N3 level of N, in both cropping systems, and maize monocropping combined with nitrogen levels of N1 and N2. This might have been due to enhanced supply of nitrogen from fertilizer. Additionally, there may have occurred greater exploitation of a larger soil total volume for nutrients and water due to different rooting habits of the component crops in an intercropping system.

The effect of cropping systems × location interaction on N uptake in maize was significant only under maize monocropping system. The higher uptake in maize monocropping system at both Chitedze research station than Makoka research station at both sites was because the maize did not face competition for nutrients from legumes, as they were sole crops.

N uptake by maize was not significantly affected by the interaction of nitrogen levels × location. It is possible that this finding might be influenced by the location conditions such as moisture, soil aeration, soil drainage and soil textures which have an impact on N-transport and N -transformation processes that limit N availability to crops or lead to losses such as through leaching.

The nitrogen level × cropping system × location interaction effect on N uptake by maize was significant. The higher uptake under combination of maize monocropping system, N3 level of nitrogen at Chitedze research station was because sole maize did not have any competition from legumes for resources such as nutrients. N uptake was significantly lower under cowpea/maize intercropping system combined with N0 level of nitrogen at Makoka Research Station. It is possible that maize suffered stiff competition for resources from legumes.

5.3 Main effects of cropping system, nitrogen level, location on maize height and leaf area index

Nitrogen application increased maize height compared to control. This might be attributed to N being a critical macronutrient for plant growth and development. This finding is supported by Hussain *et al*. (2003) who reported that N fertilizer application increased maize height. The results indicated that the maximum plant height (179.78 cm) was obtained with the highest N level (105 kg N ha^{-1}), while the least value (130.82 cm) was recorded at zero N application. Increase in plant height in response to higher N levels could be attributed to more biomass produced which in turn brought an increase in internodal extension and reciprocal shading and hence the taller plants (Niaz *et al*., 2014). Increase in plant height might also be attributed to prolonged vegetative growth which increased the plant height. Thakur *et al*. (1997) suggested that higher N application increased cell division, cell elongation, nucleus formation as well as green foliage. Taller maize provides a better advantage of trapping more solar radiation, than the intercropped legumes, which is very critical for the growth and development of the crop (Thwala and Ossom, 2004). These results concur with the findings of both Gozubenli (1997) and Tufekci (1999) who reported increases in maize height when rates of N were increased. Similar findings were also reported by Sahoo and Panda (2009) who reported that plant height increased gradually with increasing the nitrogen levels.

It was expected in this study that maize height would be higher under intercropping systems, due to soil improvement by cowpea and beans, and lower under monocropping because of depletion of soil fertility. This was, however, not the case. Maize height obtained under monocropping was not significantly different from the intercropping systems. This may be attributed to the competition for space, water, sunlight and nutrients due to increased plant density in the intercropping systems. These findings concur with the findings of Lemlem (2013), who reported no difference in plant height for sole maize and maize-cowpea intercropping.

Maize plant height was significantly affected by location. Maize planted at Chitedze was significantly taller (173.50 cm) than at Makoka (145.04 cm). The differences could be attributed to variations in both climatic and environmental factors such as higher temperature and limited moisture in Makoka. The high temperature could have resulted in high evaporation, which eventually led to more competition for water between crops. The findings also concur with the results documented by Thobatsi (2009).

Maize supplied with N fertilizer had significantly larger LAI than maize without N fertilization. This is attributed to role of N in enhancing rapid vegetative growth and its direct involvement in cell division (Adeleke and Haruna, 2012). The increased LAI with increasing nitrogen application rates might be due to the effect of nitrogen on the rate of growth of meristem and the appearance and development of leaves (Ahmad *et al*., 1993).

The main effects of cropping system and location on LAI were not significant. Thobatsi (2009) reported no significant differences in LAI between cowpea/maize intercrop and sole maize cropping systems, which agrees with findings of this study. This may be due to suppression by legumes as they are robust and vigorously twining herbaceous plant and so easily outgrows other plants in competition for plant growth factors (Andrea and Pablo, 1999). Studies conducted by Thobatsi (2009) and Sebetha (2015) reported that leaf area index of maize was significantly affected by location and cropping system, contrary to the results of this study. This may be attributed to lower nutrients availability in the soil fixed by the legumes because of the legumes' rhizobium association property was minimal as the legumes were not inoculated with rhizobium.

5.3.1 Interaction effects of cropping system, nitrogen level, location on maize plant height and LAI

Maize height was significantly affected by the interaction of cropping system × levels of N. Significantly higher maize height was observed under cowpea/maize intercropping system and N3 nitrogen level than under the same cropping system with N0 nitrogen level. The increase in maize height with application of nitrogen fertilizer was due to better vegetative development. N has an important role in plant growth as it is present in the structure of protein and nucleic acids, which are the most important building and information substances of every cell. So N supply to the plant will influence the amount of protein, amino acids, protoplasm, and chlorophyll formed which in turn influences cell size, leaf area, and photosynthetic activity (Sharifi and Namvar, 2016).

Maize height was significantly affected by the interaction of cropping system ×location × levels of N. Significantly higher values were observed under the treatment combination of cowpea/maize intercropping system, N3 level of nitrogen and Chitedze research station site while significantly lower values were obtained under the treatment combination of cowpea/maize intercropping system, N0 level of nitrogen and Makoka research station site. It is possible that these differences may be due to changes in environmental conditions and differences in N uptake in these two locations.

The effect of interactions between time × location, time × nitrogen levels, time × cropping systems on maize height were not significant. These findings might be attributed to variations in environmental factors in the study sites (locations). Environmental factors such as temperature, moisture supply, soil aeration and soil structure, soil reactions, biotic factors and absence of growth-restricting substances can be a limiting factor affecting plant growth hence affecting maize plant height. Previous studies conducted (Sebetha 2015) reported that maize plant height was significantly affected by the interaction of location x season, and nitrogen x season.

Interactions between nitrogen level × cropping system had a significant effect on LAI. The LAI values were significantly higher under combination of intercropping systems (bean/maize intercropping and cowpea/maize intercropping) and all levels of nitrogen and not significant in maize monocropping and all levels of nitrogen. This could be due to superior cell expansion, more rapid cell division and parallel augmented photosynthate construction with increment in mineral N fertilizer rates, which in turn increases LAI (Niaz *et al.*, 2014). This is in agreement with the findings of researchers (Amanullah and Shah, 2008; Amanullah *et al.*, 2009).

The effect of interaction between nitrogen levels × location was also only significant for LAI but not maize height because of the improvement in light interception with increased levels of mineral N which resultantly improves LAI. Significantly higher LAI mean values were obtained in the combination between N3 level of nitrogen and Makoka Research Station site because increment in mineral N fertilizer levels has been ascribed to superior cell expansion, more rapid cell division and parallel augmented photosynthate construction which consequently leads to increment in LAI (Niaz *et al.*, 2014).

The interactive effect of cropping system× level of nitrogen ×location was significant ($P<0.05$) for LAI. Significantly higher LAI values observed under the treatment combination of maize monocropping system, N3 level of nitrogen and Makoka research station site was because of the absence of competition for available resources from legumes. Significantly lower values recorded under the treatment combination cowpea/maize intercropping system, N0 level of nitrogen and Makoka research station was because the cowpea under intercropping offers more competition for available resources.

These findings concur with the findings of Sebetha (2015) who reported that maize leaf area index was significantly affected by the interaction cropping system x site x nitrogen.

5.4 Main effects of cropping system, nitrogen level, location on legume grain yield, legume biomass, weight of nodules and number of nodules.

The main effect of cropping system on legume grain yield, DM yield, and weight of nodules and number of nodules was significant. Higher values of legume DM yield were reported under sole cowpea (2.66 Mt/ha) and sole bean (1.75Mt/ha) while lower values were obtained under cowpea/maize intercropping (1.26Mt/ha) and bean/maize intercropping system (0.81Mt/ha). Legume grain yield was also significantly higher under sole crops. These findings might be attributed to the well-known idea that cereals take up nutrients, especially N, mainly during the vegetative growth stage and associated vigorous growth may cause shading of the legume and thereby reduce its growth during later growth stages resulting in low yielding ability (Banik *et al*., 2006). The yield advantage observed in the legume sole crops than intercrops may be attributed to the absence of competition from other crops. These results are supported by the findings of Birteeb *et al*., (2011) who reported significantly reduced legume DM yield of intercropped legumes.

The higher yield of cowpea planted solely than intercropped cowpea confirms the findings of Van Kessel and Roskoski (1998) that yield of intercropped cowpea was less than half that of monocropping cowpea at the same row spacing. Cowpea could not maintain its yield potential when intercropped with maize. Chemeda (1997) also reported significantly higher values of legume grain yields under sole cowpea compared to cowpea intercrop and this observation was attributed to competition for water, nutrients and shading under maize plants in the intercropping system. The reduction in intercropped bean yield observed in this study is in agreement with the findings of Alhaji (2008) who reported reduction in legume yield due to high maize density in the intercropping system.

The main effect of N level on legume grain yield, DM yield, and weight of nodules and number of nodules was not significant. These findings may be attributed to the fact that application of mineral nitrogen reduces both nodulation and the rate of nitrogen fixation by legumes (Houwaard, 1979). These findings are in agreement with the findings of Bagayoko *et al*. (1996) who observed that cowpea grain and DM yield were not influenced by N application. Legume grain yield and number of number of nodules per plant were higher under N0 (0 kg N ha^{-1}) than 52.5, 78.75 and 105 kg N ha^{-1}, however, they were not significantly different from the parameters obtained under 0 kg N ha^{-1}. It was expected that legume grain yield, DM yield, and weight of nodules and number of nodules under N fertilizer application would be lower than the control since N fertilization has a negative effect of legume growth, development and yield.

Legume DM yield was significantly affected by location. Legume DM yield was higher at Makoka than at Chitedze. It was also observed that the number of nodules per legume plant was affected by the location of the study site. Legumes planted at Chitedze Research Station had significantly higher number of nodules per plant (19.40) than at Makoka (6.80). This may be attributed to different soil properties and climatic conditions of these two sites. On the other hand N fertilizer application has a well-established negative effect on nitrogen fixation of legume root nodules. It is also reported that with increasing doses of N there is a nearly linear decrease in the number of root nodule (Becker *et al*., 1986). This finding concurs with what Sebetha (2015) observed. He reported that number of nodules per cowpea plant was affected by location. The effect of location on number of number nodules can be attributed to fluctuations in pH, nutrient availability, temperature, and water status, among other factors that greatly influence the growth, survival, and metabolic activity of nitrogen fixation bacteria and plants, and their ability to enter into symbiotic interactions (Werner and Newton, 2005).The results on the number of nodules per plant concur with the ranges reported by Bhuvaneswari *et al*. (1998).

5.4.1 Interaction effects of cropping system, nitrogen level, location on legume grain yield, legume biomass, weight of nodules and number of nodules

Legume grain yield, DM yield, weight and number of nodules were significantly affected by the interaction effect of cropping systems × levels of nitrogen. With no nitrogen applied, the yields of beans in intercropping treatments were lower than their comparable sole crops. Thus under these low nitrogen conditions the beans suffered strong competition from the maize, an effect widely reported from most other cereal/legume studies. Findings of the study agree with the study of Sebetha (2015) who reported that the interaction of nitrogen and location significantly affected the number of nodules per cowpea plant. In addition common beans are poor N fixers, in comparison to other legumes; hence they do not contribute significantly towards the N requirement by maize (Westermann *et al*., 1981; Bliss, 1993; Martinez-Romero, 2003).

Significantly higher values were obtained under the following treatment combinations: cowpea/maize intercropping and N0, cowpea/maize intercropping and N3, cowpea/maize intercropping and N3, and bean/maize intercropping and N1, respectively. On the other hand significantly lower values were obtained under the following treatment combinations; bean/maize intercropping system and N0, bean/maize intercropping system and N2, bean/maize intercropping system and N0, and cowpea/maize intercropping and N2 for legume yield, DM, weight and number of nodules, respectively. This might be attributed to cowpea having a higher potential of fixing N from the atmosphere through biological nitrogen fixation than beans (Freitas *et al*., 2010).

The interaction effect of cropping system × location was significant for legume grain and DM yield. The results indicate that significantly higher values of legume yield and DM yield were obtained under the treatment combination of cowpea/maize intercropping system and Chitedze research station site and sole cowpea and Makoka research station site respectively. This might be attributed to good environmental factors present on both locations such conducive temperature, good moisture content and good soil structure which were conducive for the production of cowpeas. This is in agreement with what was reported by Sebetha (2015) that the interaction significantly affected legume grain yield. Legume yield, DM yield and weight of nodules were significantly affected by the interaction effect of nitrogen levels and location. These findings contributed to the significance of comparing cropping systems towards improvement of legume yields since such interaction effect on legume yield was not revealed during previous studies.

The interaction effect of cropping system, nitrogen level and location was significant on legume yield, dry matter and weight of nodules. The interaction was however significant for number of nodules per cowpea plant (cowpea/maize intercropping).This is in agreement with what was reported by Sebetha (2015) that the interaction significantly affected the number of nodules per cowpea plant.

5.5 Yield advantages

The land equivalent (LER) indices in maize/cowpea (1.56) and maize/bean (1.39) intercrops were higher than both sole cowpea and bean. The values indicate that for the same amount of grain yield,39 -56% more area would be required for solitary cropping system compared to intercropping. The LER values were greater than 1 showing the advantage of intercropping over sole cropping in regard to the use of environmental sources for plant growth (Yilmaz *et al*., 2008). The results mean that these two intercrops require relatively less area to match the average yields of the corresponding sole crops. It is clear from the results that these intercrops would be advantageous in areas where labour or land is a limiting factor. A LER greater than 1.0 has been reported with bean/maize intercropping (Latati *et al*., 2013). Partial LER values also showed that, compared to common bean, cowpea appeared to have more beneficial land use efficiency.

5.6 Nutrient Use Efficiency (NUE) of Maize

Maximum maize NUE (48.63 kg/kg) was obtained at application rate of 78.75 kg N ha^{-1} and the minimum value (44.86 kg/kg) was recorded at the highest N rate (105 kg N ha^{-1}). The decrease in NUE with increasing N fertilizer rate above N2 (78.75 kg N ha^{-1}) is because yield rises less than the N supply in soil and fertilizer (Lopez-Bellido and Lopez-Bellido (2001). Raun and Johnson (1999), Pierce and Rice (1988), Sowers *et al.*, (1994) and Zhao *et al.*, (2006) also reported that high rates of N decreased NUE in cereals. The findings of Kanampiu *et al.*, (1997) generally indicated decreases in NUE but increases grain protein content and N loss with increasing N fertilizer rate.

5.7 Correlation coefficients for agronomic traits of maize grown under monocropping and intercropping systems

Maize grain yield was positive and highly significantly correlated with Maize 100 seed weight ($r^2 = 0.83$, $P < 0.001$), DM yield ($r^2 = 0.83$, $P < 0.001$) and cob weight ($r^2 = 0.87$, $P < 0.001$). These findings are in agreement with the findings of Garba (2015), whose study showed that the results of correlation analysis indicated that that grain yield was positively and highly correlated with dry cob weight, 100 grain weight and stover yield. These findings might be attributed to the influence of rates of nitrogen fertilizer application. Similar findings have been reported by Thobatsi (2009) and Pearl (2012) who reported that 100 seed mass of maize was significantly correlated to maize grain yield. Nitrogen uptake is closely correlated with DM yield which may reflect on nutrient uptake ability of N for maize growth.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Diminishing land sizes, due to the ever increasing human population, and continuous cultivation practices have led to declining soil fertility and maize yield in Malawi. The study to determine effects of mineral N fertilizer application and legume integration on maize nutrient uptake and yield, demonstrated that;

1. N uptake increased with increase in fertilizer rate. Higher values were obtained with the application of 105 kg N ha^{-1}.
2. The interaction of cropping system × N level affected N uptake by maize. Significantly higher values were recorded under cowpea/maize intercropping system and N3 nitrogen level (105 kg N ha^{-1}).
3. Application of N fertilizer played a vital role in maize development and subsequently yields. Maize height and LAI increased with application of N.
4. Maize grain yield was not significantly affected by the interactions but strongly correlated to the yield parameters.

6.2 RECOMMENDATIONS

From this study, the following recommendations can be made:

1. Chitedze is recommended as a better location for production of SC 403 maize variety and the legumes. This is due to its adequate climatic factors and good soil properties.
2. The LER values obtained for intercropping were higher than 1. This confirms the advantage of maize-common bean and maize-cowpea intercropping over sole cropping system as sustainable in Malawi.
3. Judicious use of mineral N fertilizer should be practiced by farmers. The rate of 105 kg N ha^{-1} produced maximum maize yield per unit area. This, however, did not entail better NUE. Most of the fertilizer remains unutilized hence leading to soil toxicity. 78.75 kg N ha^{-1} would be the recommended mineral N fertilizer rate.
4. Further research is needed to quantify BNF by both cowpea and bean cultivars under intercropping system with varied N levels.

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APPENDICES

Appendix A: Analysis of variance (Anova) table for grain yield

Source of variation	df	Mean squares
Rep	2	10.76 ns
Plot	2	0.63 ns
Rep*Plot	4	0.98 ns
Treat	3	76.06***
Plot*Treat	6	1.47 ns
Location	1	40.78***
Plot*Location	2	2.07 ns
Treat*Location	3	1.31 ns
Plot*Treat*Location	6	0.85 ns
Error	42	0.97
CV	22.95	
R^2	0.88	

Ns = non-significant. *** Highly significant ($p<0.0001$)

Appendix B: Anova table for weight of 100

Source of variation	df	Mean squares
Rep	2	78.97ns
Plot	2	5.32ns
Rep*Plot	4	13.12ns
Treat	3	296.45***
Plot*Treat	6	18.46ns
Location	1	302.17***
Plot*Location	2	23.29 ns
Treat*Location	3	11.26ns
Plot*Treat*Location	6	5.36ns
Error	42	11.32
CV	8.99	
R^2	0.77	

Ns = non-significant. *** Highly significant (p<0.0001)

Appendix C: Anova table for maize DM yield

Source of variation	df	Mean squares
Rep	2	1.58ns
Plot	2	0.92ns
Rep*Plot	4	0.32ns
Treat	3	36.82***
Plot*Treat	6	0.31ns
Location	1	0.47ns
Plot*Location	2	0.52ns
Treat*Location	3	0.61ns
Plot*Treat*Location	6	0.08ns
Error	42	0.27
CV	18.78	
R^2	0.92	

Ns = non-significant. *** Highly significant (p<0.0001)

Appendix D: Anova table for maize cob weight

Source of variation	**df**	**Mean squares**
Rep	2	0.12ns
Plot	2	0.01ns
Rep*Plot	4	0.17ns
Treat	3	3.01***
Plot*Treat	6	0.05ns
Location	1	0.46ns
Plot*Location	2	0.12ns
Treat*Location	3	0.05ns
Plot*Treat*Location	6	0.04ns
Error	42	0.03
CV	12.79	
R^2	0.88	

Ns = non-significant. *** Highly significant (p<0.0001)

Appendix E: Anova table for N uptake by maize

Source of variation	**df**	**Mean squares**
Rep	2	19600.33ns
Plot	2	1256.12ns
Rep*Plot	4	8395.10ns
Treat	3	64666.53***
Plot*Treat	6	1716.69ns
Location	1	108342.79***
Plot*Location	2	8952.97ns
Treat*Location	3	5672.77ns
Plot*Treat*Location	6	1954.34ns
Error	42	4992.83
CV	56.87	
R^2	0.67	

Ns = non-significant. *** Highly significant (p<0.0001)

Appendix F: Anova table for maize plant height

Source of variation	**df**	**Mean squares**
Rep	2	1777.43***
Plot	2	382.29ns
Rep*Plot	4	1449.97***
Treat	3	39246.64***
Plot*Treat	6	483.43ns
Time	4	310857.72***
Treat*Time	12	799.65***
Location	1	72888.05***
Time*location	4	5142.42***
Plot*time	8	130.77ns
Plot*Location	2	797.99***
Treat*Location	3	282.80ns
Plot*Treat*Time*Location	74	111.99ns
Error	234	118.06
CV	6.82	
R^2	0.98	

Ns = non-significant. *** Highly significant ($p<0.0001$)

Appendix G: Anova table for maize leaf area index

Source of variation	df	Mean squares
Rep	2	0.23ns
Plot	2	0.29ns
Rep*Plot	4	0.11ns
Treat	3	2.11 ***
Plot*Treat	6	0.11ns
Location	1	0.01ns
Plot*Location	2	0.43ns
Treat*Location	3	0.08ns
Plot*Treat*Location	6	0.12ns
Error	42	0.12
CV	14.39	
R^2	0.67	

Ns = non-significant. *** Highly significant ($p<0.0001$)

Appendix H: Anova table for legume grain yield

Source of variation	df	Mean squares
Rep	2	0.14ns
Plot	1	2.00ns
Rep*Plot	6	0.32ns
Treat	3	0.43ns
Plot*Treat	3	0.58ns
Location	1	0.06ns
Plot*Location	1	1.36ns
Treat*Location	3	1.22ns
Plot*Treat*Location	3	0.80ns
Error	32	0.41
CV	63.36	
R^2	0.63	

Ns = non-significant. *** Highly significant ($p<0.0001$)

Appendix H: Anova table for legume DM yield

Source of variation	df	Mean squares
Rep	2	4.38***
Plot	1	2.48ns
Rep*Plot	6	0.74ns
Treat	3	0.12ns
Plot*Treat	3	0.04ns
Location	1	7.36***
Plot*Location	1	2.12ns
Treat*Location	3	0.04ns
Plot*Treat*Location	3	0.80ns
Error	32	0.23
CV	37.95	
R^2	0.84	

Ns = non-significant. *** Highly significant ($p<0.0001$)

Appendix I: Anova table for legume nodules number

Source of variation	df	Mean squares
Rep	2	259.66ns
Plot	1	1220.08ns
Rep*Plot	6	141.52ns
Treat	3	70.75ns
Plot*Treat	3	18.97ns
Location	1	2164.89ns
Plot*Location	1	1220.08ns
Treat*Location	3	94.30ns
Plot*Treat*Location	3	27.41ns
Error	32	130.43
CV	87.18	
R^2	0.67	

Ns = non-significant. *** Highly significant ($p<0.0001$)

Appendix J: Anova table for legume nodules weight

Source of variation	df	Mean squares
Rep	2	322.35ns
Plot	1	6.09ns
Rep*Plot	6	297.54ns
Treat	3	8.72ns
Plot*Treat	3	0.75ns
Location	1	13.82ns
Plot*Location	1	22.03ns
Treat*Location	3	10.12ns
Plot*Treat*Location	3	4.86ns
Error	32	50.69
CV	72.13	
R^2	0.72	

Ns = non-significant. *** Highly significant ($p<0.0001$)

Appendix K: Physical and chemical characteristics of soils at Chitedze and Makoka Agricultural Research Stations at the end of cropping.

Chitedze Research Station

Soil Properties

Cropping system	N level	pH	% OC	%OM	%N	P (µ/g)	K (Cmol/kg)	Ca (Cmol/kg)	Mg(µ/g)	Zn(µ/g)
sole maize	N1	6.46	1.97	3.40	0.17	16.51	0.21	4.28	0.75	1.54
	N3	6.36	2.00	3.45	0.17	12.86	0.19	4.46	0.95	1.40
	N0	6.44	2.05	3.54	0.18	17.34	0.17	4.07	2.56	1.64
	N2	6.44	1.97	3.40	0.17	15.52	0.17	3.93	1.97	1.64
bean/maize intercropping	N2	6.27	2.11	3.64	0.18	13.92	0.15	4.29	2.03	1.62
	N0	6.30	2.03	3.51	0.18	5.62	0.16	3.78	2.80	1.50
	N1	6.34	2.04	3.52	0.18	11.69	0.16	4.00	2.27	1.59
	N3	6.26	2.08	3.58	0.18	13.90	0.11	3.69	1.93	2.35
Cowpea/maize intercropping	N3	6.62	1.96	3.37	0.17	21.54	0.16	4.31	1.70	1.62
	N1	6.77	2.01	3.46	0.17	12.57	0.13	3.97	1.70	1.37
	N2	6.80	2.07	3.57	0.18	16.29	0.12	3.92	1.61	1.71
	N0	6.75	2.10	3.61	0.18	17.34	0.11	3.73	2.18	1.84
Sole cowpea		6.55	2.03	3.51	0.18	4.06	0.13	4.11	1.52	1.73
Sole bean		6.56	2.19	3.78	0.19	6.41	0.13	3.90	1.36	1.55

Appendix k continued

Makoka Research Station

Soil Properties

Cropping system	N level	pH	% OC	%OM	%N	P (µ/g)	K (Cmol/kg)	Ca (Cmol/kg)	Mg (µ/g)	Zn (µ/g)
sole maize	N1	6.09	0.5	0.862	0.0431	82.95	0.10	1.59	0.64	0.15
	N3	6.11	0.44	0.75	0.04	84.90	0.09	1.50	0.84	0.12
	N0	6.12	0.31	0.53	0.03	88.65	0.11	1.61	0.69	0.12
	N2	6.00	0.64	1.10	0.06	93.16	0.09	1.80	1.33	0.23
bean/maize intercropping	N2	6.04	0.48	0.83	0.04	80.36	0.08	1.48	0.55	0.14
	N0	6.10	0.44	0.77	0.04	72.62	0.08	1.28	0.53	0.12
	N1	6.04	0.51	0.88	0.04	70.28	0.10	1.66	0.62	0.18
	N3	6.05	0.52	0.89	0.04	89.36	0.10	1.26	1.67	0.10
Cowpea/maize intercropping	N3	6.24	0.40	0.69	0.03	85.47	0.10	1.14	0.85	0.20
	N1	6.21	0.60	1.03	0.05	77.48	0.09	1.40	0.74	0.16
	N2	6.10	0.54	0.93	0.05	73.87	0.09	1.74	0.67	0.19
	N0	6.13	0.46	0.80	0.04	80.52	0.10	1.65	0.70	0.17
Sole cowpea		6.08	0.53	0.91	0.05	80.54	0.09	1.32	0.73	0.15
Sole bean		6.04	0.50	0.86	0.04	80.40	0.10	1.41	0.63	0.12