RESPONSE OF MAIZE TO SELECTED PRODUCTIVITY TRAITS AND BIOLOGICAL NITROGEN FIXATION IN COWPEA-MAIZE COMBINATIONS UNDER CONSERVATION FARMING SYSTEM

By

SIMUNJI SIMUNJI

A Thesis Submitted to the University of Zambia in fulfilment of the requirements for the degree of Doctor of Philosophy in Agronomy.

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DECLARATION

I, Simunji Simunji, declare that the contents of this thesis represent my own work, and that the thesis has not previously been submitted for academic examination towards any qualification at this or any other University.

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Signature

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Date

APPROVAL

This Thesis of Simunji Simunji has been approved as fulfilling requirements for the award of the degree of Doctor of Philosophy in Agronomy by the University of Zambia.

Examiner	Signature	Date
1. Dr. Tembo Langa	………………	………………..
2. Dr. Paul Simfukwe	………………	………………..
3. Dr. Godfrey Sakala	………………	………………..

ABSTRACT

Maize productivity among the smallholder farmers in Zambia is generally low, resulting in average national grain yield of 2.3 tons per hectare. This challenge is mainly attributed to low and erratic rainfall, low soil fertility, and poor farming practices. This study was conducted to (i) evaluate the grain yield performance of selected drought and Low N tolerant maize varieties under conventional and conservation farming systems. (ii) evaluate the performance of cowpea genotypes for Biological Nitrogen Fixation (BNF) in conservation farming system. (iii) identify maize – cowpea combinations that result in high water use efficiency (WUE) and nitrogen use efficiency (NUE) for high maize productivity under CF system. The trials were conducted for two seasons at two sites of different soil types, fertility status and rainfall patterns. The three maize varieties (GV 640, GV 635 and ZMS 606) were evaluated in maize – cowpea rotation. Four cowpea genotypes used for rotation were Lutembwe (LTPRT) Bubebe (BBPRT), LT 11-3-3-12 (LT) and BB 14-16-2-2. The experimental designs used were split plot for objective(i) and (iii) and Randomized Complete Block Design for objective (ii). ^{15}N and ^{13}C discrimination isotopic technics were used to determine NUE, BNF, d^{13}C and WUEi. Soil moisture storage (SMS) was measured using Divinner 2000 at the Chisamba site and the HH soil moisture meter at Batoka site. The maize grain yields of 8203 kg ha^{-1} and 4996 kg ha^{-1} under the conservation farming system (CF) at Chisamba and Batoka respectively were significantly higher ($P<0.05$) than 6987 kg ha^{-1} and 2281 kg ha^{-1} under conventional farming system (CONV) respectively. The yield of maize from CF was 17.4 % more than from CONV practice at the well- endowed fertile site (Chisamba) whereas at the poorer and drought-prone site (Batoka), yields from CF were 119 % more than from CONV practice. Maize variety ZMS 606 that yielded 7973 kg ha^{-1} was superior over GV 640 and GV 635 during the 2015/2016 season. GV 640 had the highest yield of 9539 kg ha^{-1} during the 2016/2017 season. Cowpea genotype LT 11-3-3-12 exhibited highest Biological Nitrogen Fixation of 86.1 kg N ha^{-1} and 16.5 kg N ha^{-1} followed by genotype BB 14-16-2-2 that fixed 57.9 kg N ha^{-1} and 4.5 kg N ha^{-1} at Chisamba and Batoka sites respectively. The nitrogen use efficiency (NUE) was significantly ($P<0.001$) higher under the conservation farming system (CF) with mean values of 26.48 % and 13.90 % than conventional system (CONV) at Chisamba and Batoka respectively. Under CF, water use efficiency of 10.16 kg ha^{-1} mm^{-1} at Batoka and 18.84 kg ha^{-1} mm^{-1} at Chisamba was superior over CONV attributed to cowpea genotype BB 14-16-2-2. The soil moisture storage at 10 cm and 20 cm soil depths under CF was higher than under CONV by 10.3 % at the well-endowed fertile site (Chisamba) whereas at the poorer and drought-prone site (Batoka), was higher under CF than CONV by 22.7 %. Cowpea genotype LT 11-3-3-12 was most effective for moisture storage in the soil at both sites. Maize variety GV640, genotypes LT 11-3-3-12 and BB 14-16-2-2 could be most efficient for intrinsic water use as indicated by lowest discrimination of ^{13}C values of -12.13 ‰, -27.71 ‰ and -27.51 ‰ respectively. Therefore, the study identified ZMS 606 and GV 640 with high yielding, NUE and WUE as efficient drought and low N varieties for rotation with cowpea genotypes BB 14-16-2-2 and LT 11-3-3-12 with high dry biomass and BNF to ensure improved maize productivity under CF among smallholder farmers in Zambia.

Keywords: ^{13}C, conservation farming, cowpea genotypes, ^{15}N, nitrogen fixation, nitrogen use efficiency, water use efficiency

DEDICATION

I wish to dedicate this thesis to my wife, Petty Wamunyima. M. Simunji, my Children; Girls (Namakau and Likando), Boys (Likezo and Mutemwa) and my Niece Mulemwa Kwalela.

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LIST OF ABBREVIATIONS AND ACRONYMS

BBPRT	Bubebe cowpea parent
BB	Bubebe cowpea mutant genotype
BK	Batoka
BNF	Biological Nitrogen Fixation
CC	Climate Change
CA	Conservation Agriculture
CEC	Cation Exchange Capacity
C/N	Carbon Nitrogen ratio
CSA	Climate Smart Agriculture
C1, C2, C3, C4	Cowpea 1, Cowpea 2, Cowpea 3, Cowpea 4
CT	Conventional tillage
CF	Conservation Farming
CH	Chisamba
CONV	Conventional Farming
$d^{13}C$	Carbon 13 discrimination
ET	Evapotranspiration
FAO	Food and Agriculture Organization
FWUE	Field Water use efficiency
GART	Golden valley Agricultural Research Trust
HI	Harvest Index
G x E	Genetic and Environmental interaction
IAEA	International Atomic Energy Agency
IAPRI	Indaba Agriculture Policy Research Institute
NCP	Non cowpea treatment
NUE	Nitrogen Use Efficiency

NUpE	Nitrogen Uptake Efficiency
NUtE	Nitrogen utilization efficiency
MT	Minimum tillage
P	Precipitation
PE	Physiological Efficiency
PRB	Permanent raised beds
RWC	Relative water content
SOC	Soil organic carbon
TE	Transpiration Efficiency
UNZA	The University of Zambia
Y	Yield
ZARI	Zambia Agriculture Research Institute

CHAPTER ONE

1.0 GENERAL INTRODUCTION

In Zambia about 80% of the one million five hundred smallholder farmers depend on producing maize (*Zea mays),* a primary staple food for well over 90% of the Zambians (IAPRI, 2015). The major maize-producing areas in Zambia are based in region II of the Zambian agro- ecological zones. According to Bunyolo et al. (1997), region II covers the central part of Zambia extending from east to west subdivided into a sub-region IIa comprising the sandveld plateau of Central, Eastern, Lusaka and Southern province and sub-region IIb comprising the Kalahari sand plateau and the Zambezi flood plains in the western province.

Due to poor soil fertility, the productivity of maize which is a staple food among the smallholder farmers is very low, ranging from 1.1 t ha^{-1} to 2.3 t ha^{-1}. These yields are very low when viewed against average potential yield of maize which is currently at 10 t ha^{-1}(Indaba Agricultural Policy Research Institute (IAPRI), 2015). The major causes of low yields countrywide are prolonged droughts, poor soil fertility, insufficient plant nutrients and poor farming practices such as the use of unimproved varieties and in appropriate tllage practices. Nitrogen nutrient in the soil is most limiting because of leaching, volatilization and run off surface-applied nitrogen.

In the past few years, fertilizer prices have almost become unaffordable by most smallholder farmers (Aagaard, 2011). Despite the Government subsidies on fertilizers for smallholder farmers, crop yields do not seem to improve. The support through subsidy on fertilizer fell short of meeting the targeted demand for the 1,000,000 small holder farmers' requirement, leaving large areas unfertilized or inadequately fertilized. During the 2009/10 season the government decided to reduce the quantity of fertilizer pack by 50% to ensure an increased number of farmers receiving fertilizers. This decision may still not solve the problem because farmers fail to apply adequate fertilizer on large cultivated fields resulting in soil mining.

There is much evidence that climate change is also likely to lead to decreases in Global efficiency and resilience of agriculture production while at the same time being confronted with increasing demand from a growing population (Food and Agricultural Organization [FAO], 2010). Agriculture is thus not only a cause of climate change but also strongly impacted on it. Based on economic importance, agricultural systems are more than any other sector directly linked to vulnerable people's livelihood and their food security situation. Measures that promote climate change mitigation there by contain the potential to strongly co- benefit adaptation and food security, if targeted adequately. In the advent of Climate change (CC) where rainfall patterns have reduced and temperatures increased, the use of climate-smart-agriculture technologies could improve maize productivity among smallholder farmers in Zambia. Climate-Smart Agriculture refers to all farming practices that contribute to improve maize productivity. FAO (2010) defined Climate-Smart Agriculture (CSA) as a farming system that seeks to increase productivity and food security sustainably, strengthen farmers' resilience to climate variability and change and remove green-house gases emissions. Improving soil quality is one of the fundamental activities of CSA, as higher quality soils are better able to retain moisture and reduce run off – two critical features in responding to drought and flooding (Peter and Bram, 2010).

The observation on soil fertility improvement under cover crop by Karsky and Salini (2003) showed that cowpea increased soil nitrogen up to 80 kg N $ha^{-1.}$ Being a food legume, cowpea provides the needed proteins in rural households through both grain and leaves used as a relish. Cowpea also plays a multipurpose role of potential to be used for human food; livestock feed and weed control (Rao and Mathuva, 2000).

Therefore, cowpea *(Vigna unguiculata*) becomes one of the main legumes contributing to the economy of nitrogen in the cropping systems with low input through the Biological Nitrogen Fixation (BNF) (Abaidoo et al., 2007). The crop may contribute some of the acquired nitrogen to soil organic matter and nitrogen needs of succeeding and associated crops (International Atomic Energy Agency (IAEA), 2008). Symbiotically nitrogen can reduce the rate of soil degradation where legume–cereal rotations are practiced. The amounts of nitrogen contributed by various legumes that include cowpea vary between 50- 300 kg ha^{-1} per year. These values will depend on the legume species, plant densities, cropping system and legume genotypes (Makoi et al., 2009). Awonaike et al. (1990) reported the BNF of Cowpea being between 74 kg N ha^{-1} to 116 kg N ha^{-1}. Cowpea varieties vary in nitrogen fixation potential due to differences in the number, weight, efficiency of nodules and farming systems (Makoi et al., 2009). Cowpea–maize rotation tends to increase soil fertility after a season of rotation. Jeranyama et al. (2000) indicated that maize produced after cowpea yielded 1940 kg ha^{-1} compared to the control with 1220 kg ha^{-1}. Maize/ Cowpea rotation was reported by Hardter et al. (1991) to produce highest maize grain yield compared to mono-cropping due to BNF. In order to intensify the cereal production, additional amounts of nitrogen are necessary to maintain the soil fertility in the maize – legume rotation systems. According to Fujita et al. (1990), leguminous crops are sources of nitrogen and contribute to an increase in the nitrogen uptake of the non- leguminous associated crops. While Senaratne et al. (1995) indicated that 161 mg N $plant^{-1}$ were fixed by intercropped cowpea which obtained 81% of its N derived from atmosphere.

However, yields of maize can be increased by the use of an improved and sustainable farming system where the maize crop is rotated with legume crop that fixes nitrogen in the soil. Maize-Cowpea rotation involves the planting of maize crop after the cowpea legume crop and this technology facilitates the improvement of maize productivity through increased soil fertility from cowpea Biological Nitrogen Fixation [BNF], (Verhulst et al., 2014). Soil quality can, therefore, be efficiently, sustainably and effectively managed with the use of newly adapted technologies to improve the production potential in appropriate systems. Some of these systems include crop rotations of cereal crops with legumes such as cowpeas that can fix substantial soil nitrogen (Phiri et al.,2006). Therefore, screening of cowpea genotypes that have high potential for nitrogen fixation and at the same time have a low proportion of N derived from the soil should be a priority for farmers.

The use of improved maize varieties tolerant to low nitrogen and water in the nitrogen and water-stressed environment under the minimum tillage with maize- legume rotation could increase Nitrogen Use Efficiency (NUE), Water Use Efficiency (WUE) of maize and adoption of the farming system in Zambia. This makes an alternative option for improving maize production by the smallholder farmers. Sumanta et al. (2013) reported that conservation agriculture increased nitrogen use efficiency by 11% over the conventional system. Therefore, the synergy of improved maize varieties for drought and nitrogen stressed environments, minimum tillage and rotation with cowpea legume could improve maize yields among small holder farmers in Zambia. This kind of technology should provide solutions to common doubts raised by many smallholder farmers of low maize productivity in the areas stressed with water and nitrogen.

In recent years, the University of Zambia has produced some cowpea mutantation derived genotypes from the two released parent cowpea varieties. However, these genotypes that have not been evaluated for biological nitrogen fixation and their contribution to water and nitrogen use efficiency in maize production through fixed nitrogen and soil cover.

This study evaluated the selected three drought and low N tolerant maize varieties and four cowpea genotypes for maize productivity, Biological Nitrogen Fixation (BNF), Nitrogen use efficiency (NUE) and Water Use Efficiency (WUE) under conservation farming system.

1.1 Statement of the Problem

Some of the major limiting factors affecting maize production in Zambia include; low soil nitrogen, high fertilizer cost, poor farming practices, and unimproved varieties. Also, climate change that causes global warming, frequent droughts and erratic rainfall pattern. Effects of climate change on agriculture have over 30 years been observed in the form of droughts floods and irregular rainfall (de Wit, 2006). Therefore, marginal areas between semi- arid and moderate rainfall areas are affected by adverse changes in temperatures, precipitation and diseases (Dinar et al., 2012). Due to these challenges maize yields among smallholder farmers is on average at 2.3 t/ha which is far much lower than maize potential yields of 8.0 to 15.0 t/ha in Zambia (IAPRI, 2015). This indicates that productivity enhancement and better resource utilization are of paramount importance to meet the country's food and nutritional security.

Breeding maize varieties for high Nitrogen Use Efficiency (NUE) and Water Use Efficiency (WUE) and produced under the improved farming system (CF) would contribute to the mitigation of maize productivity challenges. When included in the maize-legume rotation under minimum tillage, improved cowpea varieties are expected to optimize maize production over some time. NUE and WUE are partial Factor Productivity of the crop yield per unit of input applied (water or N) and is indicative of the degree of economic and environmental efficiency in the use of nutrient inputs (Doberman, 2005).

1.2 Justification

The Food and Agriculture Organization (FAO) predicts that agricultural water withdrawals will increase by approximately 14 % during 2000-2030 to meet food demand. For various reasons, feasible expansion of irrigated agriculture accommodates only a portion of this increased demand, and the rest must come from an increase in the productivity of rainfed agriculture through possible interventions. Improving WUE by 40 % on rainfed and irrigated lands would be needed to counterbalance the need for additional withdrawals for irrigation over the next 25 years from other demand for food. Encouraging small holder farmers to use improved maize varieties in conservation farming system would optimize productivity among smallholder farmers. Water and nitrogen use efficiency in conservation farming systems is likely to be improved and can improve food security, income and nutrition among small holder farmers. Varieties of maize efficient in using water and nitrogen will use less water and N to produce substantial grain yields per kg of N or water applied and this would reduce water and N losses. Due to the high cost of fertilizers, farmers are challenged to use adequate nitrogen fertilizers on the maize crop, contributing to low yields. Introducing cowpea genotypes in conservation farming systems that have a high potential to fix nitrogen in the soil could improve maize productivity and reduce the inorganic fertilizers required for maize production among smallholder farmers. Using cowpea genotypes in the cowpea- maize rotation, enhances increased sequestration of carbon in the soil. Therefore, the system would reduce effects of climate change as reported by Gondwe, 2014 that Zambia's climate would be warmer with reduced rainfall in all agro-ecological zones, especially in Region I with rainfall less than 800 mm per season.

Zambia Agricultural Research Institute (ZARI) through CIMMYT and seed companies developed drought tolerant and low nitrogen maize varieties that Zambia could utilize and improve productivity through screening maize genotypes under conventional farming systems. This means that the varieties' efficiency for water and nitrogen use is not well investigated or understood when produced in the conservation farming systems in Zambia.

The study evaluated improved maize varieties for water and nitrogen use efficiency under maize – cowpea rotational and conservation farming systems in Zambia. The information generated from the proposed study will help farmers to use improved maize varieties and improved farming practices to increase yields.

1.3 Objectives

Main: The study's main objective was to assess the performance, water and nitrogen use efficiency of selected drought and low N tolerant maize varieties and biological nitrogen fixation in cowpea – maize combinations under conservation farming system.

The specific objectives were:

(i) To evaluate the yield performance of drought and Low N tolerant maize genotypes in conventional and conservation farming systems.

(ii) To evaluate the cowpea genotypes' performance for Biological Nitrogen Fixation in the conservation farming system and conventional farming system.

(iii) To identify maize – cowpea combinations with high water use efficiency (WUE) and nitrogen use efficiency (NUE) for high maize productivity in the conservation farming system.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Impact of Conservation Farming on maize yield performance

Conservation agriculture (A) has been defined as management of soil, water and agricultural resources to achieve economic, ecological and socially sustainable agricultural production (Jat et al., 2012). CF is more sustainable agriculture production practice than narrowly defined ‘conservation tillage’ (Naresh et al., 2014). CF may be considered a new paradigm to achieve higher production by mitigating water and nutrient stress in rain-fed regions by adopting reduced tillage, crop rotations and residue retention and addressing the global warming problem (Sumanta et al., 2013). A review by Thierfelder et al. (2013) indicated that conservation farming is a crop management system of three basic principles applied in a mutually reinforcing manner as one of the options to alleviate soil fertility decline. CF is based on a combination of: (1) minimum soil disturbance, i.e., no soil inversion with the plough or hoe; (2) surface crop residue retention as mulch with living or dead plants; and (3) crop rotations and associations of different crop species over time. Conservation agriculture is widely adaptable, and the application of its principles may vary among individual farmers depending on the site and the farmer’s circumstances.

Conservation Farming is a concept for optimizing crop yields, economic and environmental benefits in synchrony with minimum-tillage, adequate retention of crop residues on the soil surface for mulching, innovative cropping systems, and measures to reduce soil compaction through controlled traffic (Sumanta et al., 2013. CF systems also improve soil health and reduce the carbon emissions equivalent to 13ton ha^{-1} (Mandal et al., 2004) by decreasing tillage intensity and contributing to carbon sequestration (Srinivasarao et al., 2012). Baker et al. (2007) estimate that the conversion of all croplands to CF globally could sequester 25 Giger tons of carbon (Gt C) over the next 50 years, making CF among the most significant opportunities from all sectors for stabilizing global Green House Gases (GHG) concentrations. Thierfelder et al. (2012) showed that maize yields in a direct- seeded CF treatment, using cowpea seeded with a dibble stick in full rotation, increased by up to 78% after four cropping seasons in comparison to a conventional control using a ridge and furrow system. They further indicated that maize yields for animal traction rip-line seeded and direct- seeded plots were, on average, 75% and 91% higher than a conventionally tilled control plot after six cropping seasons. CF's yield performance under CONV in sub-Saharan Africa has mixed results (Guzha, 2004; Stone and Schlegel, 2006). Experiments conducted by Materechera and Mloza-Banda (1997) illustrated an on-significant yield difference between CONV and CF in the first two years of a three-year study in third year, the grain yield under CA was significantly lower. Results from the Laikipia CA project showed similar maize yield in plots managed under CONV and CA (Apina et al., 2007).

On the other hand, improved soil water supply, rooting depth and crop yields through the use of minimum tillage techniques have been reported in the semi-arid regions of Kenya (Gicheru et al., 2004). In Zimbabwe, Thierfelder and Wall (2012) reported higher yields in CA plots than in CONV plots on sandy soils in dry seasons but lower yields in CA plots in very wet seasons due to water logging. Maize yields were reported higher in CA plots than in CONV after the first season (Ngwira et al., 2012). Thierfelder at al. (2014) reported that yield advantages on two manual CF systems planted with dibble stick with sole maize and maize- legume intercropping were 1152 kg ha^{-1} and 1172 kg ha^{-1} respectively. While the ox- drawn CF had slightly smaller yield benefit of 458 kg ha^{-1} on ripped line seeded system and 761 kg ha^{-1} on direct-seeded compared to ploughed. Sumnta et al. (2013) in the pooled data showed that seed (3.0 t ha^{-1}) and stover (5.5 t ha^{-1}) yields in maize in CA was on par with conventional system but significantly higher grain (4.7ton ha^{-1}) and stover (7.9ton ha^{-1}) yields were realized with balanced fertilization. In the case of horse gram, significantly higher yields were obtained in CA (572 kg ha^{-1}) compared to conventional (389 kg ha^{-1}). This was due to the status of soil organic carbon, other labile pools of carbon and major nutrients (N, P, K) that was improved in the CA. Maize grain yield was higher in the CA (2.69ton ha^{-1}) compared to plough tilled (2.23ton ha^{-1}) on a tropical Alfisol (Mbah and Nneji, 2010). Many studies showed improvement of soil organic carbon (SOC) contributed to improvement of water retention which had a very impact on maize yield improvement (Srinivasarao et al., 2012).

Long-term application of crop residue or organic amendments can increase water retention up to 2-4% in semi-arid alfisols, helping to mitigate intermittent dry spells or terminal water stress (Srinivasarao *et al.*, 2012). Sumanta et al. (2013) observed that maize grain yield was sustained with mulch and fertilizer in the no-till system and was more effective with fertilizer and residue mulch than without. Due to surface residue's insulation effects, temperature fluctuations were minimized under zero tillage and residue retention. Hence, under conventional tillage in hot tropical soils, the surface residue cover reduces soil peak temperatures that are too high for optimum growth and development to an appropriate level, favouring biological activity, initial crop growth, and root development. Therefore, CA shows considerable potential for stabilizing maize crop production in semiarid zones (Lal, 1995). In low-yielding environments, CF can double the maize yields obtained under conventional tillage (Thierfelder et al., 2013). According to Paudela et al. (2014), average maize grain yields ranged from 2.05 - 2.2 and 1.67 - 2.2 tonha^{-1}, respectively for year one (2011) and year two (2012), which were much lower than the national average of 2.8 tonha^{-1}. There was a significant reduction in maize yield in year two compared to year 1. Farmers attributed the lower grain yield of maize yield in 2012 to relatively unfavourable rainfall conditions.

Rusinamhodz et al. (2011) observed that a long-term tillage and residue retention effect on maize grain yield under contrasting soil textures, nitrogen input, and climate showed an increase in maize yield over time with conservation agriculture practices that include rotation and high input use in low rainfall areas. Mulch cover in high rainfall areas leads to lower grain yield due to waterlogging, soil texture is important in the temporal development of conservation agriculture effects, and improved grain yields are likely on well-drained soils. Conservation agriculture practices require high inputs, especially soil N, for improved maize yields, and that increased yields are observed under rotation. In contrast, reduced tillage with no mulch cover leads to lower grain yield in semi-arid areas.

Benefits of CF including nutrient cycling, carbon sequestration, and pest and disease control are quite variable, depending on the site-specific context, management, soil type, and climate (Naresh et al., 2016). Conservation farming system therefore, has effects on the soil fertility status that affect performance of maize yield some of which have been highlighted below:

2.2 Impact of conservation farming system on physical soil properties

2.2.1 Bulk density

In their study, Verhulst et al. (2011) reported that most of the physical soil parameters measured were significantly affected by the farming system, and only bulk density showed no effect. A layer of 7 to 15–20 cm depth has high bulk density, low porosity, and high mechanical resistance, referred to as a no-till pan. The tillage effect on soil bulk density remains unchanged in deeper soil layers that it is generally similar in no-till and conventional tillage. However, Lal (2000) reported that annual application of 16 t ha^{-1} of crop residue for three years decreased bulk density from 1.20 to 0.98 g cm^{-3} in the 0-5 cm layer on a sandy loam under conservation farming system. In contrast, Hu et al. (2007) reported that no-till significantly increased the topsoil (0-5 cm) bulk density, but reduced tillage maintained a lower bulk density than conventional tillage. According to Curtis and Post, there is a strong correlation between organic matter and bulk density. Pravin et al. (2013) stated a reverse correlation between organic matter and bulk density and bulk density and organic matter. In contrast, Sakin (2011) obtained a strong negative correlation of r = -0.8869 between organic matter and Bulk density. Many researchers reported the effect of sand content on soil bulk density to be higher than that of the other soil properties. Pravin et al. (2013) indicated that clayey soils tend to have lower bulk densities and higher porosities than sandy soils with a high positive correlation with sand content (r = 0.9094). While significant negative correlation of bulk density was observed with clay content (r = -0.6332) and silt content (r = - 0.7343) of soil samples.

2.2.2 Soil Water infiltration

Infiltration is generally higher in conservation farming with residue retention compared to conventional tillage and no-till without residue. Abid and Lal (2009) observed significantly higher infiltration in no- till (I= 71.4 cm) than conventional till (I = 48.9 cm) on silt loam soil. Tillage and residue management also influenced cumulative and steady-state infiltration (Sharratt et al., 2006). The higher contribution of large pores and flow-active porosity throughout the profile in conventional till had showed increased infiltration rate than in no till system (Naresh et al., 2016). Detailed studies undertaken at the Monze Farmer Training Centre revealed that CF treatments, especially that using cotton in rotation, increased water infiltration and soil moisture.

In some years, infiltration was five times higher on CF fields than on those using conventional tillage (Thierfelder et al., 2012).

2.2.3 Soil Water Storage

Conservation farming practices have proven effective in increasing plant-available water under drought and improving crop water-use efficiency (Bradford and Peterson, 2000). Nielsen (2006) showed the combined effects of residue management and tillage method on precipitation stored in the soil. Tanwar et al. (2014) found the amount of irrigation water applied to wheat ranged from 2890 to 3167 m^3 ha^{-1} in the bed planting system and 3830–3970 m^3 ha^{-1} in conventional planting. Bed planting saved 23%, 24%, and 19% irrigation water over the conventional system during 2009–2010, 2010–2011 and 2011–2012. Vita et al. (2007) stated that higher soil water content under conservation farming systems than under conventional tillage indicated the reduced water evaporation during the preceding period. They also found that soil water content under conservation farming was about 20% greater than under conventional tillage across the growing seasons. Sharma et al. (2011) reported that no-tillage retained the highest moisture followed by minimum tillage, raised bed, and conventional tillage at different soil depths. Rotation with or without legumes improved water infiltration (between 70 and 238%), soil moisture, soil carbon, macro-fauna, and crop productivity. Maintenance of crop residues on the soil can be an effective means for improving plant available water (Naresh et al., 2014). Moisture accumulated more with depth and with residues than without zero tillage (Govaerts et al., 2007).

2.3 Impact of conservation farming system on Chemical Soil properties

2.3.1 Soil Reaction (pH)

Soils that are considered acid have pH lower than 5.5 and may have high concentration of aluminium and manganese (Samuel et al, 1985). Soils with low pH have chemical constraints and reactions between them that limit the growth of the maize crop. At low pH, the main factor contributing to reduced crop productivity is toxicity from the excessive free and exchangeable aluminium and manganese levels. Soil with too low pH results in nitrogen deficiency of the herbage (Semu, 2008). Deficiency of nitrogen, phosphorus, calcium, magnesium, potassium sulfur, molybdenum, zinc and copper in acid soils is another contributing factor to low maize productivity (Adams and More, 1983). According to Mengel and Kirkby (1987), the effect of aluminium toxicity first appears in the root system which becomes stubby due to the inhibition of elongation of the main axis and lateral roots. Mormura et al. 1978 described inhibition of cell division in root apical meristems as a primary effect of aluminium toxicity. Inhibition of cell division may be due to the binding of aluminium to DNA which is in accord with the localization of aluminium in the nuclei after short- term treatment with aluminium. However, the maize crop grows well and give better yields in soils with a pH of 5.5-6.0 (Mbah and Nkpanji, 2007). Raising the pH of acid soils is also a means of providing more suitable soil bacteria growth conditions which may influence various process such as microbial N_2 fixation, denitrification of NO_{-3} and mineralization of organic soil N (Marschener,1993).

The pH of the soil is affected by the farming system used on the farm. Govaerts et al. (2007) found a higher pH in permanent bed with all the residues retained than with part or all the residues removed in a rain-fed experiment. Duiker and Beegle (2006) did not observe significant tillage effects on the 0 –15 cm soil layer's average pH. Kettler et al. (2000) observed that the main effect of ploughing on soil pH was more significant for 0–7.5 cm soil depth and conservation farming system, which leaves plant residues at or near the soil surface, were of lower pH than mould board ploughing treatments at all soil depths. However, Ismail, (1994) found higher pH levels in conventional farming system than in conservation farming systems. Tillage and straw management usually had little or no effect on soil pH in any soil layer (Malhi et al., 2011). Clark et al. (1999) found that soils in the organic and low-input systems had higher soil organic C, soluble P, exchangeable K, and pH. In contrast, Kumar and Yadav (2005) observed a slight decrease in the soil pH than initial values in the conventional tillage, Chinese seeder and Pantnagar zero- till drill. The lower pH in the conservation farming system was attributed to the accumulation of organic matter in the upper few centimetres (Rhoton, 2000), causing increases in the concentration of electrolytes and pH reduction. Retention of crop residue on the soil (Sushant et al., 2004) reduced the bulk density, enhanced organic carbon, and electrical conductivity, and reduced the soil's pH.

2.3.2 Cation Exchange Capacity

Kumar et al. (2015) reported that the cation exchange capacity (CEC) was increased due to tillage crop establishment. The significant loss of aggregate stability for the zero-till system is of particular concern. It suggests that the increased aggregate stability of surface soil under no-till is due to surface residue rather than an intrinsic property of zero-tillage. This observation is consistent with that of Hammer beck et al. (2012). However, the average CEC in the 0–15 cm layer was not significantly different between tillage systems in the same study. This was confirmed by Govaerts et al. (2007), who did not find an effect of tillage practices and crop on CEC. However, the retention of crop residues significantly increased the CEC in the 0–5 cm layer of permanently raised beds than the soil from which the residues were removed, but there was no difference in the 5–20 cm layer. Ohanty et al., 2015 observed that adoption of minimum tillage enhanced the CEC of soils even within a short span of two years and the increase was 11.2% over the conventional tillage system. These results show that CF practice modifies top soil and soil organic matter is the major contributor.

2.3.3 Soil organic carbon and total nitrogen

Soil organic carbon (SOC) is an important index of soil quality because of its relationship to crop productivity (Lal et al., 1997). Godde et al. (2016) reviewed that Carbon sequestration in agricultural soils can mitigate greenhouse gas emissionsand improve soil biological, physical, and chemical properties. Rotation with or without legumes improved water infiltration (between 70 and 238 %), soil moisture, soil carbon, macro-fauna and crop productivity (Thierfelder et al., 2012). Decomposition rates of soil organic matter are lower with minimal tillage and residue retention, consequently organic carbon content increases with time (Gwenzi et al., 2009). Soil organic matter is an important determinateof available water content because it is a significant soil component at a volume basis. Hudson (1994) observed that 1-6% of organic matter by weight was equivalent to approximately 5 to 25 % volume. Mrabet (2000) reported higher crop yields in conservation farming systems. The improvement was a result of better water use and improved soil quality in soil organic C and N. Tillage practice can also influence the distribution of soil in the profile with higher soil organic matter (SOM) content in surface layers with zero tillage than with conventional tillage, but a higher content of SOC in the deeper layers where residue is incorporated through tillage (Jantalia et al., 2000). Soil C storage is affected more by quantity than by the type or quality of organic inputs. The quality of the residues is determined primarily by the C: N ratio and can be modified by the amounts of lignin and polyphenolics in the material (Palm and Sanchez, 1991). Quality may affect short-term soil C storage and dynamics but does not seem to influence the longer-term C stabilization and storage in the soil (Chivenge et al., 2011). However, quality of the residues may affect soil fertility and thus the amount of residues produced for C inputs. For example, materials with high C: N, characteristic of cereal crop residues, reduce the available N in the soil due to N immobilization and could result in lower crop production, while residues with high N contents and low C: N ratios, as is the case with many legume residues and legume cover crops, increase soil N availability and possibly crop production (Palm et al., 2001). It is generally recognized that the differential effects of rotations on soil C are related to the amounts of above and below-ground biomass (residues and roots) produced and retained in the system (West and Post, 2002). Unfortunately, few studies have measured or reported the residue inputs, particularly root biomass or rooting patterns, to explain rotation effects better. In Brazil, Boddey et al. (2010) attributed higher soil C storage in No- Till (NT) than Conventional tillage (CT) to the inclusion of legume intercrops or cover crops in the rotations, and not to higher production and residue inputs. They indicated that slower decomposition of residues and lower mineral N in NT than CT results in higher root: shoot ratios and below ground C input with NT (Boddey et al., 2010). Crop residues provide a source of organic matter, so when returned to the soil, the residues increase organic C and N storage in soil. In contrast, their removal results in a substantial loss of organic C and N from the soil system (Malhi and Lemke 2007). Therefore, one would expect a dramatic increase in organic C in soil from a combination of ZT, straw retention and proper/ balanced fertilization (Malhi et al., 2011). Naresh et al. (2016) also found significantly higher plant organic matter content in the conservation farming system and was probably due to higher biomass C. The increase of organic matter content in the conservation farming system was 79.3, 93.0 and 104.3 mg·kg^{-1} with crop residues at 2, 4 and 6ton ha^{-1}. Singh et al. (2014) found that the carbon stock of 18.75, 19.84 and 23.83 Mg ha^{-1} in the top 0.4 m soil depth observed under the conventional system increased to 22.32, 26.73 and 33.07 Mg ha^{-1} in 15 years of no-till in sandy loam, loam and clay loam soil. This increase was highest in clay loam (38.8%) followed by loam (34.7%) and sandy loam (19.0%) soil. The carbon sequestration rate was 0.24, 0.46 and 0.62 Mg ha^{-1} $year^{-1}$ in sandy loam, loam and clay loam soil under a conservation farming system. Thus, fine- textured soils have more potential for storing carbon and conservation farming practice enhances carbon sequestration rate in soils by providing better conditions in terms of moisture and temperature for higher biomass production and reduced oxidation (Gonzalez-Sanchez et al., 2012). Intensification of cropping systems with high above and below-ground biomass (i.e., deep-rooted plant species) input may enhance conservation farming systems for storing soil carbon relative to conventional system (Luo et al., 2010). Gupta et.al. (2014) reported that conservation tillage caused 21.2%, 9.5%, 28.4 %,13.6 %,15.3 %,2.9 % and 24.7 % higher accumulation of SOC in >2 mm, 2.1–1.0 mm,1.0–0.5 mm, 0.5–0.25 mm, 0.25–0.1 mm, 0.1–0.05 mm and <0.05 mm sized particles than conventional system treatments. The contents of active carbon (AC) and microbial biomass carbon (MBC) in the long-term trial and contents of active carbon (AC) in the short-term trial were higher for the conservation system than the traditional system at 0–5 cm depth for both sampling periods (Melero et al., 2009). Further studies have reported that microbial biomass and potentially mineralizable nitrogen in the 0–7.5 cm surface layer of no-till soils was 34 % higher than those of ploughed soils. However, the opposite was true at 7.5- to 15 cm depth (Doran, 1987). Gupta et al. (1994) found higher values of microbial biomass carbon (MBC) in the first 5 cm of the soil profile under NT than under traditional tillage after one year of conservation management. Wright et al. (2005) found MBC to be greatest under no-till management but only in the surface 2.5 cm with little tillage effect to 20 cm. They found an increase of MBC and mineralizable N in the surface soil with corn and cotton cropping sequences for twenty years under no-till and minimum tillage systems but little change in MBC concentration in the 2.5 to 20 cm depths. The contents of active carbon (AC) and microbial biomass carbon (MBC) in the long-term trial and contents of active carbon (AC) in the short-term trial were higher for conservation farming system than traditional tillage at 0–5 cm depth for both sampling periods (Melero et al., 2009). There was a consistent increase in biological activity and N mineralization with the conservation farming system (Green et al., 2007). Similar increases with depth have been observed in arid wheat- based systems where total soil N (TSN) increased by 38–68 % (Dou and Hons, 2006). Farming systems can greatly modify edaphic factors and influencethe rate of C mineralization (Huggins et al., 2007; Curtin et al., 2012). Therefore, measurement of a suite of SOC fractions and elucidation of the interactive relationships among different SOC fractions would perhaps more reflect tillage and N management induced changes in soil quality (Strosser, 2010). The review showed that minimum tillage under conservation farming system enhances high levels of organic matter and available nitrogen for crop production.

2.4 Biological Nitrogen Fixation

Biological Nitrogen Fixation (BNF) is key to sustain agriculture and reduce soil fertility decline. Biological Nitrogen Fixation estimate the amount of fixed nitrogen and selects the most effective *Rhizobial* strain x plant genotype combination. BNF is microbial process of major importance in the nitrogen economy of agricultural ecosystems. This process can only occur in the presence of an enzyme (complex) known as Nitrogenase which is synthesized by only a few, specialized groups of bacteria, actinomycetes and blue algae- green algae (Msumali et al., 1996). Increased BNF in mixed legume and cereal crops is being obtained by selecting legumes and genotypes for increased productivity and/or to minimizing effects of nutrient limitations, low soil moisture, soil acidity, and pests and disease (Peoples and Crawell, 1992). BNF, a microbial process that converts atmospheric nitrogen into a useable plant form, offers an alternative for expensive inorganic chemical fertilizers reported harmful to the environment. Therefore, Nitrogen -fixing systems provide an economically attractive and ecologically sound means of reducing external inputs and improving internal resources (Bohlool et al., 1999). Inputs of biologically fixed N into agricultural systems may be derived from symbiotic relationships involving legumes and *Rhizobium* species, partnerships between plants and *Frankia* species or cyanobacteria, or from non -symbiotic associations between free-living diazotrophs and plant roots. It is assumed that these N_2- fixing systems will satisfy a large portion of their N requirements from atmosphere N_2. Other fixed N will be contributed to soil reserves for the benefit of other crops or forage species (People and Crawell, 1992).

Cowpea *(Vigna unguiculata*) is one of the main legumes contributing to the economy of nitrogen in the cropping systems with low input through the Biological Nitrogen Fixation (BNF) (Sanginga et al., 2000). The crop may contribute some of the acquired nitrogen to soil organic matter and nitrogen needs of succeeding and associated crops (International Atomic Energy Agency (IAEA), 2008). Symbiotically nitrogen can reduce the rate of soil degradation where legume–cereal rotations are practiced. The amounts of nitrogen contributed by various legumes that include cowpea vary between 50-300 $kgha^{-1}$ per year. These values will depend on the legume species, plant densities, cropping system and legume genotypes (Makoi et al., 2009). Awonaike et al. (1990) reported the BNF of Cowpea between 74 kg N ha^{-1} to 116 kg N ha^{-1}. Cowpea varieties vary in nitrogen fixation potential due to differences in the number, weight, efficiency of nodules and farming systems (Makoi et al., 2009). Cowpea–maize rotation tends to increase soil fertility after a season of crop rotation. Jeranyama et al. (2000) indicated that maize produced after cowpea yielded 1940 kg ha^{-1} compared to the control with 1220 kg ha^{-1}. Maize/ Cowpea rotation was reported by Hardter et al. (1991) to produce the highest maize grain yield compared to mono-cropping due to BNF. To intensify the cereal production, additional amounts of nitrogen are necessary to maintain soil fertility in the maize – legume rotation systems. According to Fujita et al, 1990, leguminous crops are sources of nitrogen and contribute to an increase in the nitrogen uptake of the non-leguminous associated crops, while Senaratne et al. (1995) indicated that 161 mg N $plant^{-1}$ was fixed by intercropped cowpea which obtained 81% of its N derived from the atmosphere. Some of the farming systems that include crop rotations of cereal crops with legumes such as cowpeas can fix substantial amount of nitrogen (Phiri et al., 2006).

According to Bado et al. (2006), groundnut was found to fix 8 to 23 kg N ha^{-1} and the percentage of N derived from the atmosphere varied from 27 to 34 % while cowpea fixed 50 to 115 kg N ha^{-1} and percentage of N derived from the atmosphere varied from 52 to 115 kg N ha^{-1}. Compared to the NPK fertilizer alone, legumes fixed more N from the atmosphere when dolomite or manure was associated with mineral fertilizers. A significant correlation ($p<0.05$, R2 =0.94) was observed between total yields of legumes and total N derived from the atmosphere. Compared to mono-cropping of sorghum crop, soils that had cowpea – sorghum and ground nut -sorghum rotations improved soil mineral N from 15 kg N ha^{-1} to 22 kg N ha^{-1} respectively. The uptake of soil N was doubled under the legume-cereal crop rotation with succeeding increased yields of more than 290 %.

2.4.1 Factors affecting amounts of N2 fixed in the soil and the relative contribution of symbiotic versus asymbiotic BNF to the N economy of soils

The amounts of nitrogen fixed in a biological system, are determined by several factors and according to van Reuler and Prins (1993), these include the following:

(i) Availability of energy sources

(ii) Types of symbiotic BNF associations

(iii) Overall agronomic management in the case of the legume – (*brady) rhizobial* association.

The amount of N_2 fixed in the soil depend on the mode of fixation (Symbiotic or asymbiotic BNF). Generally, the symbiotic mode of fixation contributes substantially more to the N economy of soils than the asysmbiotic process. The process of BNF is a reductive process, with high energy requirements. Estimates indicate that 1 kg of N biologically fixed requires the oxidation of 100 kg of carbonaceous materials (Hansen, 1993). Carbonaceous materials are generally found in the rhizosphere soils in the form of root exudates, sloughed-off root hairs and other root tissues. Therefore, it was observed that amounts of N_2 fixed in non – rhizosphere soils were relatively lower between 3-5 kg N ha^{-1} due to energy shortage, compared to estimates of 40 kg N ha^{-1} in the rhizosphere of cereals and grasses. On the other hand, in the symbiotic mode, energy supply in the form of photosynthate to the micro-symbiont host is not limiting as long as the micro-symbiont is actively growing (Msumali et al., 1996).

The amounts of N_2 fixed are affected by the type of symbiotic BNF associations. It has been reported that the legume- *Brady rhizobial* associations make a much more contribution to the N economy than any of the other associations (International Rice Research Institute [IRRI], (1987). Therefore, it is important to note that the inherent characters of the micro-symbiont have a profound influence on the BNF process when the symbionts are in association. For a given species of Rhizobium or *Brady rhizobium*, many strains exist which differ in their symbiotic effectiveness in fixing N, in their competitiveness in nodulating their homologous hosts, and in their ability to tolerate adverse biotic and edaphic factors. Some of the native *Brady rhizobium* strain isolates have been reported to have high N_2 fixing capabilities in cowpeas comparable to the N fertilized plants with the equivalent of 70 kg ha^{-1} of inorganic N, with some of them showing superiority in symbiotic effectiveness relative to the standard strain.

This suggests that native isolates are a potentially useful source of strains for preparing highly effective cowpea inoculants (Fening and Danso, 2002).

The host plants (legumes) profoundly influence the amounts of N_2 fixed when associated with the micro-symbionts. Legumes are diverse in growth habits, nodulating patterns, and the growing season's size and length. They, therefore, differ in their ability to support N_2 fixation (Wangari and Msumali, 2000). Thus, the field bean is universally known to be a poorer fixer (< 50 kg N ha^{-1}) than soybeans that can fix up to 150 kg N ha^{-1} or Cowpeas, which fixes between 150 to 200 kg N ha^{-1}. Within a species of legumes, different cultivars exist that show differences in susceptibility to infection by a particular strain of brady rhizobium and the overall expression of the BNF potential. Abaidoo et al. (2017) found that total N fixed by cowpea genotypes was in the range of 11.9 - 40 kg N ha^{-1}. However, Belane et al. (2011) reported the highest amount of N-fixed by cowpea cultivar as 182 kg N ha^{-1}. In contrast, Munjonji et al. (2017) showed cowpea genotype with low grain yield performing better for BNF of 71 kg N ha^{-1} under well-watered and 39 kg N ha^{-1} under severe water stress.

The availability of nutrients is among the main factors that affect BNF, and phosphorus (P) is among the main nutrients that influence this process. Although P is extracted in smaller amounts compared with other macronutrients, it is important to establish nodulation because it increases the number of root hairs and promotes more sites of infection for N_2-fixing bacteria (Nkaa et al., 2014). The efficiency of N_2 fixation is dependent on the availability of P in the symbiotic process (Burity et al., 2000). Thus, for every 5-10 kg N fixed, 1 kg of available P must be supplied. Phosphorus deficient soils do not support substantial BNF by legumes. This explains why mycorrhizal inoculation enhances P-uptake in P-deficient soils has been found to improve N_2 fixation and yield of legumes compared to the growth performance of non-mycorrhizal plants. Among the existing soluble P, single superphosphate (SSP), triple superphosphate, and thermos-phosphate are considerably used. High doses are applied in highly weathered soils due to adsorption to clay minerals and iron and aluminum oxides. However, the soils with high mineral nitrogen levels do not generally favor BNF (van Reuler and Prins, 1993). High levels of N in the soil tend to restrict legume nodulation and BNF.SSP has the advantage of adding S to the soil and, consequently, meeting the plants' requirements regarding this element, while thermos-phosphate adds Ca and Mg to the soil. According to Wangari and Msumali (2000), adequate supply of plant nutrients such as Ca, Mg, S, Mo and Fe is important for proper functioning of the nitrogenase enzyme during nodulation. The extreme soil acidity (pH < 5.0) does not favor the survival of the micro-symbionts. The host legume and BNF process are adversely affected by acidic conditions mainly due to nutrient deficiency or other element toxicities such as Al^{3+}, Mn^{2+}, and Fe^{2+}. Therefore, evaluates, contribution of conservation farming system for biological nitrogen fixation improvement at two sites of different soil types, rain fall pattern and soil fertility status.

2.4.2 Benefits of Biological Nitrogen fixation as an alternative for N fertilizers

Nitrogen, an element vital for plant growth constitutes 78% of the earth's atmosphere. In spite of its abundance it is one of the most limiting factors for crop growth, and nitrogen fertilizers represent one of the high crop production costs. However, nitrogen can also be supplied to crops by biological nitrogen fixation. This process is becoming more important for not only reducing energy costs, but also attempting to develop sustainable agricultural production. Legumes in symbiosis with rhizobia, are the best-known nitrogen-fixing systems. To reduce nitrogen fertilizer, use and potential ground water pollution it is necessary to increase the use of nitrogen fixing systems to maintain or increase crop yields. Nitrogen fixing micro-organisms will therefore be an essential component of sustainable agricultural systems. Tauer (1989) recently stated that 'increasing the efficiency of legumes to fix N_2 may have an annual US benefit of $1,067 million while decreasing N fertilization by 1,547 thousand metric tons. Total elimination of N fertilization of the major crops has an annual US benefit of $4,484 million'. Economic evaluations of the benefit of biological nitrogen fixation have not been performed for developing countries but it is likely that comparable benefits could be expected. Biological nitrogen fixation is important from the point of view of saving N fertilizer and reducing crop production costs.

2.4.3 Methods used to measure Biological Nitrogen Fixation

In order to have proper management and fully understanding of the benefits of legume-Rhizobium symbiosis for biological nitrogen fixation (BNF), it is necessary to quantify the amount of nitrogen fixed. Some of the methods used to measure BNF have been reviewed (Azam and Farrog, 2003).

2.4.3.1 Dry matter method

This is the easiest method for a rough estimation of the BNF. The measurement is based on the legume crop's ability to meet the N requirements from BNF up to 90 %. However, due to inherent differences in the cultivars for exploiting the native N, the dry matter, method may not be reliable for estimating BNF (Hay dock et al., 1980).

2.4.3.2 Nodule number and mass

The legume's nodule number and mass depend on effective and relevant rhizobia in good numbers in the plant rhizosphere (Graham et al., 1981). Nodule number and mass method rely on the assumption that similar amounts of native soil N are made available to the plants irrespective of their genetic differences whether, legume or not. Therefore, fixed N = Total N (fixing crop)- Total N (non- fixing crop).

2.4.3.3 Acetylene reduction

The assay gives an estimate of the activity of nitrogenase on the enzyme that is involved in the reduction of several compounds including N_2 (Edwards et al., 1981).

2.4.3.4 Content of Ureides and other metabolites

In legumes, N – containing compounds originating from BNF (Ammonia) are inco-operated into glutamine and glutamate via glutamine synthetase (GS) and Glutamine oxoglutarate aminotransferase pathway respectively. Analysis of the compounds can provide information on the relative dependence of plants on soil N and BNF (Pate and Atkins, 1983).

2.4.3.5 Use of Isotope ^{15}N

The ^{15}N techniques are currently the most accurate method to measure the nitrogen fixed in a given system. Nitrogen-15 techniques, though relatively expensive, usually provide results that have lower variability and are of higher sensitivity, resulting in more precise information in a shorter period. The method exploits the dilution effect through the differences in ^{15}N abundance of different N sources (IAEA, 2008). Some advantages of this method include: (i) it gives a truly integrated value for N_2 fixation because it is more sensitive and accurate, (ii) can be used directly in the field situations,

(iii) and can differentiate between the sources of N such as from fertilizer and soil. In addition, their use and applications require scientific and technical staff with adequate skills and expertise, adequate financial resources and functional laboratory facilities to properly conduct the experiments, perform the isotope measurements and interpret the results. The study used isotope ^{15}N as one of the modern and accurate techniques to measure BNF in cowpea genotypes.

2.5 Nitrogen Use Efficiency

Maize (*Zea mays. L.*) requires high amounts of nitrogen (N) inputs for optimum grain and silage production. This is mainly due to the ability of the crop to produce large quantities of dry matter (Moser et al., 2006). However, Nitrogen is the most limiting nutrient for crop production in many parts of the world including Zambia, therefore efficient use of Nitrogen in plant production is an important goal in crop management. Thus, improving NUE is relevant for maize, for which global NUE has been estimated to be less than 50% (Raun and Johnson, 1999).

According to Nele Verhulst et al. (2014), Nitrogen Use Efficient (NUE) is the ratio of grain yield per unit of available N in the soil, including the present residual soil nitrogen and Fertilizer nitrogen (NUE = N exported from the field into crops/(N applied). Moll et al. (1982) on the other hand defined NUE as the grain yield or biomass production yield obtained per unit of N available in the soil (already present and originating from fertilizer application) and is inversely proportional to the amount of N fertilizer applied (Herel and Lemaire, 2005). However, not all available nitrogen comes from nitrogen fertilizer. Still NUE is a function of soil structure, climate conditions interactions between soil and bacterial process and the nature of organic and inorganic nitrogen sources. In conservation farming, effects of nitrogen fertilizer can be noticed in the following cropping seasons over several years. This is especially the case when fertilizer is applied in combination with residues retention since can increase temporally immobilization of fertilizer, which was released in the following years (Verhulst et al., 2014). Habbib et al. (2016) reported positive results in NUE, N harvest index, N, remobilization and N remobilization efficiency in maize under no-till compared to conventional tillage after four years of trials both on station and on-farm.

Research results on the effect of rotation in conservation agriculture systems on NUE are inconsistent. Still most studies found adverse effects of crop mono culture on yield and nitrogen use efficiency and positive effects of legumes introduced in the rotation. Acharya, (2018) reviewed that agronomic N use efficiency (kg/kg) in maize under permanently raised beds (PRB) and conventional tillage (CT) method were found 28% and 16% respectively in an experiment conducted in Uzbekistan. N recovery efficiency in maize crop was also found higher in the permanent raised beds (80%) than in CT (44%) (Devkota et al., 2015). An experiment conducted in Portugal reveal that increasing soil organic matter from 1% to 2% will increase nitrogen-use efficiency from 19.1 to 36.6 kg of wheat per kg of applied nitrogen under Portugal's condition due to residue retention and cover cropping (Carvalho and Lourenço, 2014). With the integrated soil–crop management practice and high mineral fertilizer use, N and P uptake by all crops was higher than for the un-amended soil conditions (Amouzou et al., 2018). Reicosky and Archer (2007), however, reported that larger amounts of CO_2 were released into the atmosphere as the result of tillage, which, in turn reduced the soil carbon (C) content but in contrast, conservation tillage practices under continuous cropping systems are known to improve SOM content (Awale et al., 2013).

NUE can hence be improved by increasing the physiological efficiency (PE) = dry matter/ unit nitrogen uptake and recovery efficiency (RE) = nitrogen uptake/unit of available nitrogen (Fageria and Bligar, 2005). Based on the physiological and agronomic point of view, NUE is an outcome of two biological processes. It includes: (i) N uptake efficiency (NUpE) which is the amount of N taken up per unit of available N, and (ii) N utilization efficiency (NUtE) which corresponds to the increase in biomass or yield per unit of N taken up (Daubresse, 2010). During the plant developmental cycle, some complex physiological processes are involved in controlling plant NUE notably N uptake, N assimilation and N translocation (Sinclair, 2004). Huang et al. (2017) reviewed that the simplest definition of plant NUE is the grain yield per unit of supplied N, an integration of NUpE and NUtE. Further, NUE is described as utilization index (UI) which is the absolute amount of biomass produced per unit of N. NUE can also be NUEg which is grain production per unit of N available and HI which is grain production of the total plant biomass.

Inter- and intra-specific variation for plant growth and mineral nutrient use efficiency (NUE) is under genetic and physiological control and are modified by plant interactions with environmental variables (Bertin and Gallais, 2000). There is need for breeding programs to focus on developing cultivars with high NUE. Identification of traits such as nutrient absorption, transport, utilization, and mobilization in plant cultivars should greatly enhance fertilizer use efficiency. The development of new cultivars with higher NUE, coupled with best management practices (BMPs) will contribute to sustainable agricultural systems that protect and promote soil, water and air quality (Baligar et al., 2007). Raun and Johnson, (1999) indicated that Worldwide, nitrogen use efficiency (NUE) for cereal production is approximately 33%. The findings showed that 67% of the applied fertilizers is lost through gaseous plant emission, soil denitrification, surface runoff, volatilization, and leaching.

Nitrogen Use efficiency can, therefore, be calculated with the following formulas: Dry biomass yield/ nitrogen applied ratio, Dry biomass yield/ available nitrogen ratio, Maize grain yield/nitrogen applied ratio, Maize grain yield/ available nitrogen ratio, nitrogen content in maize stover and grain, nitrogen uptake, Dry biomass yield/ nitrogen uptake ratio, Nitrogen uptake/ available nitrogen ratio (IAEA, 2008). Field et al. (1983) defined instantaneous nitrogen-use efficiency (NUE) as the ratio of photosynthetic capacity to leaf nitrogen content.

2.5.1 Benefits of Nitrogen Use efficiency

Nitrogen Use Efficiency (NUE) technologies have the potential to reduce the quantity number of nitrogen fertilizers lost due to leaching into the soil and water ways. Farmers may reduce costs of fertilizers by using improved farming methods like conservation agriculture and improved varieties that are tolerant to low soil nitrogen. Use of NUE technologies can further reduce emissions of Green House Gases (GHGs) due to less volatilization of N_2O gas into the atmosphere (IAEA, 2007). Dangers of over-application of nitrogen to crops could be resolved by selecting genotypes for improved NUE (Dai-Yin and Hongxuan, 2015). NUE reveals importance of nitrogen allocation, storage, recycling and turnover of biomass growth (Hirose, 2012).

Nitrogen fertilizers have been reported to be essential in boosting crop productivity in recent decades. They help farmers grow healthier crops that can feed a growing population. However, most plants can only absorb part of the nitrogen in fertilizer, which leaves essential nutrients unused. Therefore, new seed traits that allow crops to use nitrogen more efficiently and effectively can provide an immense boost to productivity and help farmers grow significantly more food, especially as climate change threatens production (Crop life International, 2014).

Synthetic nitrogen (N) fertilizer application to farmland resulted in a dramatic increase in crop yields but with considerable negative impacts on the environment. Therefore, new solutions are needed to increase grain yields while maintaining simultaneously, or preferably decreasing, applied N to maximize the nitrogen use efficiency (NUE) of crops. This is done by developing crop plants with enhanced NUE, using more classical genetic approaches based on utilizing existing allelic variation for NUE traits (Han et al., 2015). Plant NUE is inherently complex with each step including N uptake, translocation, assimilation and remobilization coupled with interactions between genetics and environment. Enhanced NUE can be achieved through genetically modifying plants and integrated agricultural management practices. Genetically modified plants are the most effective biotechnological method for increasing NUE. It involves overexpression of nitrate and ammonium transporters responsible for N uptake by roots and by manipulating key genes controlling the balance of nitrogen and carbon metabolism (Huang et al., 2017). Huang et al. (2017) further explained that water is another key factor that determines crop yield and NUE. Without sufficient water, plants cannot extract nutrients from the soil.

2.5.2 Methods used to assess Nitrogen Use Efficiency

Assessment of plants for their ability to absorb and utilize nutrients for maximum yields is important. Therefore, NUE is mainly affected by uptake, which hinges on root parameters. Baligar et al. (2001) stated that NUE is a function of the soil's capability to sufficient stock levels of nutrients and the plant's ability to acquire, transport in roots and shoots, and remobilize to other parts of the plant. According to Huang et al. (2017), NUE calculations include N utilization, N content, and N availability. Estimates of nitrogen uptake efficiency (NupE), nitrogen utilization efficiency (NutE), nitrogen harvest index (NHI), harvest index (HI), NUE agronomic efficiency (NUE-AE and NUE partial factor productivity (NUE-PFP) were computed. Computed based on differences in crop yield and total N uptake with above-ground biomass between fertilized plots and unfertilized control (difference method) or by using ^{15}N labelled fertilizers to estimate crop and soil recovery of applied N (Dobermann, 2005).

Traits related to NUE were calculated according to Moll et al. (1982), Huggins and Pan (1993), and López-Bellido et al. (2004) using the following equations: -

$$\text{NUE (kg kg}^{-1}\text{)} = \text{Gy/N supply} \quad (1)$$

$$\text{NUtE (kg kg}^{-1}\text{)} = \text{Gy/Nt} \quad (2)$$

$$\text{NHI (\%)} = (\text{Ng/Nt}) \times 100 \quad (3)$$

where, Gy corresponds to grain yield (kg ha^{-1}), Nt to total plant N of the whole plant biomass at maturity (kg ha^{-1}), Ng is the grain N (kg ha^{-1}) and N supply, the soil N available to the crop (expressed in kg kg^{-1}) from residual and supplied by fertilizr.

2.6 Water Use Efficiency

According to Singh and Sinha. (1977) water use efficiency (WUE) is used to evaluate applied water benefits through economic crop production. It is very important in crop production and irrigation water management described in two ways. Field water use efficiency (FWUE) is a ratio of the amount of economic crop yield to the amount of water required for crop growth. FWUE = kg of economic yield/ha.mm of water. WUE can also be described as the ratio of economic yield to consumptive use of water or evapotranspiration. This is a quantitative measurement of how much biomass or yield is produced over a growing season, normalized with the amount of water used up in the plant. Consequently, biomass production per unit evapotranspiration (ET) has been used extensively as an interim measure of WUE. ET includes non- productive evaporation (E) of water from the soil surface and productive transpiration (T) of soil stored water by the plant. Evaporation of free water from leaf surfaces adds to non-productive evaporation (interception evaporation). Therefore, maximum water use efficiency is achieved by both improving T as a proportion of ET because water lost as evaporation from soil is non-productive and transpiration water use (TWUR) because maximal TWUE needs maximal yield per unit of water transpired (Brian et al., 1999).

Conservation Farming (CF) based farming system was reported to alter the water balance's partitioning, decreasing soil evaporation and increasing infiltration and deep percolation, leading to increased yields and WUE (Acharya, 2018). Water use efficiency is increased and save water by 15-50% through the adoption of CA technologies. It reduces water runoff, better water infiltration and more water in the soil profile throughout the crop growing period. The system has potential to increase water application efficiency by over 50 % (Karki and Shrestha, 2015). According to Cooper et al. (1988), the ratio of the mass of carbon dioxide fixed as carbohydrate to the mass of water transpired from leaves is a valuable quantity because it can be predicated readily from physiological and physical principles. Water use efficiency is determined by Dry biomass yield/ water received ratio; Maize grain yield/water received ratio, water uptake, Dry biomass yield/ water uptake ratio, Water uptake/ water received ratio. Further, Field et al. (1983) describe instantaneous water-use efficiency (WUE) as the ratio of photosynthetic capacity to transpiration.

Sharma et al. (2012) argued that water input to a field or an agricultural system is not the same as the water used or depleted for crop production but may be worked out as output per unit of irrigation supply. Water productivity is estimated from the amount of water directly consumed by the agricultural system (evaporation and transpiration) and not the amount of irrigation water applied or rainfall received (Molden et. al., 2010). This is important because water that is taken or received and not consumed, is available downstream and hence is excluded from the calculation. At a given scale, this may be estimated through a simple water balance equation or by following the water accounting framework as given by Molden et al. (2003) who indicated that, the key term is evapotranspiration (ET), which can be estimated as:

$$ET = P + I + G \pm Q - \Delta S$$

where, P is precipitation, I is irrigation, G is net groundwater flow, Q is run-on or runoff and ΔS is change in soil water content within the root zone and all measured in millimeters of water. Sadras and lawson, (2016) however, expressed the formula to determine evapotranspiration (ET) as: $ET = I + P - R - D - SW$. Where I is irrigation water, P is precipitation (rainfall), R is Erosion, D is downward drainage below the crop root zone. Therefore, water use efficiency (WUE) in relation to grain yield or biomass is defined as: WUE= y/ET. where y is grain yield or dry matter($kgha^{-1}$) and ET is total evapotranspiration during growing period of the crop.

WUE is described as the ratio of total biomass or grain to water supply or evaporation which implies consumptive water use (Dastane, 1974). This means WUE is estimated from consumptive water use and yield data. Consumptive water use is calculated as the sum of effective rainfall and changes in soil moisture storage (mm) (Dastane, 1974).

2.6.1 Use of isotopic carbon to determine Water Use Efficiency

According to Anthony et al. (2006), Carbon accounts for approximately 40 percent of plant dry weight, and is assimilated into plants by photosynthesis. The carbon in atmospheric CO_2 and throughout the biosphere occurs as two stable (i.e., nonradioactive) isotopic forms. The most common form is ^{12}C, which accounts for about 98.9 % of the C in atmospheric CO_2. The other stable isotope, ^{13}C, makes up about 1.1 percent of atmospheric CO_2. Dercons et al. (2006) further explained that isotopic ratio of ^{13}C to ^{12}C in plant tissue is less than the isotopic ratio of ^{13}C to ^{12}C in the atmosphere, indicating that plants discriminate against ^{13}C during photosynthesis. The isotopic ratio of ^{13}C to ^{12}C in C_3 plants ($d^{13}C$) varies mainly due to discrimination during diffusion and enzymatic processes. The rate of diffusion of $^{13}CO_2$ across the stomatal pore is lower than that of $^{12}CO_2$ by a factor of 4.4 ‰. In addition, there is an isotope effect caused by the preference of ribulose bisphosphate carboxylase (*Rubisco*) for $^{12}CO_2$ over $^{13}CO_2$ (by a factor of ~27 ‰). In both cases, the processes discriminate against the heavier isotope, ^{13}C (Farquhar et al., 1989). Based on the work of Farquhar the linkage between discrimination against ^{13}C during photosynthesis and water use efficiency may be demonstrated by the following relationships. The stable isotope ratio ($d^{13}C$) is expressed as the $^{13}C/^{12}C$ ratio relative to a standard (PeeDee Belemnite) (Craig 1957). The resulting $d^{13}C$ value may be used to estimate ^{13}C isotope discrimination as: $D = (d_a - d_p)/(1+ d_p)$. Where d_p is the isotopic composition of the plant material and d_a is that of the air (assumed to be 8‰). As CO_2 assimilation (A) increases or stomatal conductance (g_s) decreases, inter cellar CO_2 decreases resulting in decreased discrimination against ^{13}C. The relationship between c_i and D is represented by the model of Farquhar et al (1982):

$D = 4.4 + 22.6\ (c_i/c_a)$.

where c_i is the intercellular CO_2 and c_a is atmospheric CO_2 (≈ 355 ppm).

The amount of isotopic discrimination that occurs during assimilation may be compared by D or $d^{13}C$. Carbon isotope discrimination (D) may be intuitively easier to grasp. Still, it cannot be calculated if atmospheric $d^{13}C$ is not known or cannot be assumed to be equal to ambient (e.g., growth chamber experiments).

2.6.2 Relationships Between Carbon isotope discrimination and Water Use Efficiency

Carbon isotope discrimination has been proposed as a method for evaluating water use efficiency (WUE) in C_3 plants and as a precise technique for screening plants with higher tolerance under water deficit conditions (Raza et al., 2013). According to Oner (2014), Water use efficiency may be estimated from measurements of dry weight accumulation over time relative to the amount of water transpired (transpiration efficiency, TE) or by measure of gas exchange (instantaneous water use efficiency, WUE*i*). Instantaneous WUE may be calculated as the ratio of assimilation to stomatal conductance or transpiration (A/g_s or A/E). Because E is a function of both g_s and vapor pressure deficit, A/g is sometimes referred to as intrinsic water use efficiency. Based on the relationships described above, D is linked to WUE_i through the effects of *A and* g_s on c_i. As WUE*i* increases due to stomatal closure (decrease g_s) or an increase in A, intercellular CO_2 declines and discrimination decreases. Therefore, WUE*i* is inversely related to D and positively associated with $d^{13}C$.

A strong correlation between D or $d^{13}C$ and c_i/c_a or WUE*i* has been reported for numerous crop and tree species. Johnson and Handley, (2000) observed that correlations between D and A/g ranged between –0.77 and –0.91 for crested wheatgrass in a series of greenhouse and field studies. In the same trials the correlation between D and transpiration efficiency ranged between –0.73 and –0.94. In a study of western larch (*Larix occidentalis* Nutt.) seedlings, Zhang and Marshall (1994) found that D was significantly ($P<0.001$) correlated with transpiration efficiency ($r= -0.85$) and instantaneous water use efficiency ($r = -0.70$). Dercon et al, (2006), concluded in an experiment that a clear and significant water and nitrogen effect on the isotopic discrimination in maize was observed and opposite in direction from C3 plants. In particular, the D values decreased with increased water supply. In addition, isotopic discrimination was observed to be variable within plant parts showing that D values measured in different plant parts at harvest can be used as a historical account of how water availability varied during the cropping period. Yu et al., (2004) modelled WUE of soyabeans and maize plants under drought stress and nitrogen deficiency. They found that WUE was negatively correlated with ^{13}C discrimination and further stated that WUE was higher at high fertilization than at low fertilization. Ebdon, and Kopp (2004) found similar results where WUE and D values in maize were significantly and negatively correlated.

Contrary to D, WUE strongly increased with increasing nitrogen availability which can be linked to the fact that plants are more potent at higher N availability and therefore transpire more water. In the cultivated tomato, *Lycopersicon esculentum* Mill. cv. UC82B, Bjorn. Martin et al. (1999) observed a negative correlation between $d^{13}C$ and WUE in the F_2 generation, and WUE was generally positively correlated with dry matter weight (DW). Averaged across environments, the top 10 % of the plants ranked by WUE had 47 % greater WUE than the bottom 10 %. In comparison, the bottom 10 % ranked by $d^{13}C$ had an average of 16 % greater WUE than the top $d^{13}C$ group, but in three of the four environments the bottom group accumulated 33 to 47% less DW than the top $d^{13}C$ group.

2.6.3 Genetic Variation in Carbon isotope discrimination among crop species

The correlation between water use efficiency and D was extensively studied in several crops (Dercon et al, 2006). These studies suggest that genetic variation in D may be sufficient to be useful as a selection criterion for improved water use efficiency (Farquhar et al., 1989). He further indicated that the variation in isotopic composition among plants with the C4 photosynthetic path way is less than in C3 plants. This is because the potentially significant effect of fractionation by RuBisCo is suppressed in the semi- closed bundle sheath (Bowman et al., 1989).

2.6.4 Advantages of ^{13}C discrimination as a Selection Criteria for improved WUE

Carbon isotope discrimination has several advantages to screening for drought tolerance based on TE or WUE*i*. Carbon isotope discrimination integrates c_i/c_a over the time the sampled tissue was formed. In contrast, WUE*i* measured by gas exchange provides 'snapshots' of *A/g* or *A/E* and may not be representoverall WUE. Measurements of D are much less time and labour intensive than the calculation of whole-plant water use and dry weight data needed to calculate *TE* (Farquhar et al., 1989).

2.6.5 Relevance of WUE as a drought tolerance mechanism

All other factors being equal, genotypes with high water use efficiency will survive and grow better in water-limiting environments than genotypes with low water use efficiency. However, in nature all other factors are rarely equal. The physiological basis for variation in drought tolerance in a given tree species may be due to a wide and potentially unrelated array of mechanisms including needle morphology, allocation patterns, gas exchange patters, osmotic adjustment, and hydraulic architecture. In general, selection for improved water use efficiency through analysis of carbon isotopes will be most helpful in selecting and maintaining growth under drought rather than survival. Survival mechanisms may relate more to growth phenology and allocation patterns than improved carbon gain per unit water loss (Cregg,1994). For instance, ponderosa pine populations known to vary in survival under imposed drought were compared and Zhang et al. (1994) found that variation in WUE*i* and $d^{13}C$ was minimal. In these populations increased survival under imposed drought was more strongly related to allocation to roots than gas exchange characteristics (Cregg,1993). Pennington et al. (1999) found substantial genetic variation in $d^{13}C$ of honey mesquite (*Prosopis glandulosa* Torr.). Still, they determined that a drought escape mechanism was most important for growth and survival under drought for the species. Mesquite seed sources adapted to the driest region of the species range had relatively quick seed emergence and completed growth when soil moisture was adequate.

Drought, which is low water availability or random and unpredictable weather conditions during the period of plant growth, is considered one of the most effective abiotic stress factors limiting production from plants. All field crops respond differently at different phenological stages to changing the soil's water status under drought stress, which means that plants are more sensitive to drought stress at some growth stages. For example, Blum (2005) explained that drought resistance in seedlings grown in a pot has nothing to do with drought resistance during grain filling in the field. Although the drought-resistant ideotype is still not well defined, drought resistance in its physiological context is defined according to Levitt (1972) as being determined by 'dehydration avoidance' (maintenance of water potential in tissue) and/or 'dehydration tolerance' (Price et al., 2002). Dehydration avoidance or osmotic adjustment is defined as the plant's capacity to sustain high plant water status or cellular hydration under drought stress (Blum, 2005; Cushman, 2001). There is no consistent relationship between plant production and water use efficiency (WUE). However, Munoz et al., (1998) pointed out that the high yield potential of plants under water-limited conditions is generally associated with reduced WUE mainly because of high water use.

In contrast, other researchers have explained that high WUE is primarily a function of reduced water use rather than a net improvement in plant production or the biochemistry of assimilation (Blum, 2005). WUE is generally equated with drought resistance and crop yield improvement under stress, due to variations in water use. Also as Farquhar et al. (1989), explained, carbon isotope distribution can reveal information about the physical, chemical, and metabolic processes involved in carbon transformations. This is because carbon isotope discrimination occurs during photosynthetic CO2 uptake leading to a ^{13}C-depletion of plant organic matter. Therefore, it is not surprising that the selection of high WUE using carbon isotope discrimination has resulted in earlier flowering plants that use less water over the growing season. These plants were very suitable for conditions where moderated use of the given amount of stored soil moisture is crucial (Condon et al., 2002). Maintenance of leaf turgor in the face of decreasing soil moisture has been emphasized as an essential adaptation trait that contributes to drought tolerance (Hsiao et al., 1976). Tolerance to internal water deficit has been characterized by turgor loss at lower relative water content (RWC), promoting chloroplast functioning during dehydration

(Gupta and Berkowitz, 1987; Ranney et al., 1991). The studies of dehydration tolerance in crop plants have revealed genotypic variation in plant recovery from dehydration as a measure of tolerance to be positively correlated with the plant water content status (RWC) (Chaves et al., 2002). Anyia and Herzog, (2004) pointed out that the high relative water content (RWC) of cowpea leaves was maintained in some of the genotypes by stomata closure and a reduction in leaf area. Many techniques and parameters such as leaf water potential, leaf osmotic potential, and canopy temperature have been used to screen drought- tolerant plants in different crops (Askahni et al., 2007; David et al., 2007). According to Owner, (2014), drought stress is one of the most limiting factors in agricultural productivity because of its highly negative effect on photosynthesis and the growth of plants. He indicated that the relationship between water use efficiency (WUE) and $d^{13}C$ (isotope carbon discrimination) under drought stress was inversely associated with a strong regression relationship (R2=0.75). It was further revealed that low $d^{13}C$ discrimination types had high WUE, relative water content (RWC) and total biomass under drought stress, thus the ability of the low $d^{13}C$ genotypes (high water use efficiency, WUE) to maintain higher RWC may provide a good indication of the differences in drought tolerance of safflower genotypes differing in $d^{13}C$. Ebdon and Kopp (2004) explained that low $d^{13}C$ values were associated with less wilt (r = 0.59, $P \leq 0.05$) and leaf firing (r = 0.58, $P \leq 0.05$), suggesting that Δ may be a practical selection criterion for superior performance under limiting soil moisture.

2.6.6 Factors that increase WUE

2.6.6.1 Varieties

The yields and water use efficiency of cultivars of crops differ significantly. Varieties that produce more than water use should be grown under limited water areas to increase the water productivity per unit area. Chand and Bham (2002) reported that Varsha sorghum was distinctly superior in WUE in terms of grain production as well as dry matter production to CSV 13 and CSV 15. This was also reported by Hakeem et al. (2018) that maturity and physiological traits among cultivars of sorghum have a significant effect on WUE. They further discovered that early maturing sorghum cultivar (CS 400) recorded the highest mean of WUE while the late maturing (CSR01) was lowest in WUE. However, in contrast Lingduo (2015) observed higher yield and

WUE in adapted late maturing maize varieties. Tahar et al. (2013) showed that different levels of water stress affected the growth of wheat cultivars differently, which indicates that the wheat cultivars differed in their ability to tolerate different levels of water stress. High yielding crop varieties with improved water use efficiency (WUE) are needed. Despite the feasibility of assessing WUE using other measurement techniques, breeding for WUE and high yield is a major challenge. Factors influencing the trait under field conditions are complex, including different scenarios of water availability. Plants with C_3 photosynthesis can moderately increase WUE by restricting transpiration, resulting in higher intrinsic WUE (*i*WUE) at the leaf level. However, reduced CO_2 uptake negatively influences photosynthesis and possibly growth and yield. (Sonja et al., 2018). Among crop species, Field et al. (1983) observed that intercellular CO_2 concentrations varied significantly and with highest photosynthesis per unit of leaf nitrogen tended to attain the lowest photosynthesis per unit of water transpired. The ratio of photosynthesis to transpiration, an instantaneous measure of intrinsic water- use efficiency, was highest in the species commonly found in the driest habitats and lowest in the species most common in the wettest habitats

2.6.6.2 Time of planting

Time of planting does improve the crop yields and optimum utilization of the applied recourses such as water and nutrients. Choice of varieties is also an important input factor since all the cultivars of crops cannot perform equally well under timely and late sown condition (Singh et al., 2003). Shavini et al. (2003) observed that water use efficiency of timely seeded wheat was maximum and decreased by 4.6, 25.8 and 45.4 percent in moderately late (7th December), late (21st December) and very late (7th January) seeded wheat respectively.

Timely planting coupled with selection of appropriate genotypes facilitates drought escape by matching the crop growth cycle to rainfall and temperature patterns to minimize the chance of exposure to water deficit at drought susceptible stages (Huang et al., 2006). The length of the growing season is limited by the duration of rainy season. The earliest possible planting of suitable cultivars reduces the probability of drought during the late grain-filling stage (Heisey and Edmeades, 1999).

2.6.6.3 Method of planting

Planting pattern directly affects yield, solar energy capture, and soil water evaporation have an indirect effect on water use efficiency. The correct planting method to a site of moisture availability can help increase yields and reduce water to be applied. Mahey et al. (2002) reported that consumptive use of water was highest under reduced tillage followed by zero tillage and conventional tillage. However, the WUE was highest under conventional tillage, followed by zero and reduced tillage. In contrast, Huang et al. (2006) reported the result of investigations from almost all world climatic zones. This suggests that ploughing causes common soil-related problems of compaction, soil erosion, reduced water percolation, and increased runoff, and high energy and time requirements. At the same time, conservation farming is designed to minimize soil erosion, improve water infiltration, water storage, and thus yield potential and improved water use efficiency.

2.6.6.4 Row spacing and Row orientation

Narrow row spacing and crop geometry can result in higher yields and WUE. Karrou and Nachit (2015) observed that rain water use efficiency of wheat in Morocco's semi-arid environment decreased when row spacing was changed from 21 cm to 24 cm. Jones (2007) reported that twin – row spacing as an alternative planting practice for corn silage production leads to greater WUE and faster canopy development. Planting geometries or planting patterns can influence WUE, there being many planting patterns for maize according to the environment and cultural conditions. The most common is equal row spacing pattern, of about 70-90 cm row spacing and different intra row plant spacing producing different plant population densities (Huang et al., 2006). Skip row sowing (with 1 row not planted between every 2 or 3 rows of sowing) has been proposed as a means of improving crop reliability by restricting water use early in the season and maintaining a reserve of water in the soil in the wide row space produced by the omitted row. However, though significant yield benefits were observed in grain yield of sorghum, research by Robertson et al. (2003) and Madhiyazhagan (2005) did not observe similar benefits for maize, both finding maize does not exploit the water remaining in the wide row space. However, in South Africa, relatively late maturing maize grown under an annual rainfall of 500-600 mm is often sown at densities as low as 10,000 plants per hectare in row up to 2 m apart (Heisey and Edmeades, 1999).

2.6.6.5 Weed Control and Fertilizer application

Weeds compete with field crops for natural resources such as light, nutrients and water (Norsworthy and Frederick, 2005). The impact of weeds depends on the type and intensity of interference with crop plants. In maize, like other crops, effective control of weeds leads to more efficient water use (Peterson and Westfall 2004). The most critical management interaction in many drought-stressed maize environments is between soil fertility management and water supply. Huang et al, (2006) reported that reduced plant growth rate in nutrient-deficient plants is generally associated with reduced WUE. This was in agreement with Ogola et al. (2002) who indicated that the application of nitrogen increased WUE of maize. Fertilizer use has a very marked effect on crop yield and WUE. Nitrogen and Phosphorus combination of chemical fertilizer with organic fertilizer or chemical fertilizer with bio- fertilizer has been shown to increase crop growth and development in dry and irrigated areas. The application of K fertilizer to plants is a simple agronomic practice used to increase crop tolerance to a temporary water shortage due to improved access to K that increase water uptake by the root cells (Witold, et al, 2013).

2.6.6.6 Moisture conservation practices

Moisture conservation practices have been used widely as means to improve crop yields in a limited water environment. Patil and Sheclavantar (2000) indicated that the formation of compartmental bunds, ridges and furrows improved the yields over flat-bed due to increased moisture and nutrients availability. Huang et al. (2019) observed that variation of the WUE among 12 genotypes was consistent with the grain yield with and under irrigation treatment, the average WUE for wheat genotypes was higher than that under rainfed conditions by 1.5 kg ha^{-1} mm^{-1} in the 2015–2016 growing season, and by 1.2 kg ha^{-1} mm^{-1} in the 2016–2017 growing season. The grain yields were significantly and linearly positively correlated with the WUE (R^2 = 0.8231−0.937. Evaluation of variety WUE could be performed accurately at the individual plant level (WUE_p). Stomatal conductance is considered a a vital trait associating closely with WUE_p because the trait showed a large degree of varietal variability under well-watered conditions (Xu-rong et al, 2013). In another study, Yarkpawolo et al. (2018), reported that moisture stress also causes reduction in biomass yield during an intense drought during the short growing season. In contrast

Polania et al. (2016) reported drought stress reduction in both biomass and grain yield WUE.

Depending on the level amount of crop residues left on the soil surface, Huang et al. (2006) explained that conventional tillage and conservation tillage systems could be used to determine the performance of the crop for WUE. Reports from many investigations suggest that conventional tillage causes common soil-related problems of compaction, soil erosion, reduced water percolation and increased runoff and high energy and time requirements. While conservation tillage with at least 30% residue cover (Derpsch, 2001), is generally used to reduce soil erosion and to improve water infiltration (Guzha, 2004), water storage and thus yield potential and improved WUE (Hartkamp et al., 2004).

2.6.6.7 Crop residue management

Crop residue creates barriers to soil water evaporation, protects the soil from disturbance and compaction, and provides better infiltration with minimum surface sealing and crusting. Crop residue left on the surface help better store water in the soil profile and increase water use efficiency (WUE). A review showed that soil management practices such as residue, tillage and nutrient management could increase WUE by 25 to 40 % (Hatfield et al., 2001). These practices allow to store more water in the soil profile, improve roots ability to extract water effectively, reduce losses of nutrients by leaching and to nitrogen to the soil which has a positive impact on WUE. A study showed that mulched soil achieved 40 % higher crop yield compared to the bare soil (Quemada et al., 2013). Crop residue and mulch have similar advantages as both cover soil, reduce evaporation and maintain soil temperature. Mulch can be the best option where residue retention is not possible.

2.6.6.8 Intercropping

Intercropping is a practice to have an opportunity to diversify cropping system by making the multiple land use and possibly utilize water and other resources more effectively. According to Goswani et al. (2002), WUE increased in the maize- legume intercrops as compared to mono-cropping. Intercropping may be used with maize and can use water from different soil layers by the companion crops and enhances overall WUE where water supply is adequate (Adiku et al., 1998).

CHAPTER THREE

3.0 RESPONSE OF SELECTED MAIZE GENOTYPES TO LOW NITROGEN AND DROUGHT STRESS

3.1. Introduction

The majority of the one million five hundred smallholder farmers in Zambia depend on producing maize (Zea mays) a major staple food for well over 90 % of the Zambians. The majority of maize- producing small holder farmers in Zambia are faced with many challenges to produce the crop more productively and profitably. The productivity of the maize crop among the smallholder farmers over the years has become quite low giving a national average yield of 2.3 tons per hectare (Indaba Agricultural Policy Research Institute [IAPRI], 2015). The major causes of low yields countrywide are attributed to prolonged droughts, erratic rain fall pattern, low soil fertility, insufficient plant nutrients and poor farming practices (Cakir, 2004).

The soil fertility status in several parts of Zambia is also generally low and in most cases could be caused by poor farming practices such as conventional farming or inherently infertile soils at Smallholder farms. The evidence on soil fertility improvement by cover crop was explained by Karsky, Patrice and Salini (2003) that cowpea increases nitrogen in the soil up to 80 kg N ha-1. Being a food legume, cowpea provides the needed proteins in rural households through both grain and leaves used as a relish. Cowpea also plays a multipurpose role of potential to be used for human food; livestock feed and weed control (Rao & Mathuva, 2000).

In the past few years, fertilizers prices have almost become unaffordable by the majority of the smallholder farmers (Aagaard, 2011). Despite the Government subsidies on fertilizers for smallholder farmers, crop yields do not seem to improve. There is much evidence that climate change is also likely to lead to decreases in Global efficiency and resilience of agriculture production while at the same time being confronted with increasing demand from a growing population (Food and Agriculture Organization [FAO], 2010). Measures that promote climate change mitigation there containing the potential to strongly co-benefit adaptation and food security, if targeted in an acceptable way.

In the advent of Climate change (CC) where rainfall pattern have reduced, and temperatures increased, climate- smart agriculture (CSA) technologies such as conservation agriculture could improve maize productivity among smallholder farmers in Zambia. Improving soil quality is one of the fundamental activities of CSA, as higher quality soils are better able to retain moisture and reduce run off-two important features in responding to drought and flooding (Peter and Bram, 2010). Therefore, use of improved maize varieties under the minimum tillage with maize-cowpea rotation could contribute to increased maize yield productivity and adoption of the system in Zambia. This makes alternative option for improving maize production by the smallholder farmers. Maize- Cowpea Rotation involves the planting maize crop after the cowpea legume crop and this technology facilitates improvement of maize productivity through increased soil fertility from cowpea nitrogen fixation (Verhulst et al., 2010).

To respond to these challenges, the experiment was established during the 2014/2015, 2015/2016 and 2016/2017 growing seasons whose main objective was to evaluate maize productivity in conservation farming system, while the specific objective of this study was to Evaluate maize yield performance of selected drought and Low Nitrogen tolerant maize genotypes in conventional and conservation farming system.

3.2. Literature review

3.2.1 Maize yield productivity under conservation Farming system

Conservation agriculture (CA) has been defined as the management of soil, water and agricultural resources to achieve economic, ecological and socially sustainable agricultural production (Jat et al., 2012). CF is more sustainable agriculture production practice than narrowly defined ‘conservation tillage’ (Naresh et al., 2014). CF may be considered new paradigm to achieve higher production by mitigating water and nutrient stress in rain-fed regions by adopting reduced tillage, crop rotations and residue retention and addressing the global warming problem (Sumanta et al., 2013). A review by Thierfelder et al. (2013) indicated that conservation farming is a crop management system of three basic principles applied in a mutually reinforcing manner and are proposed as one of the options to alleviate soil fertility decline. CF is based on a combination of: (1) minimum soil disturbance, i.e., no soil inversion with the plough or hoe; (2) surface crop residue retention as mulch with living or dead plants; and (3) crop rotations and associations of different crop species over time. CA is widely adaptable, and the application of its principles may vary among individual farmers depending on the site and the farmer’s circumstances.

Conservation Farming is a concept for optimizing crop yields, and economic and environmental benefits with major principles of no-tillage, adequate retention of crop residues on the soil surface for mulching, innovative cropping systems and measure to reduce soil compaction through controlled traffic (Sumanta et al., 2013. CF systems also improve soil health and reduce the carbon emissions equivalent to nearly 13ton ha^{-1} (Mandal et al., 2004) reducing the tillage intensity and contribute to carbon sequestration (Srinivasarao et al., 2012). Baker et al. (2007) estimate that the conversion of all croplands to CF globally could sequester 25 Giger tons of carbon (Gt C) over the next 50 years, making CF among the most significant opportunities from all sectors for stabilizing global Green House Gases (GHG) concentrations. Thierfelder et al. (2012) showed that maize yields in a direct- seeded CF treatment, using cowpea seeded with a dibble stick in full rotation, increased by up to 78% after four cropping seasons in comparison to a conventional control using a ridge and furrow system. They further indicated that maize yields for animal traction rip-line seeded and direct- seeded plots were, on average, 75% and 91% higher than a conventionally tilled control plot after six cropping seasons. Results on CF's yield performance in relation to CONV in sub-Saharan Africa are mixed (Guzha, 2004; Stone and Schlegel, 2006). Experiments conducted by Materechera and Mloza-Banda (1997) illustrated an on-significant yield difference between CONV and CF in the first two years of a three-year study, and during the third year the yield in CA was significantly lower. Results from the Laikaipia CA project in Kenya showed similar maize yield in plots managed under CONV and CA (Apina et al., 2007). On the other hand, improved soil water supply, rooting depth and crop yields through minimum tillage techniques have been reported in the semi-arid regions of Kenya (Gicheru et al., 2004). Thierfelder and Wall (2012) reported higher yields in CA plots than in CONV plots on sandy soils in dry seasons but lower yields in CA plots in very wet seasons due to water logging. Ngwira et al., (2012) observed maize yields were higher in CA plots than in CONV after the first season. Thierfelder et al. (2014) reported that yield advantages on two manual CF systems planted with dibble stick with sole maize and maize- legume intercropping in were 1152 kg ha-1 and 1172 kg ha^{-1} respectively. While the ox- drawn CF had slightly smaller yield benefit of 458 kg ha^{-1} on ripped line seeded system and 761 kg ha^{-1} on direct-seeded compared to ploughed. Sumnta et al. (2013) in the pooled data showed that seed (3.0ton ha^{-1}) and stover (5.5-ton ha^{-1}) yields in maize in CA was on par with the conventional system but significantly higher grain (4.7-ton ha^{-1}) and stover (7.9-

ton ha^{-1}) yields were observed under balanced fertilization. In the case of horse gram, significantly higher yields were obtained in CA (572 kg ha^{-1}) compared to conventional (389 kg ha^{-1}). This was due to soil organic carbon status, other labile pools of soil carbon and major nutrients (N, P, K) improved under CA system. Maize grain yield was higher in the CA (2.69-ton ha^{-1}) compared to plough tilled (2.23-ton ha^{-1}) on a tropical Alfisol (Mbah and Nneji, 2010). Many studies showed improvement of soil organic carbon (SOC) contributed to improved water retention which had a very impact on maize yield improvement (Srinivasarao et al., 2012). Long- term application of crop residue or organic amendments can increase water retention up to 2-4 % in semi-arid alfisols which helps in mitigating intermittent dry spells or terminal water stress (Srinivasarao *et al.,* 2012). The study by Sumanta et al. (2013) revealed that maize grain yield was sustained with mulch and fertilizer in the no-till system and was more effective with fertilizer and residue mulch than without a mulch. Due to surface residue's insulation effect, soil temperature fluctuations are decreased in zero tillage with residue retention than in conventional tillage. In tropical hot soils the surface residue cover reduces soil peak temperatures that are too high for optimum growth and development to an appropriate level, favoring biological activity, initial crop growth and root development. Therefore, CA shows considerable potential for stabilizing maize crop production in semiarid zones (Lal, 1995). CF can double the maize yields obtained under conventional tillage in low-yielding environments (Thierfelder et al., 2013). According to Paudela et al. (2014), average maize yields ranged from 2.05-2.2 and 1.67-2.2 -ton ha^{-1}, respectively for year one (2011) and year two (2012), which were much lower than the national average of 2.8 -ton ha^{-1}. There was a significant reduction in maize grain yield in year two compared to year 1. Farmers attributed the lower yield of maize yield in 2012 to relatively un -favourable rainfall conditions.

Rusinamhodzet al. (2011) noted that a long-term tillage and residue retention effect on maize grain yield under contrasting soil textures, nitrogen input and climate showed an increase in maize yield over time, with conservation agriculture practices that include rotation and high input use in low rainfall areas. Conservation agriculture practices require high inputs especially N, for improved maize yields and that increased yields are obtained with crop rotation. In contrast, reduced tillage with no mulch cover leads to lower grain yields in semi-arid areas. Benefits of CF including nutrient cycling, carbon sequestration, and pest and disease control are quite variable, from positive, to neutral or even negative depending on the site-specific context, management, soil type, and climate (Naresh et al., 2016).

3.3 Materials and Methods

3.3.1 Site description

The study was conducted at two sites at Chisamba S 14.96783°, E 028.09408°; and Batoka S16.79993°, E 027.20181° both in region II of the Zambian agro-ecological zones but with differing soil types, soil fertility status and climatic conditions. The sites were selected to assess the interactive response of the selected low nitrogen and low drought- tolerant maize varieties and cowpea genotypes for crop productivity. The Batoka site exhibits low fertility and moisture deficits (Table1 and Figure 2) while Chisamba site is well –endowed with fertility and rain fall patterns (Table 2 and Figures 1 and 3).

Soils at the Batoka site are classified as well- drained, very deep (>90 cm) strong brown to red and in places underlain by a thick pale brown to white loamy sand to sandy loam. The soils are classified as *Chromic haplic Lixisols* in the World Reference Base for Soil Resources (WRBSR, 2014). The soils are generally acidic with pH between the ranges of 3.7 and 4.4. The Cation Exchange capacity is very low while organic matter is less than 1.5 %. The soil exhibits compacted soil layer at around 15–20 cm depth (Base line data Table 1 and 2). The Batoka site lies at an altitude of 1200 m above sea level, located in the Southern Province, about 300 km from Lusaka. The site has a mean annual rainfall of about 825 mm with a dependable rainfall at 70 % probability of 539 mm. Figure 2 shows the rainfall pattern during the 2015/2016 growing seasons at Batoka. The length of the growing season is about 125 days. The total annual reference evapotranspiration (ETo) is 1251 mm which exceeds the mean annual rainfall. The mean annual temperature is 18.2 °C while the mean annual minimum and maximum are 10.9 °C and 26.5 °C respectively (Sokotela et al., 2005).

At the Chisamba site the soils are well-drained, very deep (>90 cm), reddish- brown, friable, shiny fine clayey with a humic topsoil. The soils are classified as *niti-luvic Phaeozems* (WRBSR, 2014). The soil pH is in the range of 5.5 to 6.2. The Cation Exchange Capacity and plant nutrients are relatively high. Organic matter is between 0.7 and 3.0 %. The soil is suitable for the production of most arable crops (Table 1 and

2). The Chisamba site is located between altitude 1100 and 1300 above sea level and is in Zambia's central province about 65 km north of Lusaka the capital city. The length of the growing season is about 140 days. The mean annual rainfall of about 825 mm with a dependable rainfall at 70% probability of 651 mm. Figures 1 and 3 show rainfall pattern during 2015/2016 and 2016/2017 growing seasons at Chisamba. The total yearly reference evapotranspiration (ETo) is 1511 mm. The mean annual temperature is 18.2 ℃ while the mean annual minimum and maximum are 10.9 ℃ and 26.5 ℃ (Sokotela et al., 2005).

. **Table 1**: Baseline Soil chemical properties of the experimental sites

Farming Systems	Site	Depth	pH	OM	N	P	K	Ca	Mg	Zn
		Cm		%		mg/kg		cmol(+)/kg		mg/kg
CONV	Batoka	0-15	4.12	1.32	0.08	17.4	0.1	1.27	0.29	0.04
CONV	Batoka	15-30	4.31	0.96	0.06	14.62	0.08	1.78	0.37	0.06
CF	Batoka	0-15	3.8	0.88	0.03	34.06	0.1	1.66	0.19	0.24
CF	Batoka	15-30	3.71	1.12	0.03	37.88	0.08	0.93	0.11	0.14
CONV	Chisamba	0-15	6.17	0.72	0.05	17.92	1.04	10.9	5.48	0.2
CONV	Chisamba	15-30	6.2	1.72	0.08	17.86	0.78	10.92	5.76	0.12
CF	Chisamba	0-15	5.49	2.96	0.06	18.86	1.11	8.59	4.4	0.28
CF	Chisamba	15-30	5.58	2.72	0.08	16.15	0.83	8.98	5.01	0.20

Note: CF = Conservation farming plot, CONV = Conventional farming plot, .M = Organic matter, N = total nitrogen, CEC = Cation Exchange Capacity, Ca = Calcium, K = Potassium, Mg = Magnesium, Na = Sodium, P = Phosphorus, pH = acidity level

Table 2: Baseline Soil physical properties of the experimental sites

Farming Systems	Site	Bulk Density	FC θv	PWP θv	PAW θv	Sand	Clay	Silt	Texture
		g/cm3	%	%	%	%	%	%	
CONV	Batoka	1.37	29.04	6.03	23.01	82	6.8	11.2	Loamy Sand
CONV	Batoka	1.4	29.08	4.43	24.66	82	6.8	11.2	Loamy Sand
CF	Batoka	1.37	35.73	5.22	30.51	82	6.8	11.2	Loamy Sand
CF	Batoka	1.36	43.16	14.74	28.42	82	6.8	11.2	Loamy Sand
CONV	Chisamba	1.12	27.93	10.77	17.16	46	24.8	29.2	Loam
CONV	Chisamba	1.1	18.68	4.96	13.72	42	30.8	27.2	Clay Loam
CF	Chisamba	1.14	18.00	6.28	11.72	42	30.8	27.2	Clay Loam
CF	Chisamba	1.11	15.86	4.41	11.45	40	34.8	25.2	Clay Loam

Note: FC= Soil moisture content at Field capacity, PWP = Soil moisture content at Permanent wilting point, PAW = Plant available water, BD = Bulk density.

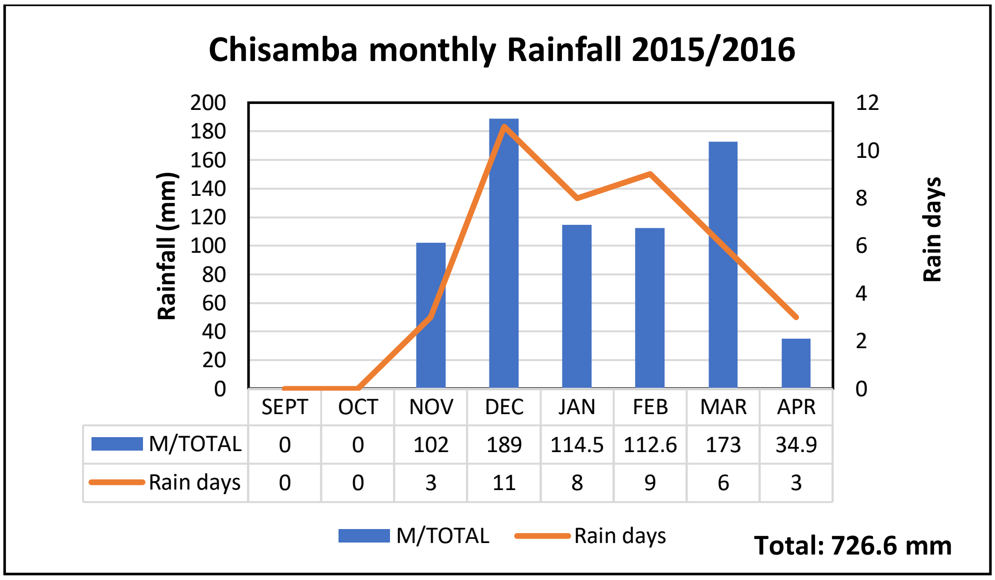

Figure 1: Monthly rainfall 2015/2016 at Chisamba

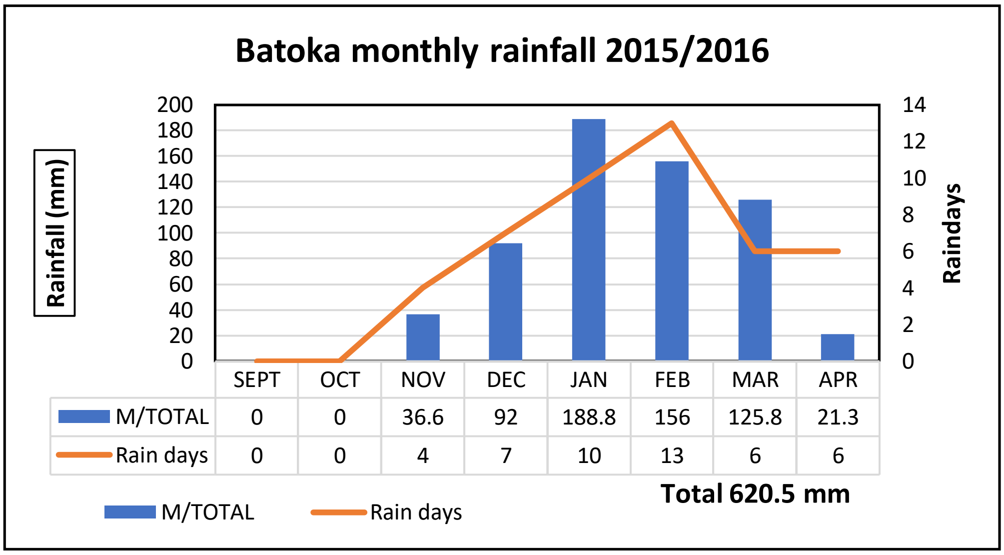

Figure 2: Monthly rainfall 2015/2016 at Batoka

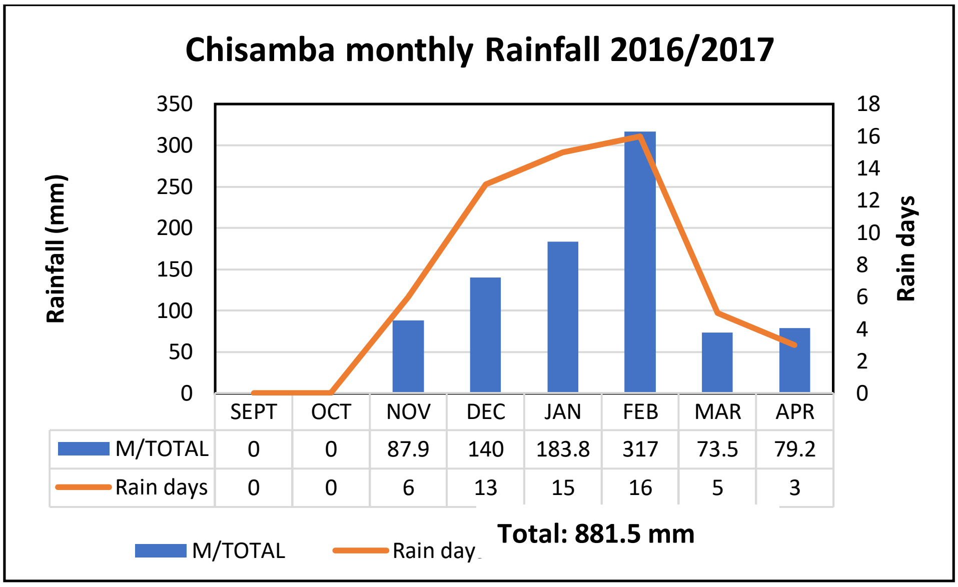

Figure 3: Monthly rainfall 2016/2017 at Chisamba

3.3.2 Source of seeds

Three maize varieties were evaluated for yield performance. Two (2) maize varieties (GV 640 and GV 635) were both selected for low nitrogen and drought tolerance traits from the Zambia Agricultural Research Institute (ZARI) maize breeding programme. The third variety was ZMS 606 from Zamseed Company and is purchased mainly by small holder farmers based in Region II of the Zambian agro-ecological zone.

The four cowpea genotypes selected for maize rotation under conservation farming system for two seasons were the two parents (Bubebe and Lutembwe) and two mutant derived genotypes (BB 14-16-2-2 and LT 11-3-3-12) one from each parent obtained from the University of Zambia School of Agricultural Sciences, Department of Plant Science. Lutembwe parent (LTPRT) and its mutant (LT 11-3-3-12) are indeterminate and running types while Bubebe parent (BBPRT) and its mutant (BB 14-16-2-2) are determinate - bushy trifoliate types. The cowpea mutants were developed from the mutation of cowpea parent materials. The parents were initially irradiated by using 150 gray (Gy) with Gamma radiation. The process developed different alleles with variants different from their parents. The mutants were selected for tolerance to abiotic (Drought, Aluminum toxicity) and biotic (pests and diseases) stresses.

3.3.3 Experimental Design

The experimental design used was a split-plot arranged in a Randomized Complete Block Design (RCBD) and replicated three times per site. The main treatments were the two different farming systems adjacent to each other. (a) Conservation farming system (CF) included minimum tillage by ox- drawn ripping, maize-cowpea rotation and crop residue retention. Four cowpea genotypes used in rotation under CF were (Bubebe and Lutembwe) and two mutants (BB 14-16-2-2 and LT 11-3-3-12). (b) Conventional farming system (CONV) involved complete tillage of soil by ox-drawn ploughing, mono-cropping and removal of maize crop residues after harvesting. The sub treatments were three maize genotypes which were ZMS 606 (M1), GV 640 (M2) and GV 635 (M3). The data was organized and analysed across sites to show the Genetic and Environmental interactions between sites, farming systems, cowpeas and maize genotypes. During the 2016/2017 growing season, maize yield response was organized and analysed for one site (Chisamba) to show farming systems x maize varieties and cowpeas x maize varieties interactions.

3.3.4 Trial Establishment

In year one (2014/15 season), maize varieties in the conventional farming systems and cowpea genotypes in the conservation farming systems were planted. The trial establishment of year one aimed at creating the rotation system for maize- cowpea in the CF and mono-cropping system for maize-maize in the conventional system. Four cowpea genotypes were analyzed for rotation potential with maize on the already established CF field plot, field plot with minimum tillage and rotation for at least three years. In year two (2015/2016 growing season). Maize varieties were planted and assessed for yield performance in the cowpea– maize rotation system on the four cowpea genotypes in the CF plot as compared to same maize varieties under maize mono- cropping system (conventional). Cowpea was planted for rotation with maize in the third year on the CF plot. In the year three (2016/2017) growing season, maize crop was planted both under conservation system and conventional systems. However, maize yield performance for 2016/2017 growing season was only evaluated at the Chisamba site.

3.3.5 Trial Plot size

Four (4) rows of 6 m length spaced at 0.75 m were marked and planted with maize at an intra-row spacing of 0.25 m. Each plot of cowpea crop had 12 rows of 6 m length spaced at 0.75 m. Cowpea seed was drilled along the ripped furrows to about 7cm between seeds. Two (2) guard rows at each end of the block for both crops were included.

3.3.6 Data collection

3.3.6.1 Soil physical properties

Soil physical properties were analyzed at base line stage and after two seasons of setting up the trials at the University of Zambia soil physics laboratory. The major soil physical properties analyzed were soil water content, Bulk density and soil texture. Soil moisture content for physical soil properties was determined by the gravimetric method using the formula on a weight basis.

$$Soil\ Moisture\ Content = \left(\frac{weight\ of\ moisture\ in\ soil\ sample}{weight\ of\ oven-dry\ soil\ sample} \right) x100$$

In a plot, two core samples were taken using soil auger on which standard 100 cm^3 core rings were attached during sampling. The core samples were collected from two depths of 0-5 cm and 5-10 cm. The soil samples were weighed for wet weight soon after sampling and were dried in an oven at 105 ^{0}C for 24 hrs. The dry weight of the samples was then determined after the soil had cooled. The data was used to compute both soil moisture (M.C) content and Bulk density (B.D). The bulk density was calculated using the formula:

$$Bulk\ Density = \frac{Dry\ weight\ of\ sample}{Volume\ of\ sample} (g/cm^3)$$

The soil moisture content at Field capacity (FC) and permanent Wilting Point (PWP) were determined to compute available plant water by subjecting soil samples to the pressure of 0.1 bars and 0.7 bars. The soils were sieved and saturated with water before they were subjected to pressure for three days when the water stopped dripping. Having exerted under pressure the soil was weighed to get wet weight and was put in the oven at 105^0C for 24 hrs to obtain the soil's dry weight for soil moisture content at FC and PWP. Plant available water (PAW) was then computed as the difference between soil moisture at FC and PWP.

3.3.6.2 Soil Chemical properties

Chemical soil properties measured were soil organic matter (O.M), pH, Nitrogen content (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na), Zinc (Zn). Baseline soil properties were determined in the first season while trial treatment effect to soil chemical properties was done in the second season at Mt. Makulu soil chemistry laboratory. Soil sampling for base line soil chemical analysis was done per replication block. Therefore, a total of six samples were taken at both sites. Five primary soil samples were collected from two depths of 0-15 cm and 15-30 cm per block using a soil auger. The five soil samples of each depth were mixed to make a composite from which about 500g per block was taken and submitted for chemical analysis. The treatment soil sampling occurred in the second season of rotation. Soil sampling was done towards the beginning of the season in the twelve plots that were planted with cowpeas of the three replications. Five primary samples per plot were collected and mixed to make a composite where about 500g per plot was taken and submitted for analysis of chemical properties.

3.3.6.2.1 Soil Reaction (pH)

The pH determination which is a measure of hydrogen ion (H^+) acidity in the soil solution, which is the negative logarithm to base 10 of the Hydrogen ions was determined using electrometric method that involves the use of a hydrogen sensitive electrode (Glass electrode) together with a reference electrode. The two electrodes were inserted in the soil/0.01M $CaCl_2$ solution mixture. The instrument was calibrated with pH 7.0 buffer.

3.3.6.2.2 Soil Organic Matter (O.M)

Organic carbon in the soil samples was determined with the Walkley –black method based on the oxidation of soil organic carbon by potassium dichromate ($K_2Cr_2O_7$) in sulphuric acid (Walkley and Black, 1934). 10mls of potassium dichromate was added to 1g of the sample. 20 mls of concentrated sulphuric acid was added and left to cool for 30 minutes for digestion in the fume hood. 200 mls of distilled and 10 mls of phosphoric acid were added and mixed. The contents were then titrated with ferrous sulphate. The titrate was subtracted from the blank read and the value was multiplied with 0.31551 to get C %. The organic matter (O.M) was obtained as 2 x C % (University of Zambia, 2018).

3.3.6.2.3 Total Nitrogen (TN)

Total Nitrogen in the soil samples was measured using the Kjeldahl Technique which determines organic and inorganic nitrogen content. This was done in three step-process. (i) The digestion process allowed Organic Nitrogen converted into NH_4^+ (ii) Distillation where NH_4^+ was distilled to the receiver flask and (iii) where Ammonia was determined. The digestion was done by boiling a homogeneous sample in concentrated sulphuric acid at 410 ^oC to oxidize organic matter into ammonium nitrogen as shown by the equation (University of Zambia, 2018)

Organic N + H_2SO. $\longrightarrow$ $(NH_4^+)2\ SO4 + H_2O + CO_2+$ Other sample matrix by products.

The distillation process involved adding an excess base (NaOH) in the acid digest mixture which converted NH_4^+ into Ammonia (NH_3). The NH_3 was then collected in a boric acid- indicator solution.

The amount of Nitrogen was calculated from the quantified amount of NH_3 using Boric Acid that contained the titration indicator while 0.25N HCl was used in the titration.

$$Percentage Nitrogen (\%) = \frac{(ml\ standard\ acid - ml\ blank) \times (N\ of\ acid \times 1.4007)}{Weight\ of\ the\ sample in\ grams}$$

3.3.6.2.4 Phosphorus (P)

Phosphorus was measured using Bray-1-P Extractant (Bray and Kurtz, 1945). An acidified extracting solution of ammonium molybdate containing ascorbic acid and antimony was added to the soil sample. A 3g air-dry soil passed through a 2 mm sieve was weighed and put into a 15 cm^3 centrifuge tube. 21 cm^3 of the extracting solution was added. The soil solution was shaken for one minute on a mechanical shaker and centrifuged at 2000 rmp for 15 minutes. 5 cm^3 of the supernatant was pippeted into 25 cm^3 volumetric flask. Approximately 10 cm^3 of distilled was added. 4 cm^3 of the extracting solution was added followed by the distilled water to make up. The amount of light absorbed by the solution at 882nm was measured with a spectrophotometer (Murphy and Riley, 1962) and (Watanabe and Olsen, 1965).

3.3.6.2.5 Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na) and Cation Exchange Capacity (CEC)

The bases were measured using Ammonium Acetate Extraction. The method used 1N ammonium acetate (NH4OAc) buffered at pH 7.0 to extract the basic cations from the soil. A 10g air-dry soil passed through a 2 mm sieve was weighed and put into a 250 cm^3 flask. 50 cm^3 of NH4OAc was added at pH 7.0. The soil solution was shaken on a reciprocal shaker for 30 minutes. The suspension was filtered using No.42 Whitman filter paper and the exchangeable cations were measured in the filtrate. The Cation Exchange Capacity (CEC) was computed as the sum of the exchangeable bases and acidity (University of Zambia, 2018).

3.3.6.2.6 Zinc (Zn)

The micronutrient zinc was extracted from the soil sample using a solution Diethylenetriaminepentaacetic acid (DTPA) at a soil to solution ratio of 1:2 volumes. The Zn element in the extract was determined by Atomic Absorption Spectrophotometry (AAS) (University of Zambia, 2018).

3.3.6.3 Plant measurement and Weather

The plant yield data collected on maize crop after rotation with cowpea genotypes were dry biomass and maize grain yields expressed in kg ha^{-1}. The weather data collected from the two sites for 2014/15, 2015/2016 and 2016/2017 growing seasons.

3.3.7 Crop management

3.3.7.1 Tillage

Minimum tillage using ox-drawn magoye ripper was done before the onset of the rains for conservation farming system. Ripped furrows were spaced at 75 cm between rows at 15 cm soil depth. Under conventional farming system, the mouldboard plough was used for tillage when the soil was relatively wet.

Figure 4: Ripped lines using ox-drawn Magoye Ripper

3.3.7.2 Planting

During the 2014/2015 growing season, maize genotypes were planted under conventional farming system (CONV). The four cowpea genotypes were grown under minimum tillage practice in the conservation farming system plot (CF) at two sites. During the 2015/2016 and 2016/2017 growing seasons, maize genotypes were planted under CONV and CF plots in rotation with cowpea genotypes. Two maize seeds were planted manually at 25 cm between stations in the ripped furrows spaced at 75 cm after the cowpea crop. Under the conventional (Mono cropping) two maize seeds were manually planted on ploughed soil at 25 cm between stations on rows spaced at 75 cm during 2014/2015, 2015/2016 and 2016/2017 on the same piece of land. The maize crop was thinned to one plant two weeks after emergence. Planting of cowpea used for rotation was done by hand through drilling along the ripped furrows at seed rate of 30 kg ha^{-1} to about 7 cm between seeds.

3.3.7.3 Fertilizer application

The maize crop was fertilized with a compound fertilizer (10 %N: 20 % P: 10 % K at 200 kg ha^{-1} providing 20 kg ha^{-1} nitrogen, 40 kg ha^{-1} P_2O_5 and 20 kg ha^{-1} K_2O at planting. Urea (46 % N was applied as the top dressing was applied to provide 92 kg ha^{-1} Nitrogen at the vegetative growth stage, five weeks after planting. The fertilizer was applied on the four rows of maize spaced at 0.75m between rows and 6 m length. Each row received 90g of basal dressing. The cowpea was applied with compound fertilizer 10 %N: 20 % P: 10 % K at 200 kg ha^{-1} providing 20 kg ha^{-1} nitrogen, 40 kg ha^{-1} P_2O_5 and 20 kg ha^{-1} K_2O at planting. The fertilizer on cowpeas was applied on the 12 rows spaced at 0.75 cm between rows and 6.0 m length. Each row received uniformly distributed basal fertilizer of 90 g. The basal fertilizer was drilled along the ripped furrows for maize and cowpea while top dressing was banded on the maize crop.

3.3.7.4 Pest and Disease Control

Two separate sprays against pests and diseases were made on cowpeas plots. The first control was at two weeks after cowpea emergency and the second at flowering stage. Maize crop was protected against fall army worm pest by spraying insecticide two times at vegetative and once at flowering stages. Ampligo insecticide marketed by syngenta was used for both crops at a rate of 20 mls per 20 litres of knapsack sprayer with a conical nozzle. The active ingredients in Ampligo are antraniliprole and Lambda- cyhalothrin.

3.3.7.5. Weed control

At planting, weed control started with Glyphosate spray targeting emerged weeds in the trial field. The subsequent weeding was done manually with hand hoes twice at two and four weeks after planting the crop.

3.3.7.6. Harvest

Two inner rows of maize crop were harvested for dry biomass and grain yield analysis. The outer two rows per plot of maize served as guard rows protecting the crop against pests and other environmental factors. Maize plants within 0.5 m from both ends were discarded leaving 5 m in length for harvest. Harvesting was done manually. The field weight was determined by weighing the total cobs harvested from the net plot. A sample of 10 cobs was taken and shelled to determine shelling percentage (SH) and field grain moisture content using a grain moisture meter. The grain yield per hectare was computed as product of shelling percentage and field weight standardized at 12.5 % soil moisture content. Yield (kg/ha) =SH/100* 10000m^2/plot area m^2*(100-sample moisture content)/(100-12.5). Measurement of dry biomass involved weighing of maize crop stover from the two rows, sampling a representative weight of about 0.5g, weighing the wet sample and drying the sample in an oven for 48 hrs at 80 ^{0}C. Dry biomass was computed as dry sample weight (kg)/ wet sample weight (kg) x Field weight x 10000 m^2/plot area m^2.

3.3.8 Data analysis

The agronomic data collected were arranged and organized using Microsoft excel. Agronomic maize yields data and effects of cowpea genotypes on maize grain and dry biomass yields were analysed with the help of Genstat 18th edition (Paul and Jac, 2016) in Split plot design across the sites for 2015/2016 growing season. The data for the 2016/2017 growing season was analysed in a split-plot design at Chisamba. The treatment differences were separated and interpreted for significant differences at a probability level of < or = 0.05. Standard Errors of Means and Least Significant Difference values were used to separate the means for significance.

3.4 Results and Discussion

3.4.1 Maize Grain Yield (kg ha^{-1})

A significant difference ($P<0.001$) for maize grain yield between the two experimental sites, farming systems, maize varieties and the interactions was observed. There were significant interactions between the site x farming systems, site x maize varieties, farming systems x varieties and site x farming systems x maize varieties in the 2015/2016 growing season (Table 3). On average, the Chisamba site produced significantly ($P<0.001$) higher maize grain yield of 7595 kg ha^{-1} than Batoka which had 3639 kg ha^{-1} during the2015/2016 growing season. The yields of maize from conservation farming system (CF) was 8203 kg ha^{-1}and were 17.4 % more than from conventional farming system (CONV) practice at the well-endowed site (Chisamba) whereas at the poorer and drought-prone site (Batoka), CF had maize grain yields of 4996 kg ha^{-1} which were 119.0 % more than in the CONV practice. Therefore, the interaction effect between site and farming systems indicated higher maize grain yield response of selected drought and Low Nitrogen tolerant maize genotypes to CF at Batoka than Chisamba. During the 2015/2016 growing season, the effect of the conservation farming (CF) system against conventional farming (CONV) system on maize grain yield of maize varieties was 16.2 %, 15.6 % and 20.6 % for ZMS 606, GV 640 and GV 635 respectively at Chisamba. Whereas at Batoka, the effect of CF over CONV was 396.0 %, 59.1 % and 61.1 % for ZMS 606, GV 640 and GV 635 respectively (Table 4). The interaction effect between farming systems and maize varieties results showed that ZMS 606 variety purchased mainly by smallholder farmers responds well under CF compared to CONV while GV 640 and GV 635 the selected low N and drought- tolerant varieties are generally stable under CF and CONV systems (Table 4).

Table 3: Mean squares for combine analysis of variance of maize varieties performance under the influence of farming systems at two sites during the 2015/2016 growing season

Variate: Maize 2015/2016		**Grain yield (kg ha^{-1})**
Source of variation	**d.f.**	**m.s.**
Site	1	266104702***
Rep/Location	4	1053386
Farming system	1	59318357***
Site x Farming system	1	8055662**
Error	4	524771
Maize variety	2	5724232***
Site x Maize variety	2	964264ns
Farming system x maize variety	2	964264***
Site x Farming system x.maize variety	2	964264***
Error	16	964264

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05.

Table 4: Influence of farming systems on maize grain yield of maize varieties at two sites during the 2015/2016 growing season

		Maize varieties			
			Low N and Drought tolerant		
Site	**Farming**	**Grain yield (kg ha^{-1})**			
	System	**M1 (control)**	**M2**	**M3**	**Mean**
Chisamba	**CF**	8569 ± 254.2	7791 ± 144.2	8250 ± 175.0	**8203 ± 191.1**
	CONV	7377 ±103.3	6741 ± 257.9	6843 ± 239.6	**6987 ± 200.3**
	Mean	**7973 ± 178.8**	**7266 ± 201.1**	**7547 ± 207.3**	**7595 ±195.7**
Batoka	**CF**	5956 ± 112.3	4613 ± 224.5	4418 ± 221.5	**4996 ± 186.1**
	CONV	1201 ± 110.2	2899 ± 242.8	2742 ± 117.1	**2281 ± 156.7**
	Mean	**3579 ± 111.3**	**3756 ± 233.7**	**3580 ± 169.3**	**3639 ± 171.4**
FPr	<0.001				
Lsd (0.05)	250.5				
CV (%)	10.8				

Note: CF= Conservation farming, CONV = Conventional farming, M1 (ZMS 606) Control = mostly purchased by smallholder farmers, M2 (GV 640) and M3 (GV 635) = selected Low N and drought tolerant ± denotes standard error of means

During the 2016/2017 growing season, significant difference (P<0.001) for maize grain yield was attained between farming systems, maize varieties and the interaction between the farming system and maize varieties (Table 5). The maize grain yield under the conservation farming system was on average 12281 kg ha^{-1} and was significantly (P<0.001) higher than the grain yield of 5220 kg ha^{-1} under conventional farming system at Chisamba by 135.3 %. The effect of conservation farming on maize grain yield was 131 %, 150 % and 124.3 % for M1 (ZMS 606), M2 (GV 640) and M3 (GV 635) respectively (Table 6).

Table 5: Mean squares for analysis of variance of maize varieties grain yield performance under the influence of farming systems at Chisamba during the 2016/2017 growing season

Variate: Maize 2016/2017		Grain yield (kg ha^{-1})
Source of variation	**d.f.**	**m.s.**
Rep	2	1696176
Farming system	1	358933436***
Error	2	501896
Maize variety	2	14223802***
Farming system xmaize variety	2	2219989**
Error	8	475845

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05

Table 6: Influence of farming systems on maize grain yield of maize varieties at Chisamba during the 2016/2017 growing season

	Maize varieties			
		Low N and Drought tolerant		
	Maize grain yield (kgha^{-1})			
Farming system	**M1 (control)**	**M2**	**M3**	**Mean**
CF	11546 ± 265.3	13624 ± 791.1	11672 ± 429.7	**12281 ± 495.0**
CONV	5003 ± 260.9	5454 ± 204.4	5204 ± 226.1	**5220 ± 230.5**
Mean	**8275 ± 263**	**9539 ± 498**	**8438 ± 328**	**8751 ± 362.5**
FPr	<0.045			
Lsd (0.05)	1019.3			
CV (%)	18.5			

Note: CF= Conservation farming, CONV = Conventional farming M2 (GV 640) and M3 (GV 635) = selected low N and drought tolerant. M1 (ZMS 606) Control = mostly purchased by smallholder farmers. ± denotes standard errors of means.

Maize varieties significantly (P<0.001) varied for maize grain yield. During the 2015/2016 growing season, the maize variety ZMS 606 control that smallholder farmers purchase yielded 8569 kg ha^{-1} of maize grain in the CF and 7377 kg ha^{-1} in the CONV. The yields were significantly higher than maize yields of GV 640 and GV 635 the selected low N and drought-tolerant varieties at Chisamba both under CF and CONV systems. At Batoka, ZMS 606 had maize grain yield of 5956 kg ha^{-1} which was significantly higher than GV 640 and GV 635 by 29.1 % and 34.8 % respectively under CF system. ZMS 606 had the lowest maize grain yield of 1201 kg ha^{1} under CONV at Batoka site (Table 4). Maize variety GV 640 that yielded 11990 kg ha^{1} of grain during the 2016/2017 growing season at Chisamba was however, significantly (P<0.001) superior over an average of (M1) ZMS 606 and (M2) GV 635 by 16.3 % while ZMS 606 with 5003 kg ha^{1} was lowest in maize grain yield under CONV (Figure 5 and Table 6).

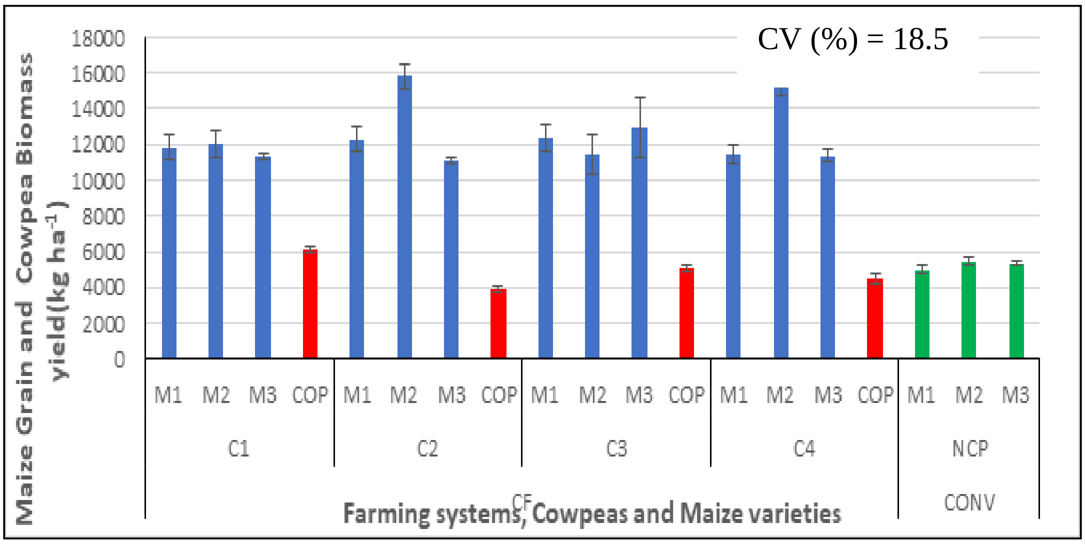

Figure 5: Effect of farming systems and cowpea genotypes on the performance of maize varieties

Note: C1 = Lutembwe parent, C2 = Bubebe parent bush type, C3 = Lutembwe mutant, C4 = Bubebe mutant, NCP = Non cowpea plot, CF = Conservation farming system, CONV = conventional farming system. Cop = cowpea dry biomass yieldError bars denote standards errors of means

The maize grain yield significantly (P<0.001) varied among the cowpea genotypes used in rotation under CF at both sites and growing seasons. Highly significant interactions (P<0.001 between site x cowpea genotypes, cowpea genotypes x maize variety and site x cowpea genotypes x maize varieties were observed for 2015/2016 growing season. A significant interaction (P<0.001) was achieved between cowpea genotypes x maize varieties for the 2016/2017 growing seasons (Table 7 and 8).

Table 7: Mean squares for combine analysis of variance of maize varieties performance under the influence of cowpea genotypes at two sites during the 2015/2016 growing season

Variate: Maize 2015/2016		Grain yield (kg ha^{-1})	Yield change (%)
Source of variation	**d.f.**	**m.s.**	**m.s.**
Site	1	276764970	22926.17***
Rep/Location	4	608909	35.94
Cowpea genotype	4	14863097	361.28***
Sitex cowpea genotype	4	2398060	144.03***
Error	16	210530	5.15
Maize variety	2	4868460	3270.54***
Site x maize variety	2	805523	3309.9***
Cowpea genotype x maize variety	8	2222556	269.27***
Sitex cowpea genotypex maize variety	8	1248500	85.67***
Error	40	191888	11

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05

Table 8: Mean squares for analysis of variance of maize varieties grain yield performance under influence of cowpea genotypes at Chisamba during the 2016/2017 growing season

Variate: 2016/2017		Grain yield (kg ha^{-1})
Source of variation	**d.f.**	**m.s.**
Rep	2	1696176
Cowpea genotype	4	94155204***
Error	8	891453
Maize variety	2	14223802***
Cowpea genotype x maize variety	8	8158125***
Error	20	1409824

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05,

During the 2015/2016 growing season, the highest maize grain yield attained by ZMS 606 under CF was mainly influenced by cowpea genotype mutant LT 11-3-3-12 at Batoka (6190 kg ha^{-1}) and was significantly higher than the NCP by 415.4 %. On average, mutant BB 14-16-2-2, BBPRT and LTPRT had increased maize grain yield of all maize varieties more than NCP by 127.0 % at Batoka. Cowpea mutant BB 14-16-2-2 significantly contributed to the high grain yield of ZMS 606 at Chisamba (9390 kg ha^{-1}) more than the NCP plot by 27.3 % and on average contributed more to all maize varieties than NCP by 22.5 % (Table 9). The results therefore, showed that the interaction effect of site, cowpea genotypes and maize varieties had highest maize yield response when ZMS 606 was planted after mutant LT 11-3-3-12 at Batoka and after mutant BB 14-16-2-2 at Chisamba.

Table 9: Influence of cowpea genotypes on maize grain yield of maize varieties at two sites during the 2015/2016 growing season

		Maize varieties			
			Low N and Drought tolerant		
		Maize grain yield (kgha^{-1})			
Site	**Cowpea genotypes**	**M1 (control)**	**M2**	**M3**	**Mean**
Batoka	**LTPRT**	6023 ± 221.6	4354 ± 217.8	5230 ± 83.8	**5202 ± 174.4**
	BBPRT	5767 ± 126.9	5326 ± 120.1	4552 ± 86.4	**5215 ± 111.1**
	LT	6190 ± 99.5	3651 ± 348.5	3497 ± 422.9	**4446 ± 290.3**
	BB	5845 ± 385.6	5120 ± 215.4	4395 ± 351.7	**5120 ± 317.6**
	NCP	1201 ± 110.2	2899 ± 242.8	2742 ± 117.1	**2281 ± 156.7**
	Mean	**5005 ± 188.8**	**4270± 228.9**	**4083 ± 212.4**	**4453 ± 210.0**
Chisamba	**LTPRT**	8415 ± 104.3	7321 ± 225.5	8691 ± 562.1	**8142 ± 297.3**
	BBPRT	7784 ± 454.5	8013 ± 149.2	8554 ± 154.2	**8117 ± 252.6**
	LT	8687 ± 235.9	7472 ± 130.3	7822 ± 178.8	**7994 ± 181.7**
	BB	9390 ± 696.5	8358 ± 142.3	7934 ± 128.4	**8561 ± 322.4**
	NCP	7377 ± 103.3	6741 ± 257.9	6843 ± 239.6	**6987 ± 200.3**
	Mean	**8331 ± 318.9**	**7581 ± 181.0**	**7969 ± 252.6**	**7960 ± 250.8**
FPr	<0.001				
Lsd (0.05)	723.8				
CV (%)	7.1				

Note: LTPRT = Lutembwe parent indeterminate type, BBPRT = Bubebe parent cowpea determinatetype, LT = Lutembwe mutant indeterminateand running type, BB 14-16-2-2 = Bubebe mutant determinatetrifoliate type, M2(GV 635) and M3 (GV 640) = selected low N and drought tolerant. M1 (ZMS 606) Control = mostly purchased by smallholder farmers. ± denotes standard errors of means

During the 2016/2017 growing season, cowpea mutant BB 14-16-2-2 and the parent BBPRT had significantly increased maize grain yield of 12734 ha^{-1} and 13065 kg ha^{1} respectively, more than non-cowpea treatment which yielded 5220 ha^{-1} at Chisamba. The significant highest maize grain yield interaction was 15820 kg ha^{1} and 15352 ha^{-1} obtained between the rotation of maize variety GV 640 with parent BBPRT and mutant BB 14-16-2-2 respectively. GV 635 however, had best grain yield response of 12,914 kg ha^{1} under rotation with cowpea mutant LT 11-3-3-12. ZMS 606 had the best yield response of 12278 kg ha^{-1} in rotation with parent BBPRT followed by its mutant BB 14-16-2-2 which had a yield of 11462 ha^{-1} (Table 10).

Table 10: Influence of cowpea genotypes on maize grain yield of maize varieties at Chisamba site during the 2016/2017 growing season

		Maize varieties			
			Low N and Drought tolerant		
		Maize grain yield (kgha^{-1})			
	Cowpea genotypes	M1 (control)	M2	M3	Mean
	LTPRT	11372 ± 286.2	13634 ± 895.9	11290 ± 177.1	**12099 ± 453.1**
	BBPRT	12278 ± 710.3	15820 ± 707.5	11096 ± 180.4	**13065 ± 532.7**
	LT	11073 ± 532.6	9691 ± 669.4	12914 ± 1680.8	**11226 ± 960.9**
	BB	11462 ± 529.1	15352 ± 616.6	11389 ± 349.4	**12734 ± 498.4**
	NCP	5003 ± 260.9	5454 ± 204.4	5204 ± 226.1	**5220 ± 230.5**
	Mean	**10238 ± 463.8**	**11990 ± 618.8**	**10379 ± 522.8**	
FPr	<0.001				
Lsd (0.05)	1861.1				
CV (%)	10.9				

Note: LTPRT = Lutembwe parent cowpea indeterminate type, BBPRT = Bubebe parent cowpea determinatetype, LT = LT 11-3-3-12 Lutembwe mutant indeterminate and running type, BB 14-16-2-2 = Bubebe mutant determinatetrifoliate type, M2 (GV 640) and M3 (GV 635) = selected low N and drought tolerant. M1 (ZMS 606) Control = mostly purchased by smallholder farmers. ± denotes standard errors of means, NCP = Non cowpea plot.

The conservation farming system's effect on maize grain yield over the conventional was much higher for maize crop produced under loamy sand soils and low rainfall of Batoka compared to Chisamba. The highest interaction effect of 80.63 % on maize grain yield was obtained between rotation of ZMS 606 and mutant LT 11-3-3-12 at Batoka. In comparison, at Chisamba, the yield response to adopting CF over CONV was highest (29.28 %) between the rotation of ZMS 606 and cowpea genotype BB 14-16-2-2 during the 2015/2016 growing season. The lowest maize grain yield response of 7.95 % was attained at Chisamba between the rotation of maize variety GV 640 and LTPRT (Table 11).

Table 11: Yield increase (%) by changing from conventional farming to maize- cowpea rotation under conservation farming system during 2015/2016 growing season of year II

		Maize varieties		
		Low N and Drought tolerant		
		Grain yield (kgha^{-1})		
Site	Cowpea genotypes	M1 (control)	M2	M3
Batoka	LTPRT	80.13 ± 1.1	41.84 ± 0.8	47.57 ± 2.0
	BBPRT	79.18 ± 1.8	51.16 ± 0.2	39.64 ± 3.6
	LT	80.63 ± 1.5	34.36 ± 3.1	14.62 ± 0.1
	BB	79.93 ± 0.6	50.01 ± 0.3	42.60 ± 3.4
Chisamba	LTPRT	14.32 ± 0.8	7.95 ± 1.6	27.39 ± 2.6
	BBPRT	10.95 ± 0.8	20.10 ± 0.1	19.99 ± 1.7
	LT	18.08 ± 1.4	14.18 ± 0.1	13.90 ± 1.7
	BB	29.28 ± 2.3	19.41 ± 1.7	17.87 ± 1.1
FPr	<0.001			
Lsd (0.05)	4.962			
CV (%)	9.3			

Note: LTPRT = Lutembwe parent indeterminatetype, BBPRT = Bubebe parent cowpea determinatetype, LT = LT 11-3-3-12 Lutembwe mutant indeterminateand running type, BB = BB 14-16-2-2 = Bubebe mutant determinatetrifoliate type, M2 (GV 640) and M3 (GV 635) = selected low N and drought tolerant. M1 (ZMS 606) control = mostly purchased by smallholder farmers. ± denotes standard errors of means

The differences in maize grain yield between Chisamba and Batoka result from variations in soil types, quality status and rainfall. The maize grain yield at Batoka was significantly lower than Chisamba site due to insufficient plant nutrients. The *Chromic haplic Lixisols*, loamy sand soils of Batoka tend to lose moisture and nutrients faster than the *Luvic phaeozems* fine clay loam soils of Chisamba. This was evident in the present study's soil baseline shown in Table 1 where plant nutrients are relatively higher at the Chisamba site than the Batoka site. Sandy soils tend to have limited plant nutrients because of excessive leaching of nutrients unlike the clay loam soils (Silver et al. (2000). The total amount of rainfall during the 2015/2016 growing season at Batoka was 620.5 mm and was lower than Chisamba which received total of 726.6 mm. The lower amount of rainfall at Batoka could have contributed to low maize grain yields because the crop was stressed, especially in the month of December (Figures 1 and 2). The higher maize grain yields obtained during the 2016/2017 growing season at Chisamba compared to maize yields attained during the 2015/2016 growing season could be attributed to higher rainfall of 881.5 mm received than 726.6 mm for 2015/2016 growing season (Figures 1 and 3). The results were in agreement with the review of Kwasi et al., (2011) that in areas such as the semi-arid and dry sub-humid environments the amount of rainfall is not only the limiting factor of rain-fed maize production but also the erratic nature of rainfall. However, water stress occurring at different crop developmental stages could limit biomass accumulation and consequently reduce the grain yield of the maize crop. The extent of reduction in maize productivity depends not only on the severity of the water stress or drought but also on the stage of crop development. Others include the crop tolerance to water stress/drought and the efficiency with which the maize crop uses available soil water for growth, biomass accumulation and yield production (Cakir, 2004).

The mineralization rate of organic matter in sandy soils could be higher than for clay loam soils hence organic matter tend to be lower in the sandy soils (Gwenzi et al., 2009). Najmadeen et al. (2010) indicated that the highest value of soil organic and total nitrogen contents were observed under fine texture soils (clay loam, loam, and silty clay loam), whereas the lowest contents were in coarse texture soil (loamy sand silty loam). Matus et al. (2008) also observed that soil organic carbon tends to be associated with the fine fraction of soils and it was significantly greater three times in clay-rich soils than coarser soils. The present study's soil chemical analysis at baseline showed an average organic matter content of 1.07 % at Batoka and 2.47 % at Chisamba (Table 1). In comparison, it was 1.65 % and 2.29 % at Batoka and Chisamba after treatment effects respectively at 0-15 cm soil depth (Tables 12 and 13). The nitrogen content was on average lower at Batoka (0.03 %) than Chisamba (0.07 %) under cowpea treated plots and could be due to low levels of organic matter at Batoka.

Table 12: Mean squares for combine analysis of variance of treatment soil Chemical properties at 0-15 cm depth

Variate: 0-15 cm soil depth		O. M%	N %	CEC (cmol kg^{-1})	Ca (mgkg^{-}	K (mg kg)	Mg (mg kg^{-1})	Na $mgkg^{-1}$	P (mg kg^{-1})	pH
Source of variation	**d.f.**	**m.s.**	**m.s.**	**m.s.**	**m.s.**	**m.s.**	**m.s.**	**m.s.**	**m.s.**	**m.s.**
Site	1	3.11908***	0.00032789**	1.4814**	87260.9***	1967492.5***	1498.171***	0.00032789***	31315.88***	39.39212***
Rep/Location	4	0.05406	0.00011407	0.2107	176.4	530.7	15.635	0.00011407	64.95	0.16822
Cowpea genotype	4	1.07691***	0.00192777***	2.3097***	4417.7***	16890.3***	158.524***	0.00192777***	723.96***	0.21783**
Site x cowpea genotype	4	0.34149**	0.00041381***	1.2828**	7706***	17445.6***	133.318***	0.00041381ns	574.23***	0.08405ns
Error	16	0.09553	0.00006197	0.2767	130.8	525.6	8.29	0.00006197	14.04	0.05399

Note: OM = Organic matter, N = total nitrogen, CEC = Cation Echange Capacity, Ca = Calcium, K = Potassium, Mg = Magnesium, Na = Sodium, P = Phosphorus, pH = acidity level

Table 13: Influence of cowpea genotypes on soil chemical properties at 0-15 cm depth at two sites

Site		Treatment Soil chemical analysis (0-15 cm depth)								
Chisamba	Cowpea genotypes	pH ($CaCl_2$)	O.M (%)	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})	Na (mg kg^{-1})	CEC (cmol kg^{-1})
	LTPRT	6.7	1.94	0.043	99.0	386.8	22.9	197.5	26.8	3.9
	BBPRT	6.8	2.60	0.068	51.9	538.3	33.1	225.3	30.1	4.7
	LT	6.6	2.80	0.075	87.0	658.9	28.9	222.4	28.2	5.1
	BB	6.7	2.70	0.062	83.7	505.3	12.8	220.7	25.8	4.4
	NCP	6.9	1.44	0.035	56.0	620.2	36.2	226.7	31.0	3.7
	Mean	**6.7**	**2.29**	**0.056**	**75.5**	**541.9**	**26.8**	**218.52**	**28.4**	**4.4**
Batoka	**LTPRT**	4.6	1.53	0.047	15.0	32.9	17.7	183.8	0.6	2.3
	BBPRT	4.3	1.26	0.047	11.8	32.2	9.8	130.8	0.7	4.1
	LT	4.2	2.08	0.092	7.0	43.3	12.3	113.8	1.1	4.4
	BB	4.2	1.98	0.080	12.7	29.3	9.5	113.4	0.9	4.1
	NCP	4.9	1.39	0.048	8.1	11	13.8	11.6	1.9	4.7
	Mean	**4.4**	**1.65**	**0.063**	**10.9**	**29.74**	**12.6**	**110.68**	**1.0**	**3.9**
	FPr	0.2	0.03	0.003	<0.001	<0.001	<0.001	<0.001	0.052	0.007
	Lsd (0.05)	0.483	0.511	0.014	7.601	39.084	5.352	20.168	2.650	0.875
	CV (%)	4.2	15.7	13.2	8.7	8.0	14.6	6.9	8.7	12.7

Note: LTPRT = Lutembwe parent indeterminate type, BBPRT = Bubebe parent cowpea determinatetype, LT = LT11-3-3-12 Lutembwe mutant indeterminate and running type, BB= BB 14-16-2-2 Bubebe mutant determinate trifoliate type, NCP = Non cowpea plot

Generally, the loamy sand soils at Batoka experimental site had higher bulk density (BD) of 1.8 g/cm^3 than the clay loam soils at Chisamba whose bulk density was 1.4 g/cm^3 (Tables 14 and 15). This could also have affected the root growth of the crop and ultimately resulted in low grain yields. On compacted soils, the root volume was found to be 27.8 % less than on non-compacted soils (Tracy et al., 2012). Similar findings were reported by Pravin et al., (2013) who indicated that clay soils tend to have lower bulk densities and higher porosities than sandy soils with high positive correlation with sand content (r = 0.9094). According to Sakin (2011) a strong negative correlation of r = -0.8869 between organic matter and Bulk density was observed. Therefore, crops produced in soils that are less compact as for Chisamba would be expected to grow well than similar crops produced in compacted soils of Batoka (Schalkwyk, 2018). Compaction increases bulk density and reduces total pore volume, consequently reducing available water holding capacity for plant growth.

The high maize grain yields at Chisamba could have been attributed to high plant available water (PAW) which was on average 16.8 % whereas at Batoka, PAW was 14.8 % (Table 15). Jabro et al. (2008) reported higher water content at FC in the clay loam soil than in the sandy loam soils. Further, lower bulk density increases the soil water content (Van Wesenbeeck and Kachanoski, 1988). In very compacted soils a decrease in bulk density will benefit both available-water capacity and air capacity (Archer and Smith, 2006). Therefore, favorable bulk density for farming t, ranges between 1.4 to 1.6 g.cm^{-3} (Hazelton and Murphy, 2007) which is in the range of soils from Chisamba. Houlbrooke et al., (1997) reported that the growth of ryegrasses was affected by increasing soil bulk density from 0.9 to only 1.0 Mg/m3, which caused penetration resistance to increase by approximately 30 %.

The present study showed that the Chisamba site with clay loam soils had higher plant available water of 14 .0 % than the Batoka site with loamy sand soils that had 7.4% at baseline stage (Table 2). In contrast, it was 16.8 % at Chisamba and 14.5 % at Batoka after cowpea treatment at soil depth of 0-15 cm (Table 15).

Table 14: Mean squares for combine analysis of variance of treatment soil physical properties at 0-15 cm depth

Variate: Moisture content		FC % v/v	PWP % v/v	PAW % v/v	BD gcm^{-3}	MC %
Source of variation	**d.f.**	**m.s.**	**m.s.**	**m.s.**	**m.s.**	**m.s.**
Site	1	6545.161***	3936.8091***	337.656***	1.62276***	1458.052***
Rep/Location	4	4.86	1.1033	9.587	0.006199	2.264
Cowpea genotype	4	112.082***	7.1357***	156.028***	0.003944ns	3.461**
Site x Cowpea genotype	4	77.743***	0.612ns	79.854***	0.006458ns	4.876***
Error	28	6.169	0.9877	6.657	0.002539	1.032

Note: FC= Soil moisture content at Field capacity, PWP = Soil moisture content at Permanent wilting point, PAW = Plant available water, BD = Bulk density, MC = oven dry soil moisture content

Table 15: Influence of cowpea genotypes on treatment soil physical properties at 0-15 cm depth at two sites

Chisamba	Cowpea genotypes	FC (% θv)	PWP (% θv)	PAW (% θv)	BD (gcm^{-3})	MC (%)
	LTPRT	35.6	21.5	14.1	1.4	12.9
	BBPRT	38.2	22.9	15.3	1.4	13.9
	LT	37.9	21.9	16.0	1.4	13.7
	BB	35.3	18.7	16.7	1.4	13.0
	NCP	43.8	21.7	22.1	1.5	11.0
	Mean	**38.1**	**21.3**	**16.8**	**1.4**	**12.9**
Batoka	**LTPRT**	15.8	2.6	13.2	1.8	0.3
	BBPRT	15.0	2.2	12.8	1.8	0.3
	LT	18.3	2.0	16.2	1.9	0.5
	BB	16.2	0.7	15.5	1.9	0.8
	NCP	16.0	1.4	14.6	1.8	0.7
	Mean	**16.3**	**1.8**	**14.5**	**1.8**	**0.5**
	FPr	<0.001	0.015	<0.001	0.083	0.005
	Lsd (0.05)	1.836	0.946	2.288	0.035	1.507
	CV (%)	5.4	7.3	7.8	3.2	15.8

Note: LTPRT = Lutembwe parent indeterminatetype, BBPRT = Bubebe parent cowpea determinatetype, LT = Lutembwe mutant indeterminateand running type, BB 14-16-2-2 = Bubebe mutant determinatetrifoliate type. FC= Soil moisture content at Field capacity, PWP = Soil moisture content at Permanent wilting point, PAW = Plant available water, BD = Bulk density, MC = oven dry soil moisture content

Cowpea genotypes and farming systems, however, did not influence the change in bulk density. This could be attributed to short period for assessment of the treatments. The results agreed with Habbib et al. (2016) who explained that influence of conservation agriculture for improved soil physical properties takes several years up to four seasons. In their study, Verhulst et al. (2011) reported that most of the soil physical properties measured significantly changed in the tillage – system but only the bulk density did not get affected.

The low soil pH in the range of 3.7 and 4.3 recorded at Batoka site could have contributed to the lower maize grain yield than at Chisamba that had soil pH of 5.5 to 6.7 (Tables 14 and 15). The soil pH at Batoka was generally lower than at Chisamba primarily due to differences in a soil type that affected the capacity of the soil to retain soil cations such as calcium (Ca), magnesium (Mg) and potassium (K). The cations at the Batoka site with loamy sand soil and lower organic matter could have leached more than at Chisamba with clay loam soils and higher organic matter content. This is because soils with high cation exchange capacity can bind more cation K^+ and Ca^{2+} to the exchange sites of clay and organic matter particle surfaces than sandy soils (The et al., 2006). The pH has effects on the growth of the plant, and it was reported that soils with low pH levels below 5.5 produce less maize grain yield than the maize yield from pH of between 5.5–6.8 (Sushant et al., 2004). According to The et al. (2006) grain yield increases are associated with mean decrease of 43% in exchangeable Aluminum (Al^{+3}) and 51% hydrogen ions (H^+). In this study, an average maize grain yield of 4453 kg ha^{-1} was attained at Batoka whose soil acidity was higher with pH 4.1 while at Chisamba which had lower soil acidity of pH 6.7 had an average maize yield of 7960 kg ha^{-1}. These results, therefore, indicated that soil pH variations between soil types could differently affect the performance of maize grain yields (Tables16 and 17).

Since calcium is essential for root health, growth of new roots and root hairs, and the development of leaves, high levels of Ca at CH could have significantly contributed to increased maize grain yields at the site (Lines-Kelly, 1992). The present study results showed that Ca content at CH was 49.3 % higher than Batoka, which could be attributed to the possibility of having Ca cations leached most in sand soils of less organic matter and clay content. Compared to Ca critical value of 200 mg kg^{-1} (Lungu, 2005) soils at BK were lower in Ca nutrient content by 80.7 % while that of Chisamba were higher by 8.5 %. Soil potassium content which was significantly higher at CH

(542.1 mg kg^{-1}) than BK (27.8 mg kg^{-1}) could have also contributed to higher yields of maize obtained at CH. This was because, low negative charges on sandy soil surface could not easily hold potassium (K^+) ions resulting into high leaching of the nutrient (Hargreaves et al., 2008). Soil phosphorus of 75.5 mg kg^{-1} which was measured significantly higher ($P<0.05$) at Chisamba with clay loam soil than at Batoka with loamy sand soil by 85.6 % at 0-15 cm soil depth could have contributed to increased maize grain yield (Table 13). The high levels of P at Chisamba having clay loam soils could have been due to less leaching of the nutrient than in sandy soils of Batoka (Liu et al., 2012). The effect of the conservation farming system on maize grain yield over the conventional was much higher for maize crop produced under the haplic and chromic lixisols (loamy sand soils) of Batoka as compared to Chisamba with luvic and isohyperthermic soils (Clay loam soils). The high performance of maize under CF was attributed to improved soil fertility status that enhanced increased water and nitrogen use efficiency by the crop.

The present study showed increased Ca content under CF at Batoka due to cowpea genotypes influence. Therefore, the results implied that acidic lixisols of Batoka would require planting of cowpea genotypes to improve the Ca content in the soil from 11.6 mg kg^{-1} in the conventional to an average of 157.3 mg kg^{-1} in the maize-cowpea rotation system (Tables 12 and 13). The study further showed that cowpea mutant LT 11-3-3-12 had significantly contributed the highest (346.3 mg kg^{-1}) content of K compared to conventional which had 315.0 mg kg^{-1}. Therefore, LT 11-3-3-12 cowpea mutant could be encouraged for production by smallholder farmers to improve the yields of maize in rotation. This is because potassium increases vigour and disease resistance of plants and helps form and translocate starches, sugars and oils to improve maize grain yield and quality (Lines-Kelly, 1992). The maize grain yields under the CF system could have further been enhanced due to high levels of P which was 36.8 % more than in the conventional system and was mainly contributed by cowpea genotypes BB 14-16-2-2, LT 11-3-3-12 and LTPRT (Tables 17). When P content in the soil is adequate above the critical level of 10 mg kg^{-1}, crop establishment and productivity are improved. According to Uchida and Silva (2000) P is required by the plant for root establishment, flower initiation, seed and grain development and has been shown to reduce disease incidence and improved yields.

Table 16: Mean squares for combine analysis of variance of treatment soil Chemical properties at 15-30 cm depth

Variate: 15- 30 cm soil depth		O. M%	N %	CEC cmol kg^{-1}	Ca mg kg^{-1}	K mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	P mg kg^{-1}	pH
Source of variation	d.f.	m.s.	m.s.	m.s.	m.s.	m.s.	m.s.	m.s.	m.s.	m.s.
Site	1	0.08613	0.00000179ns	11.4017***	202484.37***	2001370.3***	3609.04***	5986.995***	4643.65***	51.07509***
Rep/Location	4	0.07562 ns	0.00015259	0.2711	149.27	478.8	8.214	2.167	18.39	0.15511
Treat	4	2.61425***	0.00759147***	3.6201***	1259.69***	13203.8***	204.384***	3.86ns	85.16**	0.1135ns
Site.Treat	4	0.91795***	0.00202523***	0.5633ns	2239.07***	11116.5***	113.739***	0.736ns	63.59ns	0.06053ns
Error	16	0.02125	0.00006792	0.2291	26.33	553.4	5.754	3.051	24.19	0.08782

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05, O.M = Organic matter, N = total nitrogen, CEC = Cation Echange Capacity, Ca = Calcium, K = Potassium, Mg = Magnesium, Na = Sodium, P = Phosphorus, pH = acidity level

Table 17: Influence of cowpea genotypes on soil chemical properties at 15-30 cm depth at two sites

Site		Treatment Soil chemical analysis (15-30 cm depth)								
Chisamba	Cowpea genotypes	pH ($CaCl_2$)	O.M (%)	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})	Na (mg kg^{-1})	CEC (cmol kg^{-1})
	LTPRT	6.7	2.03	0.058	41.4	418.5	21.8	219.2	27.6	3.7
	BBPRT	6.6	2.28	0.061	41.6	541.9	35.5	222.4	29.3	4.6
	LT	6.5	2.69	0.103	41.4	637.4	24.5	223.6	29.1	5.1
	BB	6.8	2.66	0.083	39.1	497.1	20.0	220.4	29.5	4.5
	NCP	6.9	1.29	0.037	40.0	616.3	43.3	232.8	30.8	4.1
	Mean	**6.7**	**2.19**	**0.068**	**40.7**	**542.2**	**29.0**	**223.7**	**29.2**	**4.4**
Batoka	LTPRT	4.3	1.843	0.055	24.0	25.8	8.1	107.8	0.5	1.5
	BBPRT	4.2	1.55	0.035	12.5	19.9	9.3	62.1	0.8	3.2
	LT	3.9	3.72	0.158	21.0	45.7	3.8	51.4	1.1	4.4
	BB	3.9	1.77	0.042	15.0	21.0	5.5	62.1	0.9	3.7
	NCP	4.2	1.56	0.050	6.4	16.0	8.8	13.3	1.8	3.0
	Mean	**4.1**	**2.09**	**0.068**	**15.8**	**25.7**	**7.1**	**59.3**	**1.0**	**3.2**
	FPr	0.610	<0.001	<0.001	0.073	<0.001	<0.001	<0.001	0.911	0.088
	Lsd (0.05)	0.54	0.29	0.01341	8.178	39.531	4.001	12.922	2.89	0.83
	CV (%)	5.3	6.8	11.5	17.2	8.2	12.9	4.9	11.3	13.2

Note: LTPRT= Lutembwe parent indeterminate type, BBPRT = Bubebe parent cowpea determinate type, LT11-3-3-12 = Lutembwe mutant indeterminate and running type, BB 14-16-2-2 = Bubebe mutant determinate trifoliate type. O.M = Organic matter, N = total nitrogen, CEC = Cation Exchange Capacity, Ca = Calcium, K = Potassium, Mg = Magnesium, Na = Sodium, P = Phosphorus, pH = acidity level

In the present study soil organic matter content by mutants LT 11-3-3-12 and BB 14-16-2-2 was on average 2.8 % in the conservation farming system at soil depth of 0-15 cm at Chisamba and was higher than for the CONV by 90.9 %. Whereas at Batoka average organic matter content of mutants LT 11-3-3-12 and BB 14-16-2-2 was 2.03 % indicating 46 % higher than under CONV (Table 13) which also explained increased maize grain yields under CF. Similar results were reported by Sumanta et al. (2013) that maize grain yield increased in the conservation farming field after two growing seasons compared to conventional farming. Golden valley Agricultural Research Trust [GART] (2011) also reported that maize grain yield increased when maize was rotated with a legume crop *(mucuna pruriens)* in the CF system. Cowpea genotype BB 14-16-

2-2 significantly (P<0.05) contributed to high grain yields of maize in the cowpea-maize rotation as compared to other genotypes primarily due to high Biological Nitrogen Fixation (BNF) and Nitrogen content in the Stover (IAEA, 2008). The cowpea mutant BB 14-16-2-2 had stover nitrogen content of 4.5 % at the flowering growth stage (Tables 18 and 19). In contrast, total nitrogen fixed was 58 kg ha $^{-1}$ and this could have added to improved yields among the selected drought and low N maize varieties.

Table 18: Mean squares for analysis of variance of cowpea dry biomass nutrient content

Variate: Plant nutrients		Ca %	K %	Mg %	N %	P %	Zn ppm	Mn ppm
Source of variation	**d.f.**	**m.s**	**m.s**	**m.s**	**m.s**	**m.s**	**m.s**	**m.s**
REP	2	0.005258	0.0453	0.006058	0.0484	0.002033	2244	3403
Cowpea genotypes	3	0.001031 ns	1.5635***	0.005267 ns	7.738 ***	0.000764 ns	5394 ns	31028 ns
Error	6	0.002447	0.1139	0.001558	0.2278	0.001689	3449	17523

Note: N = nitrogen content, Ca = Calcium, K = Potassium, Mg = Magnesium, P = Phosphorus, Zn = Zinc, Mn = Manganese

Table 19: Cowpea dry biomass nutrient content

		Cowpea dry biomass nutrient content					
Cowpea Genotypes	Ca%	K%	Mg%	N%	P%	Zn ppm	Mn ppm
Lutembwe	0.127	3.057	0.283	0.63	0.29	217	1011
Bubebe	0.13	1.673	0.333	2.14	0.277	300	790
LT 11-3-3-12	0.123	3.1	0.247	2.59	0.283	250	857
BB 14-16-2-2)	0.163	3.183	0.243	4.53	0.253	306	970
LSD (0.05)	0.0988	0.6744	0.789	0.954	0.0821	117.3	264.5
FPr	0.745	0.004	0.095	<0.001	0.725	0.793	0.252
CV (%)	16.4	12.3	14.3	19.3	14.9	21.9	14.6

Note: N = nitrogen content, Ca = Calcium, K = Potassium, Mg = Magnesium, P = Phosphorus, Zn = Zinc, Mn = Manganese

Generally, Cowpea genotypes mutants LT 11-3-3-12 and BB14-16-2-2 significantly improved the cation exchange capacity (CEC) from 4.1 % under CONV (NCP) to 5.1 % and 4.5 % under the conservation farming system respectively at Chisamba. At Batoka, CEC under mutants LT 11-3-3-12 and BB14-16-2-2 increased from 3.0 % in CONV (NCP) to 4.4 % and 3.7 % respectively at 15-30 cm soil depth. The increase in CEC could have contributed to increased maize yields in the CF system (Tables 16 and 17). The results agree with Naresh et al. (2016) that retaining crop residues, significantly increased the CEC in the 0–5 cm layer of permanent raised beds compared to the soil from which the residues were removed. Mohanty etal. (2015) also observed that the adoption of conservation farming enhanced the

CEC of soils even within a short span of two years. The increase was 11.2 % over conventional tillage system.

Therefore, encouraging farmers to rotate maize with cowpeas could increase CEC consequently reducing loses of the cation nutrients and improved maize grain yields. Thus the CEC is crucial because it provides a reservoir of nutrients to replenish those removed from the soil by plant uptake (Camberato, 2007).

The maize grain yield which significantly ($P<0.001$) varied among the varieties of maize used in the study could be attributed to genotypic differences and their response to environmental conditions. The maize varieties ZMS 606 that is purchased mainly by smallholder farmers and GV 640 one of the selected low N and drought- tolerant varieties were generally superior to (M3) GV 635 indicating that the two varieties were more efficient for nitrogen and water uptake and could be recommended for drought and low N prone areas. Significant interactions for maize grain yield observed between site, farming system, cowpea genotypes and maize varieties indicated that maize grain yields could be optimized by selecting suitable maize variety and cowpea genotype for rotation under CF at specific site.

3.1.2 Maize Biomass yield

The maize biomass yields significantly ($P<0.001$) varied between sites, farming systems, cowpea genotypes and maize varieties during the 2015/2016 growing season (Table 20). The Batoka site produced 4923 kg ha^{-1} of maize dry biomass yield which was significantly ($P<0.001$) lower than of Chisamba by 75.0 %. The maize biomass yield under CF at Chisamba and Batoka was 33.9 % and 49.9 % higher than for CONV respectively. Across sites, conservation farming system that produced an average maize dry biomass of 7044 kg ha^{-1} was significantly ($P<0.001$) higher than in the conventional system by 39.4 %. Among the maize varieties, GV 635 produced the highest maize dry biomass yield under CF (9212 kg ha^{-1}) and CONV (7196 kg ha^{-1}) at Chisamba while at Batoka, GV 635 had highest dry biomass yield under CF (5633 kg ha^{-1}) and GV 640 was highest under CONV (4120 kg ha^{-1}). The lowest dry biomass yields of 6255 kg ha^{-1} and 3184 kg ha^{-1} were obtained from CONV for ZMS 606 at Chisamba and Batoka respectively (Table 21).

Table 20: Mean squares for combine analysis of variance of maize varieties biomass yield performance under the influence of farming systems at two sites during the 2015/2016 growing season

Variate: Maize 2015/2016		**Biomass yield (kg ha^{-1})**
Source of variation	**d.f.**	**m.s.**
Site	1	274753736***
Rep/Location	4	611340
Farming system	1	55111085***
Site x Farming system	1	1309083ns
Error	4	347461
Maize variety	2	3304050***
Site x Maize variety	2	2584982***
Farming system x maize variety	2	849874**
Site x Farming system x.maize variety	2	506632ns
Error	16	226700

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05, d,f = Degrees of freedom, m.s = Mean Squares

Table 21: Influence of farming systems on maize dry biomass yield (kg ha-1) of maize varieties at two sites during the 2015/2016 growing season

		Maize varieties			
			Low N and Drought tolerant		
		Dry biomass yield (kgha^{-1})			
Site	**Farming system**	**M1 (control)**	**M2**	**M3**	**Mean**
Chisamba	**CF**	8831 ± 334.5	8400 ± 148.0	9212 ± 414.8	**8814 ± 299.1**
	CONV	6255 ± 141.8	6305 ± 153.7	7196 ± 467.8	**6585 ± 254.4**
Batoka	**CF**	5014 ± 260.5	5176 ± 360.1	5633 ± 494.3	**5274 ± 371.6**
	CONV	3184 ± 161.4	4120 ± 199.7	3253 ± 243.0	**3519 ± 201.4**
FPr	<0.001				
Lsd (0.05)	295				
CV (%)	20.1				

Note: CF= Conservation farming, CONV = Conventional farming, M2 (GV 640) and M3 (GV 635) = selected Low N and drought tolerant. M1 (ZMS 606) control = mostly purchased by smallholder farmers. ± denotes standard errors of means.

During the 2016/2017 growing season, the maize dry biomass yields significantly (P<0.05) varied between farming systems. However, no significant difference was observed among the maize varieties for maize dry biomass yields on average (Table 22). The dry biomass yield was 4205 kg ha^{-1} in the CONV and was significantly (P<0.002) lower than yield under CF by 82.5 % at the Chisamba site. Under CONV, maize variety GV 635 had a significantly high biomass yield than ZMS 606 and GV 640 (Figure 6).

Table 22: Mean squares for analysis of variance of maize varieties performance under the influence of farming systems at Chisamba during the 2016/2017 growing season

Variate: Maize 2016/2017		**Biomass yield (kg ha^{-1})**
Source of variation	**d.f.**	**m.s.**
Rep	2	17354
Farming system	1	86609516**
Error	2	146681
Maize variety	2	642155ns
Farming system xmaize variety	2	1506827ns
Error	8	471271

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05, d,f = Degrees of Freedom, m.s = Mean Squares

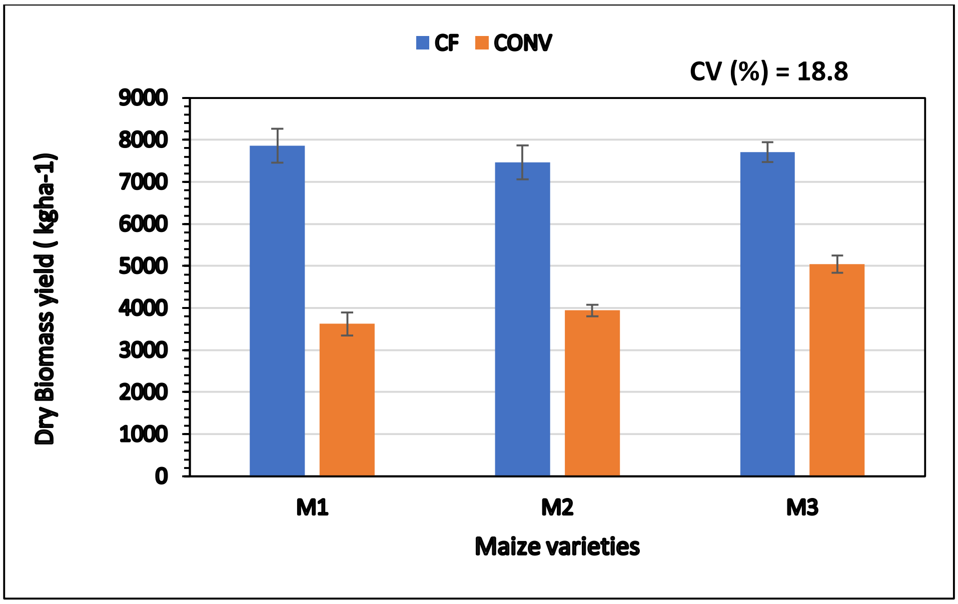

Figure 6: Effect of Farming systems on maize dry biomass yield (kg ha^{-1}) at Chisamba during the 2016/2017 growing season.

Note: M1 = ZMS 606, M2 = GV 640, M3 = GV 635. CF = conservation farming system, CONV = Conventional farming system Error bars denotes Standard Errors

The highest maize dry biomass yield of an average of 7693 kg ha^{-1} was obtained from the maize crop rotated with cowpea genotype parents LTPRT and BBPRT when compared to mutants LT 11-3-3-12, BB 14-16-2-2 and the non-cowpea conventional plots that yielded 6403 kg ha^{-1}, 6390 kg ha^{-1} and 5052 kg ha^{-1} respectively. The maize dry biomass yield under the non-cowpea was 26.6% lower than cowpea mutants LT 11-3-3-12 while BB 14-16-2-2 a was 52.3% lower than the cowpea parents (Tables 23 and 25). Cowpea genotypes significantly (P<0.001) influenced the dry biomass yield of maize varieties during the 2016/2017 growing season (Tables 24). The dry biomass yield of 4205 kg ha^{-1} under the NCP treatment was significantly lower than biomass yield in the cowpea mutant LT 11-3-3-12, parent LTPRT, cowpea mutant BB 14-16-2-2 and parent BBPRT treatments by 101.3 %, 90.1%, 69.9 % and 68.6 % respectively.

Significant interactions for maize dry biomass yield were observed between site and maize variety; cowpea genotype and maize variety; site and cowpea genotype; site, farming system and maize variety; site, cowpea and maize variety during the 2015/2016 growing season (Table 23). An average maize dry biomass yield of 9372 kg ha^{-1} was obtained under cowpea parents LTPRT and BBPRT followed by mutant LT 11-3-3-12 which enhanced yield of 8717 kg ha^{-1} at the Chisamba site. In contrast cowpea parent BBPRT influenced the highest maize dry biomass of 6711 kg ha^{-1} at Batoka site. The interaction of site, cowpea and maize varieties on maize dry biomass yield indicated highest maize dry biomass yield of 10697 kg ha^{-1} and 10190 kg ha^{-1} under the combination of cowpea genotype LTPRT with maize varieties M3 (GV 635) and M1 (ZMS 606) respectively and lowest yield of 6255 kg ha^{-1} under the influence of NCP and M1 (ZMS 606) at Chisamba site. At Batoka, the interaction effect had highest dry biomass yield of 8166 kg ha^{-1} under the influence of cowpea genotype BBPRT and M3 (GV 635) (Table 25).

Table 23: Mean squares for combine analysis of variance of maize varieties biomass performance under the influence of cowpea genotypes at two sites during the 2015/2016 growing season

Variate: Maize 2015/2016		**Biomass yield (kg ha^{-1})**
Source of variation	**d.f.**	**m.s.**
Site	1	274753736***
Rep/Location	4	611340
Cowpea genotype	4	20995227***
Sitex cowpea genotype	4	3711897***
Error	16	325263
Maize variety	2	3304050***
Site x maize variety	2	2584982***
Cowpea genotype x maize variety	8	3329179***
Sitex cowpea genotypex maize variety	8	2313889***
Error	40	283806

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05, d,f = Degrees of freedom, m.s = Mean Squares

Table 24: Influence of cowpea genotypes on maize dry biomass yield of maize varieties at two sites during the 2015/2016 growing season

		Maize varieties			
			Low N and Drought tolerant		
			Dry biomass yield (kgha^{-1})		
Site	Cowpea genotypes	M1 (control)	M2	M3	Mean
Batoka	LTPRT	4961 ± 98.8	5636 ± 238.7	5344 ± 95.7	**5314 ± 144.4**
	BBPRT	5950 ± 318.9	6016 ± 152.4	8166 ± 170.5	**6711 ± 213.9**
	LT	5354 ± 260.8	3176 ± 184.4	3737 ± 373.3	**4089 ± 272.8**
	BB	3792 ± 263.7	5875 ± 189.4	5283 ± 294.1	**4983 ± 249.1**
	NCP	3184 ± 161.4	4120 ± 199.7	3253 ± 243.0	**3519 ± 201.4**
	Mean	**4648 ± 221**	**4965 ± 193**	**5157 ± 235**	**4923 ± 216.3**
Chisamba	LTPRT	10190 ± 365.9	7804 ± 114.2	10697 ± 190.2	**9564 ± 223.4**
	BBPRT	9361 ± 197.1	8146 ± 152.1	10034 ± 229.4	**9180 ± 192.9**
	LT	8253 ± 195.6	8925 ± 194.9	8973 ± 201.8	**8717 ± 197.4**
	BB	7520 ± 399.9	8725 ± 85.4	7145 ± 223.5	**7797 ± 236.3**
	NCP	6255 ± 141.8	6305 ± 153.7	7196 ± 467.8	**6585± 254.4**
	Mean	**8316 ± 260.1**	**7981 ± 140.1**	**8809 ± 262.5**	**8369 ± 220.9**
FPr	<0.001				
Lsd (0.05)	631.6				
CV (%)	8.0				

Note: LTPRT = Lutembwe parent indeterminate type, BBPRT = Bubebe parent cowpea determinate type, LT = Lutembwe mutant indeterminate and running type, BB 14-16-2-2 = Bubebe mutant determinate trifoliate type, M2 (GV 640) and M3 (GV 635) = selected low N and drought tolerant. M1 (ZMS 606) Control = mostly purchased by smallholder farmers. ± denotes standard errors of means

While during the 2016/2017 growing season the interaction was observed between the cowpea genotypes and maize varieties for maize dry biomass yield (Table 24). The highest dry biomass yield of 9864 kg ha^{-1} was achieved under rotation of maize variety M1 (ZMS 606) with cowpea mutant LT 11-3-3-12 followed by 9203 kg ha^{-1} for M2 (GV 640) in rotation with parent cowpea LTPRT. The lowest maize dry biomass yield of 3623 kg ha^{-1} was obtained under maize variety M1 (ZMS 606) mono-cropping in the non-cowpea treatment (Figure 7).

Table 25: Mean squares for analysis of variance of maize varieties biomass performance under the influence of cowpea genotypes at Chisamba during the 2016/2017 growing season

Variate: 2016/2017		Biomass yield (kg ha^{-1})
Source of variation	d.f.	m.s.
Rep	2	17354
Cowpea genotype	4	24697159***
Error	8	891600
Maize variety	2	642155ns
Cowpea genotype x maize variety	8	3050916***
Error	20	485043

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05, d,f = Degrees of freedom, m.s = Mean Squares

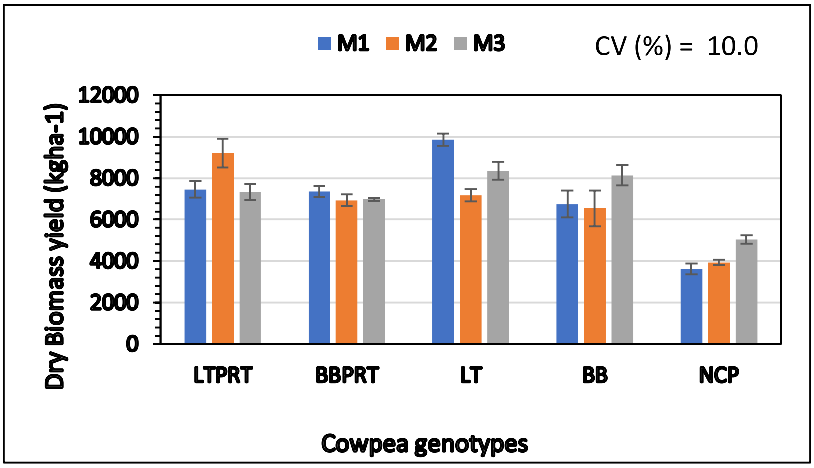

Figure 7: Effect of Cowpea genotypes on maize dry biomass yield at Chisamba during the 2016/2017 growing season. Error bars = Standard Errors of means. NCP = Non cowpea.

The lower maize dry biomass yields at Batoka could be attributed to low plant nutrient amounts due to the high rate of nutrients leaching during high rainfall days. The present study further gave evidence of higher nitrogen content measured at Batoka than Chisamba at a soil depth of 0-15 cm. It could have been attributed to organic matter decomposition rate due to sandy soils and high temperatures experienced at Batoka as compared to Chisamba (Weather data Appendix E). However, rapid mineralization of legume residues might increase the risk of nitrogen leaching at the site over time (Bado et al., 2006). Dimitrios et al. (2013), reported similar results that maize biomass production was lower in the sandy soils than in clay soil by 12.5%. O'Geen (2013) also explained that coarse textured soils (sands and loamy sands) have low plant available water (PAW) because the pore size distribution consists mainly of large pores with limited ability to retain soil moisture.

Conservation farming system produced significantly higher maize dry biomass than in the conventional system due to high nutrient content under CF that enhanced rapid plant growth (Tables 13 and 17). The results showed that cowpea genotypes used in rotation with maize, contributed significantly to the increased accumulation of biomass in the maize crop compared to the conventional system. The high maize biomass yield in the CF system was attributed to improved soil chemical fertility status by cowpea genotypes. The present study showed evidence that soil organic matter, available nitrogen and phosphorus contents were generally higher under the maize-cowpea rotation than under the non-cowpea treatment. At Batoka, soil moisture content at field capacity was higher in the CF (40 %) than in the CONV (29 %) contributing to increased maize dry biomass under CF. Therefore, the use of cowpea genotypes resulted in the significant input of organic N to the soil, which stimulated soil microbial activity and enhanced soil fertility that improved biomass yield potential (Wani et al., 1994). Maize variety GV 635 (M3) which produced 6983 kg ha^{-1} of dry biomass yield, significantly ($P<0.05$) out yielded GV 640 (M2) and ZMS 606 (M1) by 7.3 % on average. According to Gallais and Hirel, (2001), varieties of maize differ in the amount of dry biomass accumulated due to variations in the parent genotypes' genetic composition. A significant ($P<0.001$) interaction between sites, cowpea genotypes, and maize varieties for dry biomass yield observed during the study implied that accumulation of maize dry biomass yield would depend on the environmental effects and maize-cowpea combinations used in the rotation.

3. 5. Conclusion

Findings of the study revealed that agronomic yield response of the selected drought and Low N tolerant maize varieties varied according to sites, farming systems, maize varieties and cowpea genotypes.

- The maize grain and dry biomass yields of 3639 kg ha^{-1} and 4923 kg ha^{-1} produced at Batoka site were significantly lower than at Chisamba by 108.7% and 75 % respectively due to lower soil fertility status. The yield diffrences between the two sites was attributed to variations in soil type and fertility. Batoka has sandy clay loam and has poor soil fertility compared to Chisamba which has clay loam soil with relatively good soil fertility.

- The yields of maize grain under conservation farming system (CF) were 17.4 % at Chisamba and 119.0 % at Batoka more than the conventional farming system (CONV) for 2015/2016 growing season while it was 135.3 % higher under CF than CONV at Chisamba during the 2016/2017 growing season. Conservation farming system produced maize dry biomass of 7044 kg ha^{-1} higher than the conventional system by 39.4 %. The high yields under CF were attributed to improved soil properties from cowpea genotypes BB 14-16-2-2 and LT 11-3-3-12.

- Maize variety M1(ZMS 606) and M2(GV 640) had higher grain yield response of 131 % and 150 % respectively under conservation farming system in rotation with mutant LT 11-3-3-12 at Batoka and BB 14-16-2-2 at Chisamba. During 2015/2016 growing season, maize variety ZMS 606 was superior over GV 640 by 10.4% at Chisamba while it was higher than GV 640 and GV 635 by 29.1% and 34.8 % respectively at Batoka. Maize variety GV 640 was superior over ZMS 606 and GV 635 by 16.3 % during the 2016/2017 growing season.

- Among the maize varieties, GV 635 produced the highest dry biomass yield of 9212 kg ha^{-1} under CF at Chisamba while it was 5633 kg ha^{-1} at Batoka. The lowest dry biomass yields of 6255 kg ha^{-1} and 3184 kg ha^{-1} were obtained from CONV for ZMS 606 at Chisamba and Batoka respectively.

- The findings of the study therefore, gave evidence that conservation farming system with cowpea- maize rotation is a climate- smart agriculture technology that can improve maize grain yields from national yields of about 2.1ton ha^{-1} to potential grain yields of 8.0 to 15.0-ton ha^{-1}as indicated by IAPRI, (2015).

CHAPTER FOUR

4.0 EVALUATION OF SELECTED COWPEA GENOTYPES FOR BIOLOGICAL NITROGEN FIXATION

4.1 Introduction

Cowpea *(Vigna unguiculata*) is one of the main legumes contributing to the economy of nitrogen in the cropping systems with low input through the Biological Nitrogen Fixation (BNF) (Sanginga, Lyasse, & Singh, 2000). The crop may contribute some of the acquired nitrogen to soil organic matter and nitrogen needs of succeeding and associated crops (International Atomic Energy Agency (IAEA), 2008). The symbiotic nitrogen can reduce the rate of soil degradation where legume–cereal rotations are practiced. The amounts of nitrogen contributed by various legumes that include cowpea vary between 50-300 kg ha^{-1} per year. These values will depend on the legume species, plant densities, cropping system and legume genotypes. (Makoi, Chimphango, and Dakora, 2009). Awonaike, Kumarasinghe and Danso (1990) reported the BNF of Cowpea between 74 kg N ha^{-1} to 116 kg N ha^{-1}. Cowpea varieties vary in nitrogen fixation potential due to differences in the number, weight, efficiency of nodules and farming systems (Makoi et al., 2009). Cowpea – maize rotation tends to increase soil fertility after a season of crop rotation. Jeranyama, Hesterman, Waddington and Harwood (2000) indicated that maize produced after cowpea yielded 1940 kg ha^{-1} compared to the control with 1220 kg ha^{-1}. Maize/ Cowpea rotation was reported by Hardter, Harst Schmidt and Frey, (1991) to produce highest maize grain yield compared to mono-cropping due to BNF. To intensify the cereal production, additional amounts of nitrogen source are necessary to maintain the soil fertility in maize – legume rotation systems. According to Fujita et al, 1990, leguminous crops are sources of nitrogen and contribute to an increase in the non- leguminous associated crops' nitrogen uptake. While Senaratne, Liyanage and Soper, (1995) indicated that 161 mg $Nplant^{-1}$ were fixed by intercropped cowpea which obtained 81% of its N derived from the atmosphere.

The soils in Zambia are however, been reported to have inherently poor fertility status and are most vulnerable to degradation upon cultivation. Due to poor soil fertility, the productivity of maize which is a staple food among the smallholder farmers has become very low, ranging from 1.1ton ha^{-1} to 2.3ton ha^{-1}. These yields are v low when viewed against average potential yield of maize currently at 10ton ha^{-1} (Indaba Agricultural Policy Research Institute (IAPRI), 2015). One of the major limiting factors is insufficient nitrogen nutrient in the soil because of leaching and volatilization. However, yields of maize can be increased by using improved and sustainable farming system where the maize crop is rotated with legume crop that fixes nitrogen in the soil. Therefore, soil quality can be efficiently, sustainably and effectively managed with the use of newly adapted technologies to improve the production of potential in appropriate systems. Some of these systems include crop rotations of cereal crops with legumes such as cowpeas that can fix substantial amount of nitrogen (Phiri, Chipeleme and Chabala, 2006). Therefore, screening of cowpea genotypes with a high potential for nitrogen fixation and at the same time having a low proportion of N derived from the soil should be a priority for farmers.

In the recent years, The University of Zambia have produced some cowpea genotypes from the two released parent cowpea varieties that have not been evaluated for biological nitrogen fixation. There is no information documented on the cowpea varieties' ability to fix nitrogen in the soil in Zambia. This study was therefore conducted to evaluate the four cowpea genotypes for biological nitrogen fixation.

4.2. Literature review

4.2.1 Biological Nitrogen Fixation

Biological Nitrogen Fixation (BNF) is key to sustain agriculture and to reduce soil fertility decline. Biological Nitrogen Fixation estimates the amount of fixed nitrogen and selects the most effective *Rhizobial* strain x plant genotype combination. BNF is microbial process of major importance in the nitrogen economy of agricultural ecosystems. This process can only occur in the presence of an enzyme (complex) known as Nitrogenase which is synthesized by only a few, specialized groups of bacteria, actinomycetes and blue algae- green algae (Msumali et al., 1996). Increased BNF in mixed legume and cereal crops is being obtained by selecting legumes and genotypes for increased productivity and/or minimizing effects of nutrient limitations, low soil moisture, soil acidity, and pests and disease (Peoples and Crawell, 1992). BNF, a microbial process which converts atmospheric nitrogen into a plant-usable form, offers an alternative for expensive inorganic chemical fertilizers which are reported harmful to the environment. Therefore, Nitrogen -fixing systems provide an economically attractive and ecologically sound means of reducing external inputs and improving internal resources (Bohlool et al., 1999). Inputs of biologically fixed N into agricultural systems may be derived from symbiotic relationships involving legumes and *Rhizobium* species, partnerships between plants and *Frankia* species or cyanobacteria, or from non -symbiotic associations between free-living diazotrophs and plant roots. It is assumed that these N_2- fixing systems will satisfy a large portion of their N requirements from atmosphere N_2. Additional fixed N will be contributed to soil reserves for the benefit of other crops or forage species (People and Crawell, 1992).

Cowpea *(Vigna unguiculata*) is one of the main legumes contributing to the economy of nitrogen in the cropping systems with low input through the Biological Nitrogen Fixation (BNF) (Sanginga et al., 2000). The crop may contribute some of the acquired nitrogen to soil organic matter and nitrogen needs of succeeding and associated crops (International Atomic Energy Agency (IAEA), 2008). Symbiotically nitrogen can reduce the rate of soil degradation where legume–cereal rotations are practiced. The amounts of nitrogen contributed by various legumes that include cowpea vary between 50-300 kg ha^{-1} per year. These values will depend on the legume species, plant densities, cropping system and legume genotypes (Makoi et al., 2009). Awonaike et al. (1990) reported the BNF of Cowpea between 74 kg N ha^{-1} to 116 kg N ha^{-1}. Cowpea varieties vary in nitrogen fixation potential due to differences in the number, weight, efficiency of nodules and farming systems (Makoi et al., 2009). Cowpea–maize rotation tends to increase soil fertility after a season of crop rotation. Jeranyama et al. (2000) indicated that maize produced after cowpea yielded 1940 kg ha^{-1} Compared to the control with 1220 kg ha^{-1}. Maize/ Cowpea rotation was reported by Hardter et al. (1991) to produce the highest maize grain yield compared to mono-cropping due to BNF. To intensify the cereal production, additional amounts of nitrogen are necessary to maintain soil fertility in the maize – legume rotation systems. According to Fujita et al, 1990, leguminous crops are sources of nitrogen and contribute to an increase in the nitrogen uptake of the non-leguminous associated crops, while Senaratne et al. (1995) indicated that 161 mg N $plant^{-1}$ was fixed by intercropped cowpea which obtained 81% of its N derived from the atmosphere. Some of the farming systems that include crop rotations of cereal crops with legumes such as cowpeas can fix substantial amount of nitrogen (Phiri et al., 2006).

According to Bado et al. (2006), groundnut was found to fix 8 to 23 kg N ha^{-1} and the percentage of N derived from the atmosphere varied from 27 to 34 % while cowpea fixed 50 to 115 kg N ha^{-1} and percentage of N derived from the atmosphere varied from 52 to 115 kg N ha^{-1}. Compared to the NPK fertilizer alone, legumes fixed more N from the atmosphere when dolomite or manure was associated with mineral fertilizers. A significant correlation ($p<0.05$, R2 =0.94) was observed between total yields of legumes and total N derived from the atmosphere. Compared to mono-cropping of sorghum crop, soils that had cowpea – sorghum and ground nut -sorghum rotations improved soil mineral N from 15 kg N ha^{-1} to 22 kg N ha^{-1} respectively. The uptake of N was doubled under the legume-cereal crop rotation with succeeding increased yields of more than 290 %.

4.3 Materials and Methods

4.3.1 Site description

The study was conducted at two sites at Chisamba S 14.96783°, E 028.09408°; and Batoka S16.79993°, E 027.20181° both in region II of the Zambian agro-ecological zones but with differing soil types, soil fertility status and rainfall pattern. The Batoka site exhibits low fertility and moisture deficits (Table1 and Figure 2) while Chisamba site is well –endowed with fertility and rain fall patterns (Table 2 and Figures 1 and 3).

Soils at the Batoka site are classified as well- drained, very deep (>90 cm) strong brown to red and in places underlain by a thick pale brown to white loamy sand to sandy loam. The soils are classified as *Chromic haplic Lixisols* in the World Reference Base for Soil Resources (WRBSR, 2014). The soils are generally acidic with pH between the ranges of 3.7 and 4.4. The Cation Exchange capacity is very low while organic matter is less than 1.5 %. The soil exhibits compacted soil layer at around 15–20 cm depth (Base line data Table 1 and 2). The Batoka site lies at an altitude of 1200 m above sea level, located in the Southern Province, about 300 km from Lusaka. The site has a mean annual rainfall of about 825 mm with a dependable rainfall at 70 % probability of 539 mm. Figure 2 shows the rainfall pattern during the 2015/2016 growing seasons at Batoka. The length of the growing season is about 125 days. The total annual reference evapotranspiration (ETo) is 1251 mm which exceeds the mean annual rainfall. The mean annual temperature is 18.2 °C while the mean annual minimum and maximum are 10.9 °C and 26.5 °C respectively (Sokotela et al., 2005).

At the Chisamba site the soils are well-drained, very deep (>90 cm), reddish- brown, friable, shiny fine clayey with a humic topsoil. The soils are classified as *niti-luvic Phaeozems* (WRBSR, 2014). The soil pH is in the range of 5.5 to 6.2. The Cation Exchange Capacity and plant nutrients are relatively high. Organic matter is between 0.7 and 3.0 %. The soil is suitable for the production of most arable crops (Table 1 and 2). The Chisamba site is located between altitude 1100 and 1300 above sea level and is in Zambia's central province about 65 km north of Lusaka the capital city. The length of the growing season is about 140 days. The mean annual rainfall of about 825 mm with a dependable rainfall at 70% probability of 651 mm. Figures 1 and 3 show rainfall pattern during 2015/2016 and 2016/2017 growing seasons at Chisamba. The total yearly reference evapotranspiration (ETo) is 1511 mm. The mean annual temperature is 18.2 °C while the mean annual minimum and maximum are 10.9 °C and 26.5 °C (Sokotela et al., 2005).

4.3.2 Cowpea Genotypes Seed

The four cowpea genotypes evaluated for Biological Nitrogen Fixation (BNF) in the maize- cowpea rotation system were two parents, Bubebe (BBPRT) and Lutembwe (LTPRT) and two mutants LT 11-3-3-12 (LT) and BB 14-16-2-2 14-16-2-2 (BB) one from each parent respectively. The mutants were developed from mutation of cowpea parent materials. The parents were initially irradiated by using 150 gray (Gy) with Gamma radiation. The process developed different alleles with variants different from their parents. The mutants were selected for tolerance to abiotic (Drought, Aluminum toxicity) and biotic (pests and diseases) stresses.

4.3.3 Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications and analyzed across sites of different soil types and weather conditions. The four cowpea genotypes were BBPRT, LTPRT and LT 11-3-3-12 (LT) and BB 14-16-2-2 14-16-2-2 (BB). The interactions between sites and cowpea genotypes were shown.

4.3.4 Crop management

4.3.4.1 Tillage

Cowpea genotypes were planted under minimum tillage practice as one of the conservation farming principles during the 2014/15 and 2015/2016 growing seasons. Minimum tillage using ox-drawn Magoye ripper was done before the onset of the rains. Ripped furrows were spaced at 75 cm between rows at 15 cm soil depth.

4.3.4.2 Planting

Planting was done by hand through drilling along the ripped furrows at seed rate of 30 kg ha^{-1} to about 7 cm between seeds. Pearl millet used as a non -nitrogen fixing reference crop was planted in ripped furrows along the cowpea trial plot boundaries on rows spaced at 0.75 m and 1.5 m length by drilling at seed rate of 6 kg ha^{-1}

4.3.4.3 Fertilizer application

The cowpea and pearl millet plots were applied with compound fertilizer 10 % N: 20 % P: 10 % K at 200 kg ha^{-1} providing 20 kg ha^{-1} nitrogen, 40 kg ha^{-1} P_2O_5 and 20 kg ha^{-1} K_2O at planting. Each plot of cowpea crop had 12 rows of 6 m length spaced at 0.75 m. Two guard rows at each end of the blocks were included. ^{15}N labelled urea was applied to all treatment plots on 1.5 m^2 of both cowpea and pearl millet two weeks after planting to determine Biological Nitrogen Fixation. The application rate was 6.42g urea (20 kg N ha^{-1}) of 5.2 atom% ^{15}N per sub plot of 1.5 m^2 (Freitas, Silva & Sampaio, 2012) using a knapsack sprayer.

4.3.4.4 Pest and Disease Control

Two separate sprays against pests and diseases were made on cowpeas plots. The first control was at two weeks after thecowpea emergency and the second at flowering stage. Ampligo insecticide marketed by Syngenta agro chemical company was used for both crops at a rate of 20 mls per 20 liters of knapsack sprayer with a conical nozzle. The active ingredients in Ampligo are antraniliprole and Lambda cyhalothrin.

4.3.4.5 Weed control and Harvest

At planting, weed control started with Glyphosate spray targeting emerged weeds in the trial field. The subsequent weeding was done manually with hand hoes twice at two and four weeks after planting the crop. Eight net rows of cowpea were harvested to determine dry biomass and grain yields at the maturity stage. The harvesting was done with a sickle by cutting the stover at the soil base and was weighed to get the field plot weight. A sample of about 500g cowpea wet stover was collected from the plot field weight and was dried in an oven at 80 ^{o}C for 48 hrs. Sample dry weight was used to convert plot field wet weight to dry weight per hectare through a formula: (Sample dry wet/ sample wet weight) x Plot field weight x (10000/plot field area). Cowpea stover, pods and grain and pearl millet stover and head used in the assessment of nitrogen uptake were sampled at harvest from 1m net row of the labelled ^{15}N subplot.

4.3.5 ^{15}N IAEA Isotope Analysis

^{15}N labelled stovers and grains for cowpea and pearl millet crops were dried in the oven at 80^{o}C for 48 hrs. Samples were milled, sieved and packed in 10g quantity for IAEA analysis of atom % ^{15}N at the University of Florida in the United States of America. The samples were stored in the fridge at 18 ^{o}C before analysis. The atom % ^{15}N, isotopes and nitrogen content (N %) were analysed in the grains and stover. The ^{15}N results were reported as atom% ^{15}N/^{14}N.One enriched ^{15}N standard (2.0 atom % N-15, Ammonium Sulfate) and one natural abundance standard (USGS40) were measured for these results.

4.3.6 Data Collection

The data collected during crop growth were dry biomass and grain yields. The laboratory data collected included atom % ^{15}N excess and nitrogen content. The weighted atom %^{15}N was calculated from analysed atom % ^{15}N excess of cowpea dry biomass, pods and grains. The extent of nitrogen fixation (NF) was computed based on the difference between atom % ^{15}N of the parent cowpea to its mutant. The atom % ^{15}N difference was expressed in percentage as extent of nitrogen fixation by mutant over the parent. Biological Nitrogen Fixation (BNF) was estimated as % nitrogen derived from atmosphere (% Ndfa) using N- Isotope dilution technique equation of

Hardason and Danso, (1990).

$$\%Ndfa = [1-(Nfix/Nref) \times 100] \quad (1)$$

Where Nfix is ^{15}N atom % excess of the N- fixing plant and Nref is the ^{15}N atom % excess of the non-fixing plant (pearl millet) as 0.71 ^{15}N atom %. The lower the ^{15}N atom% excess in the plant the higher the plant's BNF due to dilution caused by Ndfa (IAEA, 2008). The extent to which the $^{15}N/^{14}N$ ratio decreases in the fixing crop, relative to the non-fixing plant determines BNF (Montañez andSicardi, 2013). Nitrogen (N) content in the cowpea dry biomass, grain and pod was analyzed and was used to compute total N (TN) accumulated in the dry biomass, grain and pod yields, while N fixed was calculated using the formula.,

$$Nfixed = (\%Ndfa) \times TN \quad (2)$$

Where Nfixed is nitrogen fixed and TN is total N in the dry biomass, grain and pod. According to Giller and Wilson, (1995), the Nitrogen Harvest Index (NHI) is the proportion of the N in the grain to the total above ground, was computed and compared to Ndfa for determination of N pool in the soil.

The computed data values of weighted atom % ^{15}N, Ndfa, Nfixed and NHI were statistically analysed for standard error mean separation with the help of Genstat 18th edition software (Paul and Jac, 2016).

4.4 Results and Discussion

4.4.1 Cowpea dry Biomass yield (kg ha^{-1})

The dry biomass yield was determined mainly to calculate the total nitrogen and nitrogen fixed in the cowpea genotypes' stover. Performance of cowpea genotypes on the dry biomass yield significantly ($P<0.001$) varied between sites and among genotypes (Table 26). Chisamba site (CH) produced 2802 kg ha^{-1} of cowpea dry biomass which was significantly ($P<0.001$) higher than the dry biomass at Batoka site (BK) with 1188 kg ha^{-1} during 2014/15 growing season (Figure 9). A similar trend of dry biomass yield was observed in the second growing season (2015/2016) where cowpea dry biomass yield was 4932 kg ha^{-1} at Chisamba and was significantly ($P<0.001$) higher than 1767 kg ha^{-1} produced at Batoka due to differences in soil quality (Figure 10). During the 2014/15 growing season, the cowpea genotypes LTPRT had significantly ($P<0.001$) highest dry bio mass yield of 4085 kg ha^{-1} and

1617 kg ha^{-1} followed by mutant LT 11-3-3-12 which produced 3113 kg ha^{-1} and 1147 kg ha^{-1} at Chisamba and Batoka respectively. However, mutant BB 14-16-2-2 had significantly higher dry biomass yield of 2096 than its parent BBPRT which had 1618 kg ha^{-1} at Chisamba (Figure 8). In the second growing season (2015/2016), on average cowpea genotypes BB 14-16-2-2 and LT 11-3-3-12 had higher dry biomass yield of 3293 kg ha^{-1} and 3953 kg ha^{-1} than their parents BBRT and LTPRT respectively. The biomass yields of 1950 kg ha^{-1} and 4493 kg ha^{-1} for mutant BB 14-16-2-2 were significantly superior over the parent BBPRT at Batoka and Chisamba respectively while mutant LT 11-3-3-12 which produced 2771 kg ha^{-1} had higher biomass yield than its parent LTPRT at Batoka. (Figure 9).

Table 26: Mean squares for combine analysis of variance of cowpea genotypes for dry biomass and grain yield at two sites during 2014/2015 and 2015/2016 growing season

Variate:Cowpea Yield (kg ha^{-1})		Biomass 2014/2015	Biomass 2015/16	Grain 2014/15	Grain 2015/16
Source of variation	d.f.	m.s.	m.s.	m.s.	m.s.
Site	1	14846983	59283774***	581816**	97114***
Rep/Location	4	72019	226301	30637	1390
Cowpea genotype	3	3024812	1284860***	156416***	882202***
Site x cowpea genotype	3	921871	3697188***	162441***	67912***
Error	12	57876	75308	15897	2475

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05

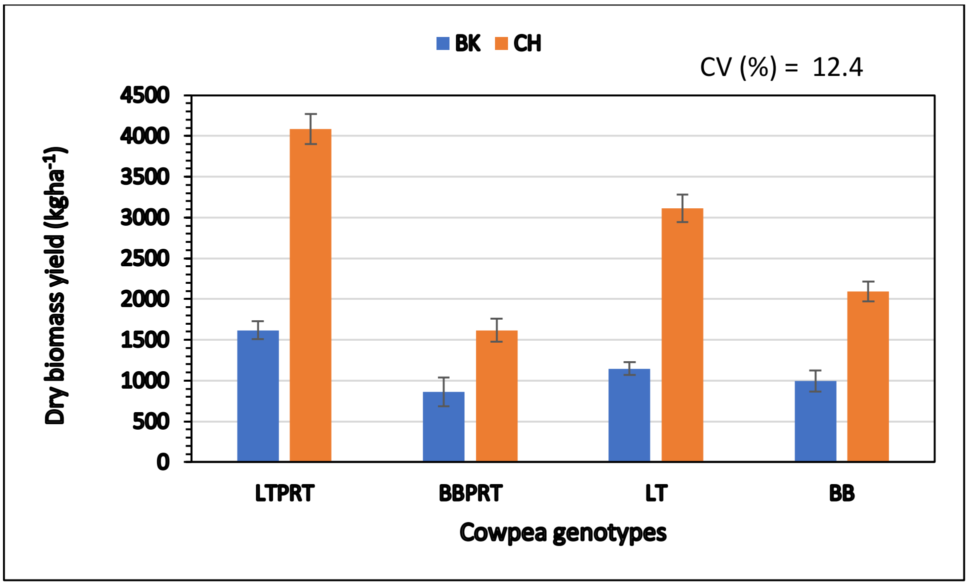

Figure 8: Cowpea dry biomass at Chisamba and Batoka sites during 2014/15 growing season.

Lsd (0.05): Cowpea: 302.6 Site: 304.2 Site x cowpea: 429.3

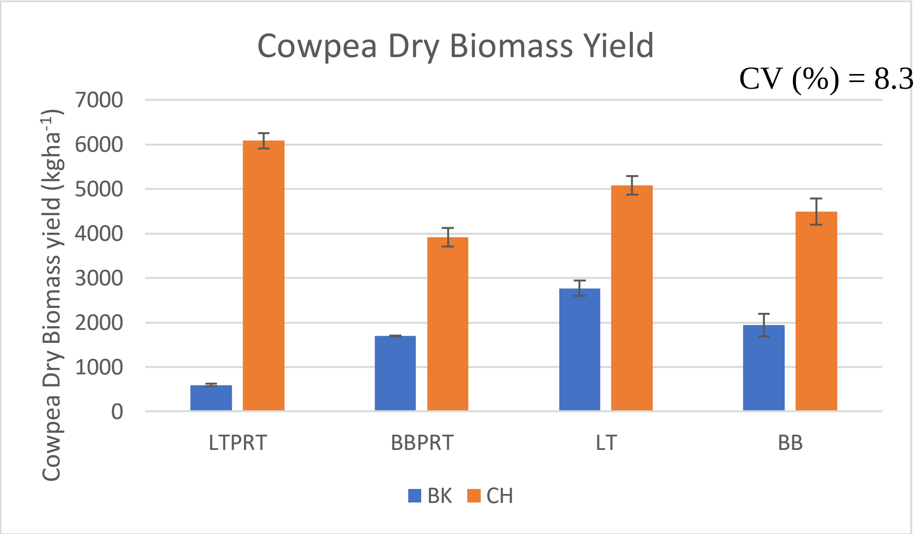

Figure 9: Dry biomass yield of the cowpea genotypes at Chisamba and Batoka (2015/2016) growing

Lsd (0.05): Cowpea: 345.2 Site: 539.2 Site x cowpea: 598.2

The dry biomass yield was determined mainly as major component for computation of total nitrogen in the dry biomass, nitrogen fixed in the stover by the cowpea genotypes and its potential for soil fertility improvement. Cowpea dry biomass is also important for improving soil fertility when the crop residue decompose to benefit the next crop in rotation (Verhulst et al., 2010). The cowpea dry biomass yield under this study significantly varied according to site and cowpea genotypes. A significant (<0.001) higher cowpea dry biomass yield obtained at Chisamba (2802 kg ha^{-1}) compared to Batoka (1188 kg ha^{-1}) could be attributed to relatively good soil physical and chemical properties as compared to loamy sand soils of Batoka. Before the cowpea was planted, baseline assessment at Batoka site showed lower soil pH, Calcium, Magnesium, Potassium, high bulk density and lower soil water content storage than soil fertility status at Chisamba. Lack of plant essential nutrients at Batoka could have reduced chlorophyll and protein synthesis for increased biomass accumulation (Marshner, 1993; Uchida and Silva, 2000). Therefore, the results suggest that high biomass yield at Chisamba would increase soil organic matter content for the benefit of the following crop in rotation compared to Batoka with low dry biomass. Among the genotypes, LT 11-3-3-12 yielded more dry biomass, which could help farmers to improve the soil fertility status if selected to be used in rotation systems at both sites. Rotation of crops increases the production of biomass necessary to improve the low level of soil organic matter (Zoumana et al., 2012).

4.4.2 Cowpea Grain Yield (kg ha^{-1})

The cowpea grain yield is important for the evaluation of cowpea genotypes with dual-purpose traits (Mfeka et al., 2018). Based on the data collected for two seasons, grain yield significantly ($P<0.001$) varied according to sites and among the cowpea genotypes (Table 26). The yield of cowpea grain was significantly lower at Batoka (224 kg ha^{-1}) than the yield obtained from Chisamba (867 kg ha^{-1}) during the 2014/2015 growing season (Figure 10). During the 2015/2016 growing season, cowpea grain yield from Batoka was 608.3 kg ha^{-1} and was significantly ($P<0.001$) higher than Chisamba with 527.3 kg ha^{-1} (Figure 11).

Among the cowpea genotypes, mutant LT 11-3-3-12 with an average yield of 689 kg ha^{-1} significantly ($P<0.001$) out yielded the rest of the genotypes in the 2014/15 growing season. Mutant LT 11-3-3-12 had significant ($P<0.001$) higher grain yield of 1093 kg ha^{-1} than its parent LTPRT by 49.7 % at Chisamba while mutant BB 14-16-2-2 with grain yield of 320 kg ha^{-1} was significantly higher than parent BBPRT by 344.4 % at Batoka during the 2014/2015 growing season (Figure 10). During the 2015/2016 growing season, genotype BB 14-16-2-2 had grain yield of 303 kg ha^{-1} significantly higher than parent BBPRT which had 272 kg ha^{-1} at Batoka. At Chisamba, genotype LT 11-3-3-12 with grain yield of 1094 kg ha^{-1} was significantly higher t than 730 kg ha^{-1} by parent LTPRT (Figure 11).

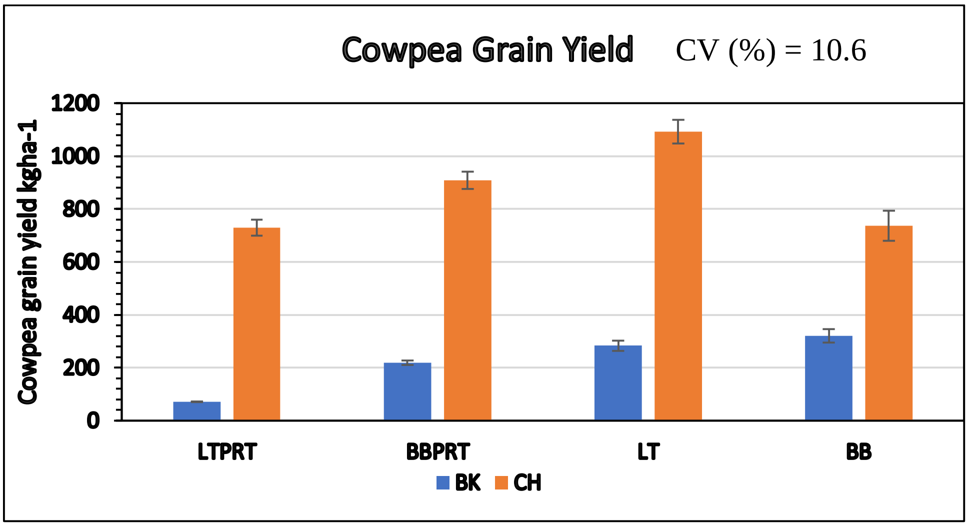

Figure 10: An interaction between sites and cowpea genotypes for grain yield (2014/15 growing season)

Lsd (0.05): Cowpea: 158.6 Site: 198.4 Site x cowpea: 244.3

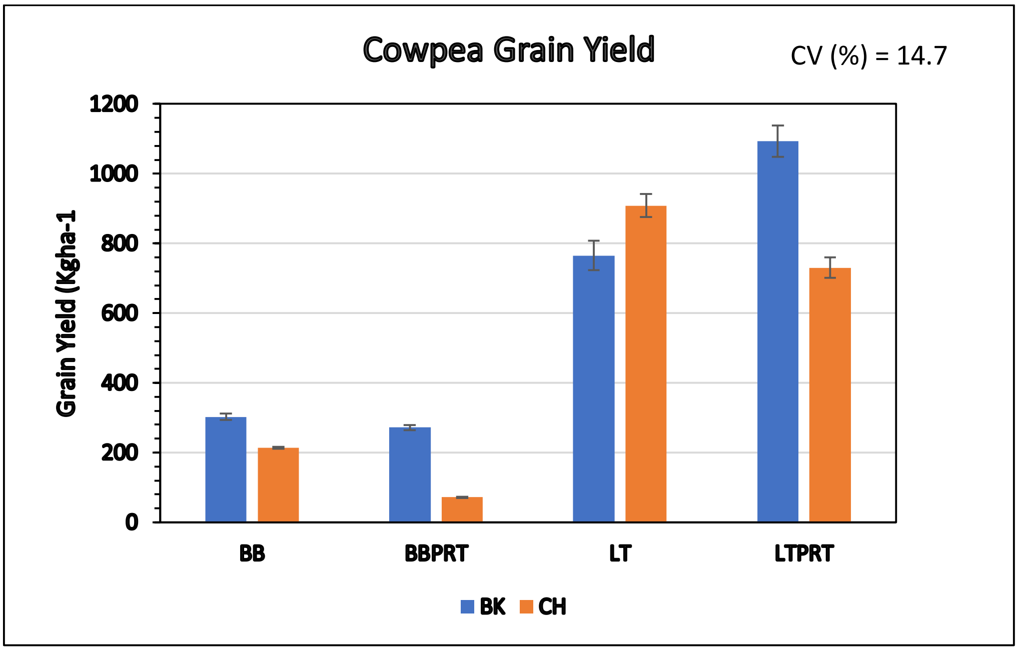

Figure 11: An interaction between Sites and Cowpea genotypes on grain yield (2015/2016).

Lsd (0.05): Cowpea: 158.6 Site: 198.4 Site x cowpea: 244.3

There was significant interaction (P<0.001) between sites and cowpea genotypes for grain yield. On average, mutants BB 14-16-2-2 and LT 11-3-3-12 exhibited stable yields at both sites and could be ideal genotypes for farmers in both areas. On the other hand, parents LTPRT and BBPRT had significant variation in grain between the sites that could perform very well at Chisamba.

The cowpea grain yield was determined as important component for total nitrogen fixed in the plant. The differences and inconsistency of cowpea grain yield between the sites and seasons could be attributed to variations in soil types and changes in weather conditions between the two sites (Ezeaku et al., 2012). Clay loam soils of Chisamba promote cowpea's vegetative growth, hence putting the crop in luxurious state against grain production in the wet season.

Warrag and Hall (1983) indicated that when the soil moisture content is above optimum at the grain filling stage it retards grain formation but enhances vegetative growth that could have contributed to low yields in the second season. According to Craufurd et al. (1997) rates of reproductive development, yield and yield components in cowpeas are sensitive to weather and locations' vagaries. The present study results showed that cowpea genotypes LT 11-3-3-12 and BB 14-16-2-2 were most consistent for grain yield compared to their parents and hence could be considered for dual purpose genotypes (biomass and grain yields production). Differences in cowpea grain yield among the genotypes could give an indication for Biological Nitrogen Fixation extent. Santiago de Freitas and Silva (2012) revealed that cowpea genotypes with the highest N content in the straw and highest BNF had the lowest grain productivity and lowest harvest index (0.14). Based on their findings, genotype mutant BB 14-16-2-2 and its parent BBPRT in the present study could have higher potential for high BNF.

The results revealed that cowpea genotypes are inherently different and can perform differently in various sites of other conditions. Ezeaku et al. (2012) confirmed that the differential performance among cowpea genotypes could be explained by variations within each locations and interactions between genotypes and locations.

4.4.3 Weighted Atom % ^{15}N

The weighted nitrogen atom % ^{15}N which was calculated from the atom % ^{15}N of the stover, pods and grain showed significant ($P<0.001$) variation between the two sites and among the cowpea genotypes (Table 27). The lower the atom % ^{15}N analyzed in the plant parts, the higher the biological nitrogen fixed by the cowpea genotypes due to dilution effect. The weighted atom %^{15}N for Chisamba was on average 0.40 while for Batoka was 0.63. The values indicated that Chisamba was 58 % atom % ^{15}N significantly ($P< 0.01$) lower than Batoka implying that Chisamba site had fixed more nitrogen than Batoka. Among the genotypes evaluated for BNF, LT 11-3-3-12 had lowest weighted atom % ^{15}N of 0.55 at Batoka and 0.42 at Chisamba compared to other genotypes. This was followed by LTPRT with 0.60 at Batoka and 0.47 at Chisamba. On average LT 11-3-3-12 had 10.3 % significantly lower % ^{15}N at ($P<0.001$) than its parent LTPRT while cowpea mutant BB 14-16-2-2 was 4.6 % significantly lower in the weighted atom % ^{15}N than the parent BBPRT (Figure 12). Therefore, the study showed that cowpea mutants LT 11-3-3-12 and BB 14-16-2-2 had fixed more nitrogen than their parents.

Table 27: Mean square of combine analysis of variance of weighted atom % 15N and extent of nitrogen fixation of mutant genotypes at two sites

Variate: Atom % ^{15}N		Weighted atm % ^{15} N		Extent.N fixation %
Source of variation	**d.f.**	**m.s.**	**d.f.**	**m.s.**
Site	1	0.2027611***	1	37.6894***
Rep/location	4	0.0001221	4	0.6388
Cowpea genotype	3	0.0070764***	1	69.0791***
Site x cowpea genotype	3	0.0054477***	1	0.0013ns
Error	12	0.0001123	4	0.632

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05

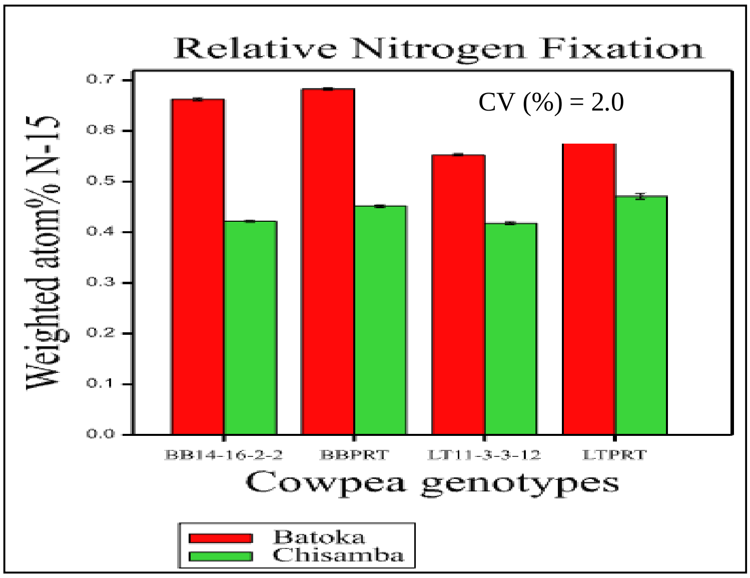

Figure 12: Weighted atom% 15N of the cowpea genotypes.

Lsd (0.05): Cowpea: 0.0133 Site: 0.0125 Site x cowpea: 0.0185

The study indicated significant difference in the weighted atom % ^{15}N between two sites. IAEA. (2008) reported that the lower the atom% ^{15}N in the sample analysis the higher the Biological Nitrogen Fixation (BNF) due to dilution of nitrogen from the atmosphere. Therefore, the data showed that the Chisamba site with lower weighted atom % ^{15}N had higher BNF than Batoka site. Chisamba site has Clay Loam soils and is rich in most of the essential plant nutrients as compared to Batoka with poor Loamy Sand soils. On average at 0-15 cm soil depth, the soil fertility status at Chisamba had plant nutrient contents that contributed to improved nitrogen fixation as pH (6.7), P (75.5 mg kg^{-1}), K (541.9 mg kg^{-1}), Ca (218.5 mg kg^{-1}) and Mg (26.8 mg kg^{-1}) compared to Batoka site that had plant nutrient contents of pH (4.3), P (10.9 mg kg^{-1}, K (29.7 mg kg^{-1}), Ca (110.7 mg kg^{-1}) and Mg (12.6 mg kg^{-1}). Some reports have indicated that Biological nitrogen fixation by legumes is usually enhanced by availability of rhizobium bacteria and phosphorus nutrient in the soil. Carsky et al. (2001) reported low Ndfa in very early maturing local cowpea varieties on relatively poor soils while Sanginga et al. (2000) found increased nitrogen balance in the soil with application of phosphorus. This showed that the high BNF determined at Chisamba could be attributed to high levels of rhizobium bacteria, high pH (5.6) and high levels of phosphorus in the soil (Table 28).

Table 28: Influence of cowpea genotypes on soil chemical properties at 15-30 cm depth at two sites

Site		Treatment Soil chemical analysis (15-30 cm depth)								
Chisamba	Cowpea genotypes	pH ($CaCl_2$)	O.M (%)	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})	Na (mg kg^{-1})	CEC (cmol kg^{-1})
	LTPRT	6.7	2.03	0.058	41.4	418.5	21.8	219.2	27.6	3.7
	BBPRT	6.6	2.28	0.061	41.6	541.9	35.5	222.4	29.3	4.6
	LT	6.5	2.69	0.103	41.4	637.4	24.5	223.6	29.1	5.1
	BB	6.8	2.66	0.083	39.1	497.1	20.0	220.4	29.5	4.5
	NCP	6.9	1.29	0.037	40.0	616.3	43.3	232.8	30.8	4.1
	Mean	**6.7**	**2.19**	**0.068**	**40.7**	**542.2**	**29.0**	**223.7**	**29.2**	**4.4**
Batoka	LTPRT	4.3	1.843	0.055	24.0	25.8	8.1	107.8	0.5	1.5
	BBPRT	4.2	1.55	0.035	12.5	19.9	9.3	62.1	0.8	3.2
	LT	3.9	3.72	0.158	21.0	45.7	3.8	51.4	1.1	4.4
	BB	3.9	1.77	0.042	15.0	21.0	5.5	62.1	0.9	3.7
	NCP	4.2	1.56	0.050	6.4	16.0	8.8	13.3	1.8	3.0
	Mean	**4.1**	**2.09**	**0.068**	**15.8**	**25.7**	**7.1**	**59.3**	**1.0**	**3.2**
	FPr	0.571	<0.001	<0.001	0.063	<0.001	<0.001	<0.001	0.904	0.103
	Lsd (0.05)	0.4872	0.2501	0.01341	8.31	39.71	4.001	11.84	2.928	0.8562
	CV (%)	5.3	6.8	11.5	17.2	8.2	12.9	4.9	11.3	13.2

Note: LTPRT= Lutembwe parent indeterminate type, BBPRT = Bubebe parent cowpea determinatetype, LT 11-3-3-12 = Lutembwe mutant indeterminate and running type, BB 14-16-2-2 = Bubebe mutant determinate trifoliate type

The study suggested that BB 14-16-2-2 and LT 11-3-3-12 mutants fixed more nitrogen than their respective parent varieties. The results further revealed that parent LTPRT and its mutant LT 11-3-3-12 had better BNF traits than BBPRT and its mutant BB 14-16-2-2 because of the lower atom% ^{15}N obtained in the genotypes. The findings with Sanginga et al. (1990) and Makoi et al. (2009) indicated genetic variability among and within legumes. An interaction in atom% ^{15}N between the sites and the cowpea genotypes was observed. The LT 11-3-3-12 mutant was more stable and fixed more nitrogen at both sites while BB 14-16-2-2 mutant tended to fix more nitrogen at Chisamba which has Clay Loam soils.

4.4.4 Extent of Nitrogen Fixation

The extent of Nitrogen Fixation (NF) was computed based on the difference between atom % ^{15}N of the parent cowpea to its mutant. The mutants were significantly ($P<0.001$) superior over their parents in terms of atom %^{15}N but the extent of NF% between them varied. The degree of nitrogen fixation by cowpea mutant BB 14-16-2-2 was 3.0 % and cowpea mutant LT 11-3-3-12 was 8.0 % over their parents BBPRT and LTPRT respectively at Batoka with Loamy Sand soils. At Chisamba, the extent of Nitrogen Fixation by mutants BB 14-16-2-2 and LT 11-3-3-12 over their parents BBPRT and LTPRT was 6.0 % and 11.0 % respectively (Figure 13). The extent of BNF by cowpea mutants over the parents was higher at Chisamba than Batoka by 35.3 %, meaning that the Chisamba site was more favourable for BNF by the mutants.

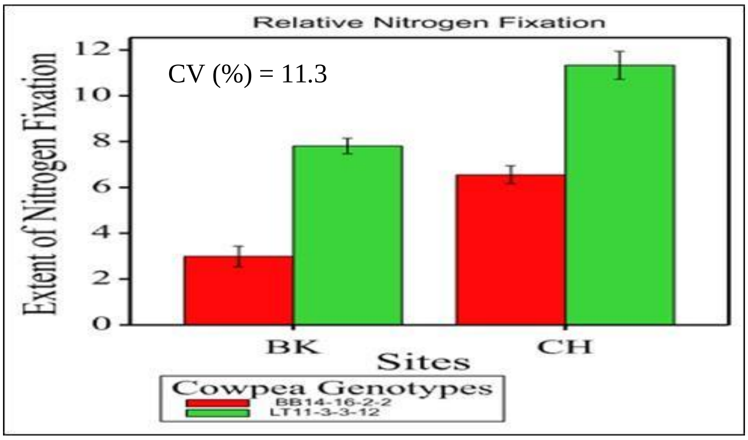

Figure 13: The Extent of Nitrogen Fixation (%) between the two mutant genotypes over the parents at two sites.

Lsd (0.05): Cowpea: 1.281 Site: 1.274 Site x cowpea: 1.501

The results showed that the genetic improvement for BNF through mutation was higher for LT 11-3-3-12 than BB 14-16-2-2 as demonstrated by the extent of biological nitrogen fixation which was on avaerage 9.5 % for LT 11-3-3-12 and 4.5 % for BB. The results agreed with Sanginga et al. (1990) on genetic variability for N fixation among legume genotypes. The extent of BNF at Chisamba site (8.5 %) was higher than at the Batoka site (5.5 %) due to differences in soil fertility status which was low at Batoka compared to Chisamba. However, in terms of adaptability, cowpea mutant BB 14-16-2-2 could be recommended for N economy improvement when produced at Chisamba with Clay Loam soils while the LT could be used in both soil types.

4.4.5 Nitrogen Derived from Atmosphere (%Ndfa)

The nitrogen derived from atmosphere (% Ndfa) calculated from the weighted atom% ^{15}N ratio of nitrogen-fixing plant and non-fixing plant (pearl millet) was significantly ($P<0.001$) varied between sites and among cowpea genotypes (Table 29). The Ndfa was 38 % at Chisamba and was significantly ($P<0.001$) higher than for the Batoka site which had 12.6 % (Table 30).

Table 29: Mean squares for combine analysis of cowpea genotypes for biological nitrogen fixation at two sites

Variate: BNF		TNBio (kgha^{-1})	NHIG (%)	Ndfa (%)	Nfixed Bio (kgha^{-1})	TN fixed (kgha^{-1})	TN (kgha^{-1})
Source of variation	**d.f.**	**m.s.**	**m.s.**	**m.s.**	**m.s.**	**m.s.**	**m.s.**
Site	1	26758.02***	56.705**	3862.2816***	7468.65***	19709.91***	79430.7***
Rep/Location	4	60.44	5.562	0.4465	13.4	1.39	7.5
Cowpea genotypes	3	1491.4***	31.109***	139.3708***	403.94***	695.82***	2698.7***
SITE x Cowpea genotypes	3	1193.75***	22.392***	121.3242***	71.74**	102.37ns	1641.9***
Error	12	76.79	2.435	0.5179	12.47	31.42	177.6

Note: ***Significant at $P \leq 0.01$, **Significant at $P \leq 0.05$, ns Not significant at $P \leq 0.05$. TNBio = Biomass total nitrogen, NHIG = Nitrogen harvest index, Ndfa = Nitrogen derived from atmosphere, Nfixed Bio= Nitrogen fixed in the biomass, TN fixed = Total nitrogen fixed, TN = Total nitrogen

Among the genotypes, mutant LT 11-3-3-12 had significant (P<0.001) highest nitrogen derived from atmosphere (31.7 %) as compared to parent LTPRT (25.6 %), BB 14-16-2-2 (23.0 %) and BBPRT (20.2 %) on average at two sites. An interaction was observed between the sites and genotypes. The Ndfa was highest for mutant LT 11-3-3-12 with 41.2 %) followed by mutant BB 14-16-2-2 with 40.6 % at Chisamba site while at Batoka, mutant LT 11-3-3-12 had the highest Ndfa of 22.2 % followed by parent LTPRT which had 17.4 % (Table 30).

Table 30: Analysis for Biological Nitrogen Fixation (BNF) by four cowpea genotypes applied with ^{15}N isotope at two sites during the 2015/2016 growing season

Site		Biological Nitrogen Fixation analysis					
Chisamba	**Cowpea genotypes**	**TNBio (kgha^{-1})**	**NHIG (%)**	**Ndfa (%)**	**NF Bio (kgha^{-1})**	**TNF (kgha^{-1})**	**TN (kg ha^{-1})**
	LTPRT	114.3	17.2	33.7	39.6	57.4	170.2
	BBPRT	75.9	24.8	36.4	28.0	54.3	149.0
	LT	133.5	21.3	41.2	55.6	86.1	208.8
	BB	93.3	19.9	40.6	37.9	57.9	142.5
	Mean	**104.3**	**20.8**	**38.0**	**40.2**	**63.9**	**167.6**
Batoka	**LTPRT**	14.7	14.5	17.4	2.3	3.5	19.9
	BBPRT	38.3	16.5	3.9	1.9	2.0	52.5
	LT	53.4	19.1	22.2	12.9	16.5	74.2
	BB	43.4	20.8	7.0	2.9	4.5	63.8
	Mean	**37.5**	**17.7**	**12.6**	**5.0**	**6.6**	**52.6**
Lsds (0.05)	**Site**	11.00	1.96	0.91	4.442	7.05	16.76
	Cowpea	8.81	2.67	0.76	4.15	1.34	3.10
	Site x cowpea	14.77	3.15	1.22	6.17	8.67	20.61
	CV (%)	12.4	8.1	2.8	15.6	15.9	12.1

Note: LTPRT = Lutembwe parent indeterminate type, BBPRT = Bubebe parent determinate type, LT 11-3-3-12 = Lutembwe mutant indeterminate and running type, BB 14-16-2-2 = Bubebe mutant determinate trifoliate type. TNBio = Total nitrogen of the biomass, NHIG = Nitrogen harvest index of the grain, Ndfa= Nitrogen derived from atmosphere, NF = Nitrogen fixed in the biomass, TNF = Total nitrogen fixed in the biomass, grain and pod, TN = Total nitrogen, Bio = Biomass, GRN = Grain

The nitrogen derived from atmosphere (% Ndfa) calculated from the weighted atom% ^{15}N ratio of nitrogen-fixing plant and 0.71 atom% ^{15}N of the non-fixing plant (pearl millet) significantly ($P<0.001$) varied between sites and among cowpea genotypes mainly due to differences in soil types and genetic variations. The nitrogen derived from the atmosphere significantly varied among the cowpea genotypes. The results showed that the mutants BB 14-16-2-2 and LT 11-3-3-12 with an average of 41.0 % derived more nitrogen from the atmosphere at Chisamba. BB 14-16-2-2 and BBPRT could have been less tolerant to poor acidic soils of Batoka compared to LT 11-3-3-12 and LTPRT which appeared relatively more tolerant at Batoka. Therefore, BB 14-16-2-2 could only be recommended for BNF in areas with soils that have high fertility status whereas LT 11-3-3-12 could be for both sites. Abaidoo et al. (2017) found similar results where % Ndfa varied among cowpea genotypes and was in between 31.3 % and 61.8 %.

4.4.6 Total Nitrogen

Total nitrogen (TN) was calculated from the total biomass and nitrogen content value in the dry biomass, grain and pod. The average total nitrogen content of 167.6 kg N ha^{-1} produced at Chisamba was significantly ($P<0.001$) higher than 52.6 kg N ha^{-1} for Batoka.The mutant LT 11-3-3-12 significantly $P<0.001$) produced the highest total nitrogen (208.8 kg N ha^{-1}) as compared to parent LTPRT (170.2 kg N ha^{-1}), while mutant BB 14-16-2-2 was not significantly ($P>0.05$) superior over the parent BBPRT at Chisamba. At Batoka site, mutant LT LT 11-3-3-12 significantly $P<0.001$) produced the highest total nitrogen of 74.2 kg N ha^{-1} followed by mutant BB 14-16-2-2 had 63.6 kg N ha^{-1}. The total nitrogen increase for mutants LT 11-3-3-12 and BB 14-16-2-2 was 272.9 % and 21.5 % over their parents at Batoka respectively (Table 30). On average, Parent LTPRT was 45% lower than its mutant LT 11-3-3-12 in nitrogen accumulated in the stover, grain and pods during the cowpea plant growth period. An interaction between the site and cowpea genotypes on total nitrogen accumulation was significant at $P<0.001$). BB 14-16-2-2 and LT 11-3-3-12 genotypes generally had better TN levels at both sites whereas BBPRT and LTPRT were much higher at Chisamba. The average total nitrogen in the dry biomass component (TNBio) was 70.8 kg N ha^{-1}, representing 71.3 % of the TN in the combined three plant components (biomass, grain and pod). TNBio at Chisamba was 104.2 kg N ha^{-1} and that of Batoka was 37.5 kg ha^{-1}. LT 11-3-

3-12 genotype that produced 133.5 kg N ha^{-1} and 53.4 kg N ha^{-1} in the dry biomass was significantly high at P<0.001 followed by BB 14-16-2-2 mutant with 93.3 kg N ha^{-1} and 43.4 kg N ha^{-1} at Chisamba and Batoka respectively. Mutants LT 11-3-3-12 and BB 14-16-2-2 were both significantly superior over their parents in the TNBio (Table 30).

Total nitrogen of the cowpea genotypes was computed to determine biological nitrogen fixed in the crop and its importance to improved soil fertility status and crop yields. The significant interaction (P<0.001) between the site and cowpea genotypes for total nitrogen implied that the sites were more favourable for specific cowpea genotypes when compared to others. The total nitrogen in the stover is important for nitrogen required in plant growth because it is returned to the soil by mineralizing plant nutrients. The nitrogen in the stover could be beneficial to the succeeding cereal crop included in the rotation. The non-N benefit of cowpea rotation to cereal yields was higher than after cereal crop (Jeranyama et al., 2000). Hardter et al. (1991) reported high maize grain yields in maize-cowpea rotation and did not show any reduction in grain yields over a period of growing seasons. In the present experiment the higher maize grain yield of 12000 kg ha^{-1} was obtained in the maize-cowpea rotation than in the mono-cropping of maize which had 4500 kg ha^{-1}. The higher grain yields of maize were due to cowpea mutants LT 11-3-3-12 and BB 14-16-2-2 which were superior over their parents in the amount of total nitrogen content from higher nitrogen fixation as described earlier and illustrated in Table 30. Hence, the study gave justification of why maize planted after cowpea increased maize grain yield more than in maize-maize mono-cropping system (Simunji et al., 2018).

4.4.7 Total Nitrogen Fixed

The total nitrogen fixed is the total amount of nitrogen fixed in the plant stover, grain and pod as a product of nitrogen derived from atmosphere and the total N content. Between the two sites, Batoka (BK) had significantly lower amount of nitrogen (6.6 kg N ha^{-1}) fixed in the plant parts (P<0.001) than at Chisamba (CH) which had 63.9 kg N ha^{-1} fixed. The LT 11-3-3-12 mutant genotype was significantly highest at P<0.001 in the amount of nitrogen fixed (86.1 kg N ha^{-1}) at Chisamba and 16.5 kg N ha^{-1} at Batoka (Tables 29 and 30). There was a significant interaction effect at P<0.05 between sites and genotypes of which mutant LT 11-3-3-12 was observed to have a potential of accumulated nitrogen fixed at both sites than BB. The other genotypes tended to fix more nitrogen only at Chisamba which had clay loam soils and favourable pH (5.5). BB 14-16-2-2 and LT 11-3-3-12 mutants had 20.5 kg N ha^{-1} and 33.4 kg N ha^{-1} respectively fixed in the dry biomass across sites. These were significantly ($P< 0.001$) higher than their parents BBPRT and LTPRT which had 14.6 kg N ha^{-1} and 20.5 kg N ha^{-1} respectively across sites (Tables 29 and 30).

The total biological nitrogen fixed (BNF) varied between the two sites due to differences in soil types and quality where Batoka was found to be less fertile than Chisamba. The variation is because BNF is affected by several factors such as energy sources, the phosphorus level in the soil, acidity of the soil and plant essential elements such as Calcium and Magnesium. Batoka site generally had less of these nutrients which are important for micro- symbionts responsible for nitrogen fixation.

The energy sources limit the BNF because the microbial process requires energy to fix nitrogen. Therefore, from this study Batoka site which produced lower maize dry biomass than Chisamba site by 70 % could have limited energy sources to support the (Brady) rhizobial associations with cowpea genotypes. It is reported that to fix 10 kg N, the microbes require 1000 kg of an easily degradable carbonaceous substrate (Msumali et al., 1996). The process of BNF is highly Phosphorus (P) demanding and for every 5-10 kg of N fixed, 1 kg of available P must be supplied. In this regard, to ensure that cowpea genotypes improve N- fixation in soils that are deficient in P at Batoka, mycorrhizal inoculation which enhances P-uptake would be important (van Reuler and Prins, 1993). The extreme soil acidity of pH 4.4 at the Batoka site does not generally support the survival of the microsymbionts. The host cowpea legume and BNF process at Batoka were affected by acidic conditions mainly due to nutrient deficiency or other element toxicities by Al^{3+}, Mn^{2+} and Fe^{2+}(Wangari and Msumali, 2000). The total nitrogen fixed which varied between the sites and among the cowpea genotypes could further be explained by available soil nitrogen content under the cowpea genotypes. Cowpea mutant LT 11-3-3-12 which had highest BNF was superior over NCP, LT PRT, BB 14-16-2-2 and BBPRT for available soil nitrogen by 66.6 %, 56.5 %, 52.3 % and 63.3 % respectively. While cowpea mutant BB 14-16-2-2 significantly contributed ($P< 0.001$) 29.9 % more to soil nitrogen content than conventional farming system (NCP) and 23. 2 % more than its parent BBPRT. The results have indicated that mutants BB 14-16-2-2 and LT 11-3-3-12 produced high content of available nitrogen for uptake by the maize crop compared to their parents BBPRT and LTPRT. This may be due to higher dry biomass yields, nitrogen content in the biomass, BNF and low C/N ratios in the stover of the mutants BB 14-16-2-2 and LT 11-3-3-12 than in their parents. The present study was in agreement with Giller, (2001) who stated that the amount of N_2 fixed greatly depends on shoot dry matter and accumulated shoot nitrogen content. Benites, (2008) reported high dry matter yield of the legume in rotation with cereal to increase soil organic carbon (SOC) which enhanced the soil to become more productive and requiring less fertilizer due to the increased values of nitrogen and other plant nutrients. Compared to maize monocropping, cowpea genotypes in the rotation increased the amount of soil nitrogen content greatly due to biological nitrogen fixation by the legume crops (Carsky et al., 1999).

The variations in the amount of nitrogen fixed by cowpea genotypes indicated that different cultivars exist that show differences in susceptibility to infection by a particular strain of (*Brady) rhizobium* and in the overall expression of the BNF potential (Wangari and Msumali, 2000). The general results on total biological nitrogen fixed agreed with those of Abaidoo et al. (2017) that total N fixed by cowpea genotypes was in the range of 11.9 - 40 kg N ha^{-1}. However, Belane et al. (2011) reported the highest amount of N-fixed by cowpea cultivar as 182 kg ha^{-1} whereas Munjonji et al. (2017) showed cowpea genotype with low grain yield performing better for BNF of 71 kg N ha^{-1} under well-watered and 39 kg N ha^{-1} under severe water stress. The amount of nitrogen fixed by the cowpea plant and partitioned to the dry biomass stover contributes to the nitrogen pool in the soil after decomposition. Part of the nitrogen in the legume plant comes from fertilizers and soil. The results were in agreement with Dakora and Keya (1997) who stated that legumes generally take more than half of their nitrogen requirement from the atmosphere and therefore take less N from the soil compared to the non N fixing crops. The present study results further showed that dry biomass yield and biological nitrogen fixed in the biomass were significantly correlated with maize grain yield (Table 31). It was, therefore, demonstrated that cowpea could be one of the main legumes contributing to the economy of nitrogen in cropping systems.

Table 31: Regression Analysis of Variance of cowpea biomass against total nitrogen and nitrogen fixed in the stover

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	309109213	103036404	22.43	0
BIO	1	37864526	37864526***	8.24	0.006
TNS	1	18436147	18436147	4.01	0.052
NFS	1	21366591	21366591**	4.65	0.037
Error	41	188342637	4593723		
Lack-of-Fit	9	87721535	9746837	3.1	0.009
Pure Error	32	100621102	3144409		
Total	44	497451850			

Maize grain yield = 6115+2.467 Bio – 210 TNS+393 NFS

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05 BIO = Biomass, TNS = Total nitrogen in the stover, NFS = Nitrogen fixed in the stover

4.4.8 Nitrogen Harvest Index (NHI)

The Nitrogen Harvest Index (NHI) which is the proportion of the nitrogen in the grain to the total nitrogen (N) in the above ground biomass, was observed lower than the proportion of N fixed in all cowpea genotypes at Chisamba. The study, therefore, indicated an increased N pool of the soil at Chisamba which had an average NHI in the grain of 20.8 % compared to the total Biological nitrogen fixed of 63.9 % (Table 30). According to Giller and Wilson, (1995) the Nitrogen Harvest Index was lower than the proportion of N fixed to the N pool of the soil. However, at Batoka site the NHI in the grain was higher (17.7 %) than total biological nitrogen fixed (6.6 %) and this implied that most of the N fixed was translocated to the grain. The results indicated a trade-off between grain production for food and soil fertility improvement by cowpea genotypes at different experimental sites as demonstrated by Ojiem et al. (2007), which also depend on the cowpea genotypes. Therefore, such competing interests need to be considered in choosing sites and cowpea genotypes for soil fertility enhancement. The potential for net N benefit and more input of residues by legumes grown in fertile soils of Chisamba could enhance soil fertility. This is achieved by improving soil structure, microbial biomass and quantity of mineralized N to benefit subsequent cereal crops more than in poorly fertile soils of Batoka (Ojiem et al., 2007).

4.5 Conclusion

The study gave an opportunity to evaluate cowpea genotypes for Biological Nitrogen fixation using the isotope atom % ^{15}N morden technique at two sites. The Biological Nitrogen fixation in the plant stover, grain and pod was estimated as the product of nitrogen derived from atmosphere and the total N content. The average total nitrogen content of cowpea genotypes produced at Chisamba was 218.6 % higher than for Batoka.The mutant LT 11-3-3-12 produced 22.6 % more total nitrogen (208.8 kg N ha^{-1}) than parent LTPRT (170.2 kg N ha^{-1}) at Chisamba while it was 272.9 % followed by mutant BB 14-16-2-2 with 21.5 % higher than parents at Batoka.

Among the cowpea genotypes, mutant LT 11-3-3-12 exhibited the highest Biological Nitrogen Fixation of 86.1 kg N ha^{-1} and 16.5 kg N ha^{-1} followed by mutant BB 14-16-2-2 that fixed 57.9 kg N ha^{-1} and 4.5 kg N ha^{-1} at Chisamba and Batoka sites respectively. Cowpea genotypes fixed more nitrogen at the Chisamba site than at Batoka due to differences in soil nutrient levels for *brady* rhizobia production which could have resulted in high number or weight of nodules. The high BNF exhibited by mutant derived genotypes LT 11-3-3-12 and BB 14-16-2-2 could improve the productivity of maize among smallholder farmers at low input management.

CHAPTER FIVE

5.0 EVALUATION OF THE PRODUCTIVITY OF COWPEA-MAIZE COMBINATIONS

5.1 Introduction

Maize is one of the three most important cereal crop species (after wheat and rice), and is grown throughout a wide range of climates (Huang et al., 2006). Maize (*Zea mays L.)* in Zambia is mainly produced by smallholder farmers and is a primary staple food for well over 90 % of the Zambians (IAPRI, 2015). However, productivity of maize among the smallholder farmers has become very low, ranging from 1.1 t ha^{-1} to 2.3 t ha^{-1}. These yields are very low when viewed against average potential yield of maize which is currently at 10 t ha^{-1}(Indaba Agricultural Policy Research Institute (IAPRI), 2015). The primary causes of low yields are attributed to prolonged droughts, poor soil fertility, insufficient plant nutrients and poor farming practices such as the use of unimproved varieties and in appropriate tillage practices.

Water and nitrogen (N) availability remain, globally, the most limiting crop growth factors (Mueller et al., 2012). The additional demand for food by the growing population will require that resource use efficiency of water and N for crops are increased. Without underestimating the role of plant genetics, efficient management of water and N has been identified as crucial for closing the yield gap of main cereal crops (Sinclair and Rufty, 2012). Therefore, crop water deficit leads to yield and biomass reductions and diminished N uptake. On the other hand, a good crop N nutritional status enhances crop tolerance to drought. A moderate increase in N supply improves water use efficiency (WUE) in semiarid environments (Cossani et al., 2012).

Maize is a C4 plant, which confers potentially more efficient use of CO_2, solar radiation, water and N in photosynthesis than C3 crops and water use efficiency (WUE) of maize is approximately double that of C3 crops grown at the same sites. Even though maize makes efficient use of water, it is considered more susceptible to water stress than other crops. This is attributed its unusual floral structure of separate male and female floral organs and the near-synchronous development of florets on a (usually) single ear borne on each stem (Cakir,2004).

Conservation farming (CF) is a concept for optimizing crop yields, and economic and environmental benefits with key elements of no-tillage, adequate retention of crop residues on the soil surface for mulching, innovative cropping systems and measure to reduce soil compaction through controlled traffic. Improving nutrient use efficiency, particularly N use efficiency in rain-fed areas, is an important challenge to agricultural scientists. Therefore, use of improved maize varieties tolerant to low nitrogen and water in the nitrogen and water- stressed environment under the minimum tillage with cowpea- maize rotation could contribute to increased nitrogen use efficiency (NUE) and water use efficiency (WUE) of maize and adoption of the system in Zambia. Cowpea-Maize rotation involves the planting of maize crop after the cowpea legume crop and this technology facilitates improvement of maize productivity through increased soil fertility from cowpea nitrogen fixation (Verhulst et al., 2010). Sumanta et al.,2013 reported that conservation agriculture increased nitrogen use efficiency by 11% over conventional system. The synergy of improved maize varieties for drought and nitrogen stressed environments, minimum tillage and rotation with cowpea legume could improve maize yields among small holder farmers in Zambia.

Several recent studies have demonstrated carbon isotope discrimination may be used as a surrogate to select for improved water-use efficiency in crops (Farquhar *et al.* 1989). In contrast, ^{15}N isotope has been used to determine nitrogen use efficiency (NUE) in crops. This kind of technology should provide solutions to common doubts raised by many smallholder farmers of low maize productivity in the areas stressed with water and nitrogen. In recent years, The University of Zambia in the have produced some cowpea mutants from the two released parent cowpea varieties that have not been evaluated for their contribution to water and nitrogen use efficiency in maize production. The experiment was therefore conducted during 2014/2015, 2015/2016 and 2016/2017 growing seasons and the specific objective was to identify cowpea–maize combinations with high NUE and WUE for high maize productivity under conservation farming system.

5.2 Literature review

5.2.1 Nitrogen Use Efficiency

Maize (*Zea mays. L.*) requires large amounts of nitrogen (N) inputs for optimum grain and silage production, mainly due to the ability of the crop to produce large quantities of dry matter (Moser et al., 2006). However, Nitrogen is the most limiting nutrient for crop production in many parts of the world including Zambia, therefore efficient use of Nitrogen in plant production is an essential goal in crop management. Thus, improving NUE is relevant for maize, for which global NUE has been estimated to be less than 50% (Raun and Johnson, 1999).

According to Nele Verhulst et al. (2014), Nitrogen Use Efficient (NUE) is the ratio of grain yield per unit of available N in the soil, including the present residual soil nitrogen and Fertilizer nitrogen (NUE=N exported from the field into crops/N applied). Moll et al. (1982) on the other hand defined NUE as the grain yield or biomass production yield obtained per unit of N available in the soil (already present and originating from fertilizer application) and is inversely proportional to the amount of N fertilizer applied (Herel and Lemaire, 2005). In conservation farming, nitrogen fertilizer effects can be noticed in the following cropping seasons over several years. This is especially the case when fertilizer is applied in combination with residues retention since can increase temporally immobilization of fertilizer, which is released in the following years (Verhulst et al., 2014). Habbib et al. (2016) reported positive results in NUE, N harvest index, N, remobilization and N remobilization efficiency in maize under no- till compared to conventional tillage after four years of trials at both on station and on-farm.

Research results on the effect of rotation in conservation agriculture systems on NUE are inconsistent. Still most studies found adverse effects of crop mono culture on yield and nitrogen use efficiency and positive effects of legumes introduced in the rotation. Acharya, (2018) reviewed that agronomic N use efficiency (kg/kg) in maize under permanently raised beds (PRB) and conventional tillage (CT) method were found 28 % and 16% respectively in an experiment conducted in Uzbekistan. With the integrated soil–crop management practice and high mineral fertilizer use, N and P uptake by all crops are higher than for the un-amended soil conditions (Amouzou et al., 2018). Reicosky and Archer (2007), however, reported that larger amounts of CO_2

were released into the atmosphere as the result of tillage, which, in turn reduced the soil carbon (C) content. In contrast, conservation tillage practices under continuous cropping systems are known to improve SOM content (Awale et al., 2013).

NUE can hence be improved by increasing the physiological efficiency (PE) = dry matter/ unit nitrogen uptake and recovery efficiency (RE) = nitrogen uptake/unit of available nitrogen (Fageria and Bligar, 2005). Based on the physiological and agronomic point of view, NUE is an outcome of two biological processes. It includes: (i) N uptake efficiency (NUpE) which is the amount of N taken up per unit of available N, and (ii) N utilization efficiency (NUtE) which corresponds to the increase in biomass or yield per unit of N taken up (Daubresse, 2010). During the plant developmental cycle, some complex physiological processes are involved in the control of plant NUE notably N uptake, N assimilation and N translocation (Sinclair, 2004). Huang et al. (2017) reviewed that the simplest definition of plant NUE is the grain yield per unit of supplied N, an integration of NUpE and NUtE. Further, NUE is described as utilization index (UI) which is the absolute amount of biomass produced per unit of N. NUE can also be NUEg which is grain production per unit of N available and HI which is grain production of the total plant biomass.

Inter- and intra-specific variation for plant growth and mineral nutrient use efficiency (NUE) are under genetic and physiological control and modified by plant interactions with environmental variables (Bertin and Gallais, 2000). There is need for breeding programs to focus on developing cultivars with high NUE. Identification of traits such as nutrient absorption, transport, utilization, and mobilization in plant cultivars should greatly enhance fertilizer use efficiency. The development of new cultivars with higher NUE, coupled with best management practices (BMPs) will contribute to sustainable agricultural systems that protect and promote soil, water and air quality (Baligar et al., 2007). Raun and Johnson, (1999) indicated that Worldwide, nitrogen use efficiency (NUE) for cereal production is approximately 33 %. The findings showed that 67 % of the applied fertilizers are lost through gaseous plant emission, soil denitrification, surface runoff, volatilization, and leaching. Nitrogen Use Efficiency (NUE) technologies have the potential to reduce the quantity number of nitrogen fertilizers lost due to leaching into the soil and water ways. Farmers may reduce costs of fertilizers by making use of improved methods of farming like conservation agriculture and improved varieties that are tolerant to low soil nitrogen. NUE is assessed through differences in crop yield and total N uptake with above-ground biomass between fertilized plots and unfertilized control (difference method) or by using ^{15}N labelled fertilizers to estimate crop and soil recovery of applied N (Dobermann, 2005).

5.2.2. Water Use Efficiency

Rain-fed agriculture is central to Sub-Saharan Africa's food production process. (Cooper et al., 2008). The majority of farmers heavily depend on rain-fed crop production systems (Boko et al., 2007), and lack the incentive to improve water use efficiency in agricultural production (Abbate et al., 2004) including the motivation to conserve water (Hsiao et al., 2007) during the crop growth period. Therefore, planning agricultural systems that are efficient users of available water, as a prerequisite for improving water productivity, requires a good understanding of crop water use vis-à-vis the water sources (water balance components) (Mulebeke et al, 2010).

According to Singh and Sinha. (1977) water use efficiency (WUE) is used to evaluate applied water benefits through economic crop production. It is very important in crop production and irrigation water management described in two ways. Field water use efficiency (FWUE) which is a ratio of the amount of economic crop yield to the amount of water required for crop growth. FWUE = kg of economic yield/ha.mm of water. WUE can also be described as the ratio of economic yield to consumptive use of water or evapotranspiration. Consequently, biomass production per unit evapotranspiration (ET) has been used extensively as an interim measure of WUE. Maximum water use efficiency can be achieved by improving T as a proportion of ET. Water lost as evaporation from soil is non-productive and transpiration water use (TWUR) and maximal TWUE needs maximal yield per unit of water transpired (Brian et al., 1999).

Low water use efficiency (WUE) has been a concern as water availability for agriculture is decreasing day by day. For saving and effective utilization of this vital resource, proper management strategies involving agro-techniques should be developed. Many promising strategies for raising WUE are available and CA and conservation tillage increase water infiltration, reduces runoff and improves soil moisture storage. Conservation Farming (CF) based farming system was reported to alter the partitioning of the water balance, decreasing soil evaporation and increasing infiltration and deep percolation, leading to increased yields and WUE (Acharya, 2018). In regions with pronounced seasonal water scarcity or low and erratic rainfall water use efficiency can be dramatically improved by the practice of CA (Peterson & Westfall, 2004). This improved water use efficiency may reduce water requirements for a crop by about 30 %, regardless of whether crops are under irrigation or rain-fed (Bot & Benites, 2005). Water use efficiency is increased and save water by 15-50% through the adoption of CA technologies (Karki and Shrestha, 2015).

Sharma et al. (2012) argued that water input to a field or an agricultural system is not the same as the water used or depleted for crop production but may be worked out as output per unit of irrigation supply. Water productivity is estimated from the amount of water directly consumed by the agricultural system (evaporation and transpiration) and not the amount of irrigation water applied or rainfall received (Molden et. al., 2010). WUE is described as the ratio of total biomass or grain to water supply or evaporation which implies consumptive water use (Dastane, 1974).

5.2.2.1. Use of isotopic carbon to determine Water Use Efficiency

The carbon in atmospheric CO_2 and throughout the biosphere occurs as two stable (i.e., nonradioactive) isotopic forms. The most common form is ^{12}C, which accounts for about 98.9 % of the C in atmospheric CO_2. The other stable isotope, ^{l3}C, makes up about 1.1 percent of atmospheric CO_2. The isotopic ratio of ^{13}C to ^{12}C in C_3 plants ($d^{13}C$) varies mainly due to discrimination during diffusion and enzymatic processes. (Farquhar et al., 1989). Based on the work of Farquhar the linkage between discrimination against ^{13}C during photosynthesis and water use efficiency may be demonstrated by the following relationships. The stable isotope ratio ($d^{13}C$) is expressed as the $^{13}C/^{12}C$ ratio relative to a standard (PeeDee Belemnite) (Craig 1957). The resulting $d^{13}C$ value may be used to estimate ^{13}C isotope discrimination as: $D = (d_a - d_p)/(1+ d_p)$. Where d_p is the isotopic composition of the plant material and d_a is that of the air (assumed to be 8 ‰). As CO_2 assimilation (A) increases or stomatal conductance (g_s) decreases, inter-cellar CO_2 decreases resulting in decreased discrimination against ^{13}C.

Water use efficiency may be estimated from dry weight accumulation measurements over time relative to the amount of water transpired (transpiration efficiency, TE) or by measurements of gas exchange (instantaneous water use efficiency, WUE*i*).

Instantaneous WUE may be calculated as the ratio of assimilation to stomatal conductance or transpiration (*A/*g_s or *A/E*). Because *E* is a function of both g_s and vapor pressure deficit, *A/g* is sometimes referred to as intrinsic water use efficiency. Based on the relationships described above, D is linked to WUE_i through the effects of *A and* g_s on c_i. As WUE*i* increases due to stomatal closure (decrease g_s) or an increase in *A*, intercellular CO_2 declines and discrimination decreases. Therefore, WUE*i* is inversely related to D and positively associated with $d^{13}C$.

5.3 Materials and Methods

5.3.1 Site description

The study was conducted at two sites at Chisamba S 14.96783°, E 028.09408°; and Batoka S16.79993°, E 027.20181° both in region II of the Zambian agro-ecological zones but with differing soil types, soil fertility status and climatic conditions. The sites were selected to assess the interactive response of the selected low nitrogen and low drought- tolerant maize varieties and cowpea genotypes for crop productivity. The Batoka site exhibits low fertility and moisture deficits (Table1 and Figure 15) while Chisamba site is well –endowed with fertility and rainfall patterns (Table 2 and Figures 14 and 16).

Soils at the Batoka site are classified as well- drained, very deep (>90 cm) strong brown to red and in places underlain by a thick pale brown to white loamy sand to sandy loam. The soils are classified as *Chromic haplic Lixisols* in the World Reference Base for Soil Resources (WRBSR, 2014). The soils are generally acidic with pH between the ranges of 3.7 and 4.4. The Cation Exchange capacity is very low while organic matter is less than 1.5 %. The soil exhibits compacted soil layer at around 15–20 cm depth (Base line data Table 1 and 2). The Batoka site lies at an altitude of 1200 m above sea level, located in the Southern Province, about 300 km from Lusaka. The site has a mean annual rainfall of about 825 mm with a dependable rainfall at 70 % probability of 539 mm. Figure 2 shows the rainfall pattern during the 2015/2016 growing seasons at Batoka. The length of the growing season is about 125 days. The total annual reference evapotranspiration (ETo) is 1251 mm which exceeds the mean annual rainfall. The mean annual temperature is 18.2 °C while the mean annual minimum and maximum are 10.9 °C and 26.5 °C respectively (Sokotela et al., 2005).

At the Chisamba site the soils are well-drained, very deep (>90 cm), reddish- brown, friable, shiny fine clayey with a humic topsoil. The soils are classified as *niti-luvic Phaeozems* (WRBSR, 2014). The soil pH is in the range of 5.5 to 6.2. The Cation Exchange Capacity and plant nutrients are relatively high. Organic matter is between 0.7 and 3.0 %. The soil is suitable for the production of most arable crops (Table 1 and 2). The Chisamba site is located between altitude 1100 and 1300 above sea level and is in Zambia's central province about 65 km north of Lusaka the capital city. The length of the growing season is about 140 days. The mean annual rainfall of about 825 mm with a dependable rainfall at 70% probability of 651 mm. Figures 1 and 3 show rainfall pattern during 2015/2016 and 2016/2017 growing seasons at Chisamba. The total yearly reference evapotranspiration (ETo) is 1511 mm. The mean annual temperature is 18.2 ℃ while the mean annual minimum and maximum are 10.9 ℃ and 26.5 ℃ (Sokotela et al., 2005).

. **Table 32:** Baseline Soil chemical properties of the experimental sites

Farming Systems	Site	Depth	pH	OM	N	P	K	Ca	Mg	Zn
		Cm		%		mg/kg	cmol(+)/kg			mg/kg
CONV	Batoka	0-15	4.12	1.32	0.08	17.4	0.1	1.27	0.29	0.04
CONV	Batoka	15-30	4.31	0.96	0.06	14.62	0.08	1.78	0.37	0.06
CF	Batoka	0-15	3.8	0.88	0.03	34.06	0.1	1.66	0.19	0.24
CF	Batoka	15-30	3.71	1.12	0.03	37.88	0.08	0.93	0.11	0.14
CONV	Chisamba	0-15	6.17	0.72	0.05	17.92	1.04	10.9	5.48	0.2
CONV	Chisamba	15-30	6.2	1.72	0.08	17.86	0.78	10.92	5.76	0.12
CF	Chisamba	0-15	5.49	2.96	0.06	18.86	1.11	8.59	4.4	0.28
CF	Chisamba	15-30	5.58	2.72	0.08	16.15	0.83	8.98	5.01	0.20

Note: CF = Conservation farming plot, CONV = Conventional farming plot, .M = Organic matter, N = total nitrogen, CEC = Cation Exchange Capacity, Ca = Calcium, K = Potassium, Mg = Magnesium, Na = Sodium, P = Phosphorus, pH = acidity level

Table 33: Baseline Soil physical properties of the experimental sites

Farming Systems	Site	Bulk Density	FC θv	PWP θv	PAW θv	Sand	Clay	Silt	Texture
		g/cm3	%	%	%	%	%	%	
CONV	Batoka	1.37	29.04	6.03	23.01	82	6.8	11.2	Loamy Sand
CONV	Batoka	1.4	29.08	4.43	24.66	82	6.8	11.2	Loamy Sand
CF	Batoka	1.37	35.73	5.22	30.51	82	6.8	11.2	Loamy Sand
CF	Batoka	1.36	43.16	14.74	28.42	82	6.8	11.2	Loamy Sand
CONV	Chisamba	1.12	27.93	10.77	17.16	46	24.8	29.2	Loam
CONV	Chisamba	1.1	18.68	4.96	13.72	42	30.8	27.2	Clay Loam
CF	Chisamba	1.14	18.00	6.28	11.72	42	30.8	27.2	Clay Loam
CF	Chisamba	1.11	15.86	4.41	11.45	40	34.8	25.2	Clay Loam

Note: FC= Soil moisture content at Field capacity, PWP = Soil moisture content at Permanent wilting point, PAW = Plant available water, BD = Bulk density.

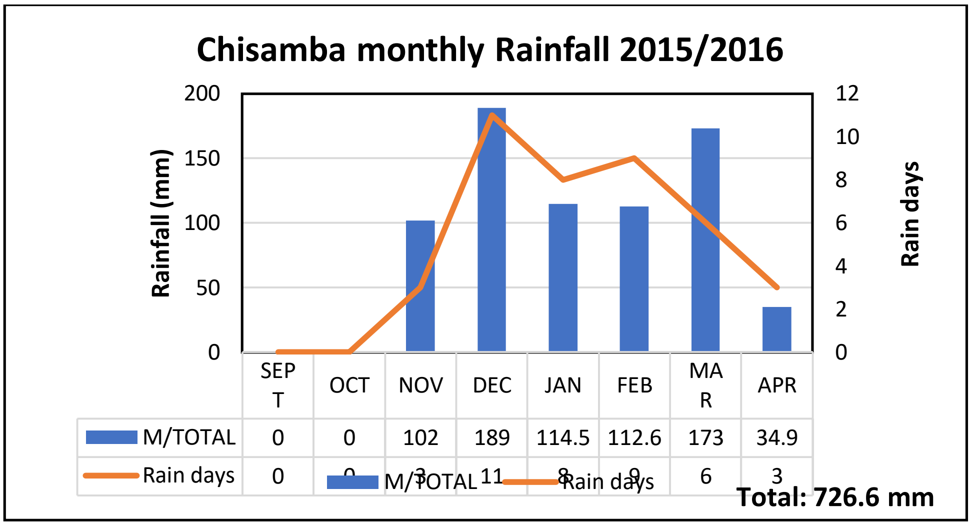

Figure 14: Monthly rainfall 2015/2016 at Chisamba

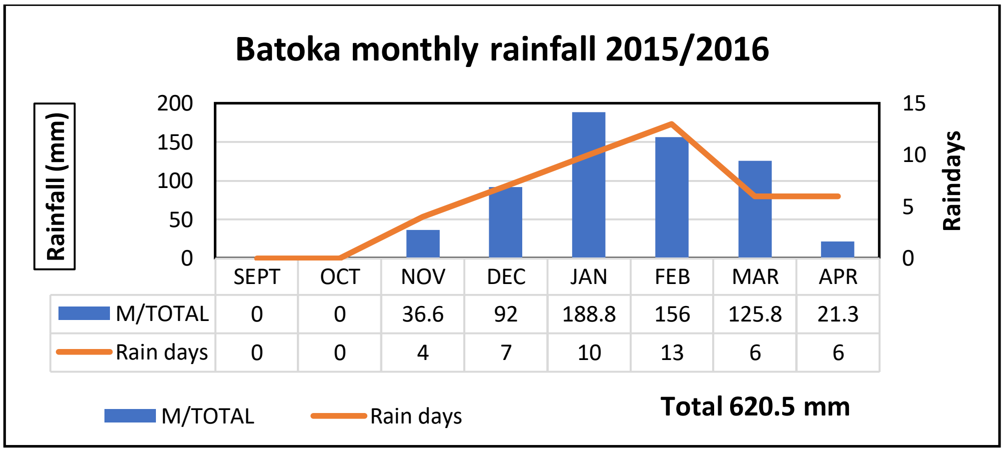

Figure 15: Monthly rainfall 2015/2016 at Batoka

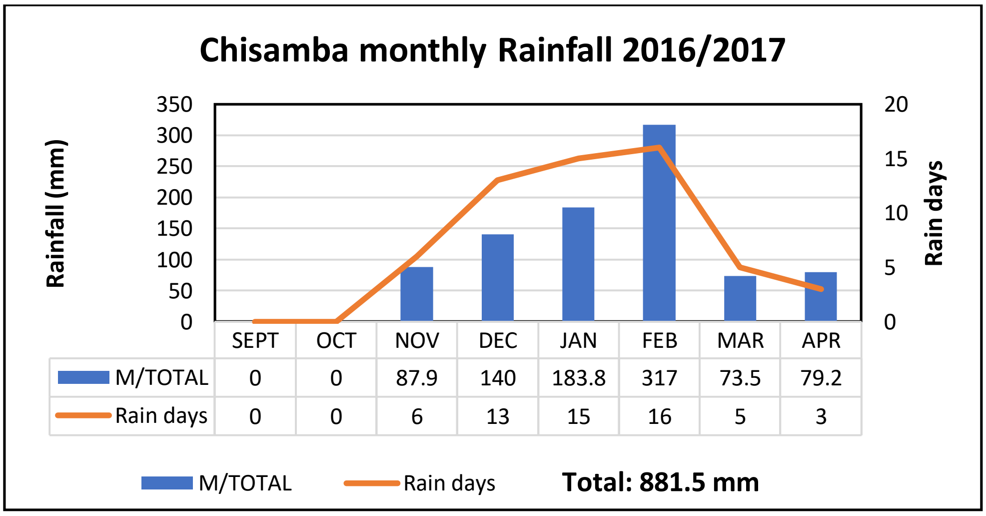

Figure 16: Monthly rainfall 2016/2017 at Chisamba

5.3.2 Source of seeds

Three maize varieties were evaluated for nitrogen use efficiency and water use efficiency performance. Two (2) maize varieties (GV 640 and GV 635) were both selected for low drought and low nitrogen tolerance traits from the Zambia Agricultural Research Institute (ZARI) maize breeding programme. The third variety was ZMS 606 from Zamseed Company and is mainly purchased by small holder farmers based in Region II of the Zambian agro-ecological zone. The four cowpea genotypes selected for rotation with maize under a conservation farming system were the two parents (Bubebe and Lutembwe) and two mutants (BB 14-16-2-2 and LT 11-3-3-12) one from each parent obtained from the University of Zambia School of Agricultural Sciences, Department of Plant Science. The mutants were developed from mutation of cowpea parent materials. The cowpea mutants were developed from mutation of cowpea parent materials. The parents were initially irradiated by using 150 gray (Gy) with Gamma radiation. The process developed different alleles with variants different from their parents. The mutants were selected for tolerance to abiotic (Drought, Aluminum toxicity) and biotic (pests and diseases) stresses.

5.3.3 Experimental Designs

5.3.3.1 Nitrogen use efficiency (NUE)

The experimental design used for assessment of nitrogen use efficiency (NUE) of maize genotypes was a split- plot arranged in a Randomized Complete Block Design (RCBD) replicated three times and analysed across two sites. The main treatments were two different farming systems. adjacent to each other. (a) Conservation farming system (CF) which included minimum tillage by ox- drawn ripping, maize-cowpea rotation and crop residue retention. The four cowpea genotypes used in crop rotation under CF were Bubebe (BBPRT), Lutembwe (LTPRT), (BB 14-16-2-2 and LT 11-3-3-12) (b) Conventional farming system (CONV) which involved complete tillage of soil by ox-drawn ploughing, mono-cropping and removal of crop residues after harvesting. The sub treatments were three maize varieties and these were ZMS 606 (M1), GV 640 (M2) and GV 635 (M3). Therefore, the interaction effects between experimental sites, farming systems, cowpea and maize genotypes were evaluated for Nitrogen Use Efficiency (NUE).

5.3.3.2 Rainfall water use efficiency (RWUE)

The experimental design used to assess rainfall water use efficiency in the maize grain and dry biomass was a split- plot arranged in a Randomized Complete Block Design (RCBD) replicated three times at two sites. The main treatments were farming systems adjacent to each other. (a) Conservation farming system (CF) which included minimum tillage by ox-drawn ripping, maize-cowpea rotation and crop residue retention. The four cowpea genotypes used in crop rotation under CF were Bubebe (BBPRT), Lutembwe (LTPRT), (BB 14-16-2-2 and LT 11-3-3-12) (b) Conventional farming system (CONV) which involved complete tillage of soil by ox-drawn ploughing, mono-cropping and removal of crop residues after harvesting. The sub treatments were three maize genotypes and these were ZMS 606 (M1), GV 640 (M2) and GV 635 (M3). The data was organized and analysed across sites to show the Genetic and Environmental interactions between sites, farming systems, cowpeas and maize genotypes. During the 2016/2017 growing season, the rainfall water use efficiency (RWUE) data was organized and analyzed for one site (Chisamba) to show farming systems x maize varieties and cowpeas x maize varieties interactions.

5.3.3.3 Soil moisture storage (SMS)

The experimental design used for assessment of soil moisture storage was a split-plot arranged in a Randomized Complete Block Design (RCBD) replicated three times and data was analysed across days after planting of soil moisture measurement (DAP) at 10 cm, 20 cm and 30 cm soil depth per site. The main treatments were farming systems adjacent to each other. (a) Conservation farming system (CF) which included minimum tillage by ox- drawn ripping, maize-cowpea rotation and crop residue retention. The four cowpea genotypes used in rotation under CF were Bubebe (BBPRT), Lutembwe (LTPRT), (BB 14-16-2-2 and LT 11-3-3-12) (b) Conventional farming system (CONV) which involved complete tillage of soil by ox-drawn ploughing, mono-cropping and removal of crop residues after harvesting. The sub-treatments were three maize genotypes and these were ZMS 606 (M1), GV 640 (M2) and GV 635 (M3). Therefore, DAP interaction effects, farming systems and maize genotypes were evaluated for soil moisture storage at 10 cm, 20 cm and 30 cm soil depth.

5.3.3.4 ^{13}C isotope discrimination

The experimental design used for assessment of ^{13}C isotope discrimination (d ^{13}C) for water stress tolerance and intrinsic water use efficiency of maize genotypes was a split-plot arranged in a Randomized Complete Block Design (RCBD) and replicated three times and analysed across two sites. The main treatments were farming systems adjacent to each other. (a) Conservation farming system (CF) which included minimum tillage by ox- drawn ripping, maize-cowpea rotation and crop residue retention. The four cowpea genotypes used in crop rotation under CF were Bubebe (BBPRT), Lutembwe (LTPRT), (BB 14-16-2-2 and LT 11-3-3-12) (b) Conventional farming system (CONV) which involved complete tillage of soil by ox-drawn ploughing, mono-cropping and removal of crop residues after harvesting. The sub treatments were three maize varieties and these were ZMS 606 (M1), GV 640 (M2) and GV 635 (M3). Therefore, the interaction effects between experimental sites, farming systems and maize genotypes were evaluated for ^{13}C isotope discrimination (d ^{13}C). The experimental design used for the assessment of ^{13}C isotope discrimination (d ^{13}C) of cowpea genotypes was Randomised Complete Block design (RCBD) replicated three times and analysed across two sites. The treatments were the four cowpea genotypes. These were Bubebe (BBPRT), Lutembwe (LTPRT), (BB 14-16-2-2 and LT 11-3-3-12). Therefore, the interaction effects between experimental sites and cowpea genotypes were evaluated for ^{13}C isotope discrimination (d ^{13}C).

5.3.5 Trial Establishment

In year one (2014/15 season), maize varieties in the conventional farming systems and cowpea genotypes in the conservation farming systems were planted. In year two (2015/2016 growing season), maize varieties were planted and assessed for nitrogen use efficiency (NUE) performance, soil water storage, rainfall water use efficiency (RWUE) and ^{13}C isotope discrimination in the maize grain and dry biomass under CF and CONV plots. The four cowpea genotypes were planted in the 2015/2016 growing season to assess ^{13}C isotope discrimination in the cowpea grain and dry biomass (stover) and for rotation with maize the following season. In year three (2016/2017 growing season, maize varieties were planted after four cowpea genotypes under conservation farming system and on conventional system and were assessed for rainfall water use efficiency at Chisamba.

5.3.6 Trial Plot size

Under the conservation farming system, each cowpea plot had 12 rows of 6 m length spaced at 0.75 m. Cowpea seed was drilled along the ripped furrows to about 7 cm between seeds. Four (4) rows of 6 m length spaced at 0.75 m were marked and planted with maize varieties at an intra-row spacing of 0.25 m. Two (2) guard rows at each end of the block for both crops were included.

5.3.7 Data collection

5.3.7.1 ^{15}N and d^{13}C IAEA Isotope Analysis

^{15}N labelled stovers and grains for maize and cowpea were dried in the oven at 80^{o}C for 48 hrs. Samples were milled, sieved and packed in 10g quantity for IAEA analysis of atom % ^{15}N and d^{13}C at the University of Florida in the United States of America. The atom % ^{15}N, ^{13}C isotopes and nitrogen content (N %) were analyzed in the grains and stover of maize and cowpea crops. The ^{13}C values were corrected based on the results of standards analyzed during each run. Samples were analyzed for ^{13}C content using the stable isotope mass spectrometer (USGS40 (NIST 8573). The ^{13}C was expressed in d^{13}C ‰ units following the international PDB standard (Limestone from the Pee Dee formation in Carolina):

$$d^{13}C = \left(\left(\frac{R\,sample}{R\,s\tan dard} \right) - 1 \right) \times 1000$$

Where R =^{13}C/^{12}C

The ^{13}C of the plant material is related to ^{13}C discrimination by the formula of Fugarha, (1989):

d^{13}C‰ = ((d$_a$-d$_p$)/ (1+d$_p$)) *1000.

Where d_a is the current atmospheric CO_2 deviation of -8‰ and d_p is the measured value of the plant material. The ^{15}N results were reported as atom% ^{15}N/^{14}N. One enriched ^{15}N standard (2.0 atom% N-15, Ammonium Sulfate) and one natural abundance standard (USGS40) were measured for these results.

5.3.7.2 Plant measurement and Weather

The plant data collected on maize varieties were dry biomass and grain yields, N % and ^{15}N atom % for computation of Nitrogen Use Efficiency, and ^{13}C isotope discrimination for surrogating intrinsic water use efficiency (WUEi) and drought tolerance of maize genotypes. The plant data collected on cowpea grain and stover were $d^{13}C$ to surrogate intrinsic water use efficiency and drought tolerance of cowpea genotypes. The weather data collected was Rainfall and Temperature.

Due to weather equipment limitations to measure evapo-transpiration, rainfall water use efficiency was instead computed in the experiment.

5.3.7.3 Soil moisture storage

The effect of conservation and conventional farming systems on soil moisture storage was assessed. The access tubes for soil moisture storage (SMS) reading were inserted per each plot of maize crop variety to 1.0 m soil depth. A diviner 2000 was used to measure soil moisture content up to 1.0 m depth once per week 12 weeks and measurement of soil moisture content started at five weeks after planting maize crop at Chisamba site. While at Batoka, soil moisture content was measured five weeks after planting with HH2 soil meter for three weeks at 10 cm, 20 cm and 30 cm depth. Soil moisture content at Batoka could not be measured beyond three weeks due to the non-availability of soil the moisture meter which got damaged. The soil moisture storage analysis was done for soil depth at 10 cm, 20 cm and 30 cm where a large quantity of root systems for crop water and nutrient uptake is generally established.

5.3.8 Crop management

5.3.8.1 Tillage

Minimum tillage using ox-drawn magoye ripper was done before the onset of the rains for the conservation farming system. Ripped furrows were spaced at 75 cm between rows at 15 cm soil depth. Under a conventional farming system, the mouldboard plough was used on wet soils after the rainfall.

5.3.8.2 Planting

Maize genotypes assessed for NUE, water storage, WUE and ^{13}C isotope discrimination were planted under minimum tillage practice as one of the conservation farming principles during the 2015/2016 and 2016/2017 growing seasons. Two maize seeds were planted manually at 25 cm between stations in the ripped furrows spaced at 75 cm. Under the conventional (Mono cropping) two maize seeds were manually planted on ploughed soil at 25 cm between stations on rows spaced at 75 cm during 2014/2015, 2015/2016 and 2016/2017 on the same piece of land. The maize crop was thinned to one plant two weeks after emergence. Cowpea genotypes were planted during the 2014/2015 and 2015/2016 growing seasons for rotation and ^{13}C isotope discrimination in the grain and stover. Planting of cowpea used for crop rotation was done by hand through drilling along the ripped furrows at seed rate of 30 kg ha^{-1} to about 7 cm between seeds.

5.3.8.3 Fertilizer application

The maize crop was applied with compound fertilizer 10 %N: 20 % P: 10 % K at 200 kg ha^{-1} providing 20 kg ha^{-1} nitrogen, 40 kg ha^{-1} P_2O_5 and 20 kg ha^{-1} K_2O at planting. Urea (46 % N) was applied as the top dressing to provide 92 kg ha^{-1} Nitrogen at the vegetative growth stage, five weeks after planting. The fertilizer was applied on the four rows of maize spaced at 0.75m between rows and 6 m length. Each row received 90g of basal dressing. The cowpea was applied with compound fertilizer 10 % N: 20 % P: 10 % K at 200 kg ha^{-1} providing 20 kg ha^{-1} nitrogen, 40 kg ha^{-1} P_2O_5 and 20 kg ha^{-1} K_2O at planting. The fertilizer on cowpeas was applied on the 12 rows spaced at 0.75 cm between rows and 6.0 m length. Each row received uniformly distributed basal fertilizer of 90 g. Basal fertilizer (D compound) was drilled along the ripped furrows for maize and cowpea while top dressing was banded on the maize crop.

5.3.8.4 Pest and Disease Control

Two separate sprays against pests and diseases were made on cowpea plots. The first control was at two weeks after the cowpea emergency and the second at the flowering stage. Maize crop was protected against fall army worm pest by spraying insecticides two times at vegetative and once at flowering stages. Ampligo insecticide marketed by Syngenta was used for both crops at application rate of 20 mls per 20 liters of water in a knapsack sprayer with a conical nozzle. The active ingredients in Ampligo are *antraniliprole* and *Lambda- cyhalothrin.*

5.3.8.5 Weed control and Harvest

Two inner rows of maize crop were harvested for dry biomass and grain yield analysis. The outer two rows per plot of maize served as guard rows protecting the crop against pests and other environmental factors. Maize plants within 0.5 m from both ends were discarded leaving 5 m in length for harvest. Harvesting was done manually with hands. The field weight was determined by weighing the total cobs harvested from the plot. A sample of 10 cobs was taken and shelled for determination of shelling percentage and field grain moisture content using a grain moisture. The grain yield per hectare was computed as product of shelling percentage and field weight standardized at 12.5 % soil moisture content. Yield (kg/ha) =SH/100* 10000m^2/plot area m^2*(100-sample moisture content)/ (100-12.5). Measurement of dry biomass involved weighing of maize crop stover from the two rows, sampling a representative weight of about 0.5g, weighing the wet sample, drying of the sample in an oven for 48 hrs at 80 ^{0}C. Dry biomass was computed as dry sample weight (kg)/ wet sample weight (kg) x Field weight x 10000m^2/plot area m^2. Two maize plants and cobs were sampled from ^{15}N isotope treated rows for analysis of ^{15}N atom %, total N and d^{13}C. Two cowpea plants were sampled from the ^{15}N isotope treated plot for d^{13}C to determine genotype tolerance to droughts. Maize and cowpea samples (Maize grain, maize stover, cowpea grain and cowpea stover) from ^{15}N isotope treated rows were dried in the oven for 48 hrs at 80 ^{0}C, milled, packed in 10 g packs and shipped to the USA for isotope analysis.

5.3.9 Data analysis

The agronomic data collected were arranged and organized using Microsoft excel. Agronomic maize and cowpea crop yields, ^{15}N, Nitrogen uptake and the absorption Nitrogen Use Efficiency (ANUE), d^{13}C for WUEi were analyzed. The Absorption NUE was calculated as a percentage of nitrogen uptake in maize grain to the Nitrogen applied (IAEA, 2008). Data were analysed with the help of Genstat 18th edition (Paul and Jac, 2016). The ANOVA tables were created on which the means were separated and interpreted for significant differences at probability level of < or = 0.05. The least Significant Difference (LSD) and Standard Error of Means were used to separate means for significance either on tables or graphs. Duncan multiple range test was also used for significant differences and mean separation on soil moisture storage. Mean square analysis of variance tables was reported in the text while the ANOVA tables of specific variables were added under appendices.

5.4 Results and Discussion

5.4.1 Nitrogen Use Efficiency (NUE)

Nitrogen Use Efficiency (NUE) by maize varieties was measured as a percentage ratio of nitrogen uptake in maize grain to the amount of nitrogen applied as ^{15}N label. The results of the NUE evaluation of the maize varieties are presented in Table 32. The NUE was highly significant (P<0.001) between experimental sites, farming systems, cowpea genotypes used in rotation and maize varieties. The farming system by maize variety and cowpea genotype by maize variety interactions were highly significant (P<0.001) for NUE in the maize crop. Site by maize variety interaction was however significant at P<0.05) while site by farming system, site by maize variety and site by cowpea genotype were not significant (P>0.05).

The uptake and use of nitrogen in the maize crop was significantly more efficient at the Chisamba site which had mean value of 23.6 % than at Batoka site by 148.4 % (Table 34). The NUE was significantly (P<0.001) found higher in the conservation farming system (CF) with mean value of 26.48 % and 13.90 % than in the conventional system (CONV) which had 20.78 % and 5.01 % at Chisamba and Batoka respectively (Table 35). Therefore, nitrogen uptake in the CF accounted for 27.4 % and 177.1 % more than the conventional farming system at Chisamba and Batoka, respectively.

Table 34: Mean squares for combine analysis of variance of maize varieties NUE performance under the influence of farming systems at two sites during the 2015/2016 growing season

Variate: Maize 2015/2016		**NUE (%)**	**Variate: Maize 2015/2016**		**NUE (%)**
Source of variation	**d.f.**	**m.s.**	**Source of variation**	**d.f.**	**m.s.**
Site	1	3917.67***	Site	1	3917.67***
Rep/Location	4	11.34	Rep/Location	4	11.338
Farming system	1	771.07***	Cowpea genotype	4	205.078***
Site x Farming system	1	36.76ns	Sitex cowpea genotype	4	19.087ns
Error	4	7.85	Error	16	11.143
Maize variety	2	62.57***	Maize variety	2	62.575***
Site x Maize variety	2	22.26**	Site x maize variety	2	22.263ns
Farming system x maize variety	2	35.17***	Cowpea genotype x maize variety	8	25.823***
Site x Farming system x.maize variety	2	67.06***	Sitex cowpea genotypex maize variety	8	29.127***
Error	16	5.29	Error	40	7.526

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05, NUE = Nitrogen use efficiency.

Table 35: The Influence of farming systems on nitrogen use efficiency (NUE) of maize varieties at Batoka and Chisamba during the 2015/2016

		Maize varieties			
		Low N and Drought tolerant			
		NUE (%)			
Site	**Farming system**	**M1 (control)**	**M2**	**M3**	**Mean**
Batoka	**CF**	16.31 ± 1.1	13.01 ± 0.6	12.47 ± 0.7	**13.9 ± 0.8**
	CONV	2.99 ± 0.2	6.55 ± 0.4	5.49 ± 0.2	**5.01 ± 0.3**
	Mean	**9.65 ± 0.65**	**9.78 ± 0.5**	**8.98 ± 0.5**	**9.5**
Chisamba	**CF**	26.66 ± 1.0	27.30 ± 1.4	25.48 ± 1.1	**26.48 ± 1.2**
	CONV	23.34 ± 2.1	25.25 ± 1.3	13.70 ± 0.8	**20.76 ± 1.4**
	Mean	**25.00 ± 1.6**	**26.28 ± 1.4**	**19.59 ± 1.0**	**23.6**
FPr	<0.001				
Lsd (0.05)	3.418				
CV (%)	19.0				

Note: M1 = ZMS 606, M2 = GV 640, M3 = GV 635. Control = mostly purchased by smallholder farmers. CF = Conservation farming system, CONV = Conventional farming system ± denotes standard errors of means.

At Batoka maize variety ZMS 606 (M1) expressed significantly (P<0.001) higher NUE of 16.3 % than GV 635 (M3) that had NUE of 12. 47 % under CF while under CONV GV 640 had higher NUE than ZMS 606 by 119.1 %. At Chisamba, significant difference in nitrogen use efficiency was observed under CONV where ZMS 606 (23.34 %) and GV 640 (25.25 %) had significantly more NUE than GV 635 by 70.4 % and 84.3 % respectively (Table 33).

The interaction between site, farming system and maize variety indicated highest NUE of 16.34 % by ZMS 606 (M1) in the CF followed by GV 640 (M2) with mean value of 13.01 % under CF at Batoka. The highest NUE of 27.3 % was obtained at Chisamba for GV 640 under CF. At Batoka, the lowest NUE of 2.99 % was obtained from ZMS 606 under CONV while at Chisamba the lowest NUE efficiency was 13.70 % for GV635 under CONV (Table 33). Cowpea genotypes significantly (P<0.001) influenced the uptake of nitrogen and use by maize varieties. The non-cowpea treatment with NUE of 5.01 % and 20.76 % was highly significantly (P<0.001) lower than the cowpea treatments at Batoka and Chisamba respectively. An interaction between cowpea genotype and maize variety showed that the increased NUE under ZMS 606 and GV 640 was mainly contributed by cowpea mutant LT 11-3-3-12 (19.63 %) and parent BBPRT (16.23 %) respectively compared to other genotypes at Batoka. On average, cowpea parent LT PRT, and mutant BB 14-16-2-2 enhanced increased NUE of ZMS 606 and GV 640 at Chisamba (Table 36).

NUE both at Batoka and Chisamba was significantly higher under conservation farming system than the conventional farming system. The best combinations for NUE were maize variety GV 640 with parent cowpea LTPRT and cowpea mutant BB 14-16-2-2 at Chisamba while at Batoka were maize variety ZMS 606 and cowpea mutant LT 11-3-3-12.

Table 36: Influence of cowpea genotypes on nitrogen use efficiency (NUE) of maize varieties at two sites during the 2015/2016 growing season

		Maize varieties			
		Low N and Drought tolerant			
		NUE (%)			
Site	**Cowpea genotyp**	**M1 (control)**	**M2**	**M3**	**Mean**
Batoka	**LTPRT**	15.08 ± 2.9	11.15 ± 0.8	15.08 ± 0.9	**13.77 ± 1.5**
	BBPRT	17.80 ± 0.7	16.23 ± 0.7	11.57 ± 0.5	**15.20 ± 0.6**
	LT	19.63 ± 1.3	11.52 ± 0.3	9.40 ± 0.4	**13.52 ± 0.7**
	BB	12.72 ± 1.4	13.13 ± 0.4	13.84 ± 0.7	**13.23 ± 0.8**
	NCP	2.99 ± 0.2	6.55 ± 0.4	5.49 ± 0.2	**5.01 ± 0.3**
	Mean	**13.64 ± 1.3**	**11.72 ± 0.5**	**11.08 ± 0.5**	**12.15 ± 0.8**
Chisamba	**LTPRT**	29.19 ± 1.4	28.18 ± 2.5	27.38 ± 2.3	**28.25 ± 2.1**
	BBPRT	23.90 ± 2.8	28.77 ± 3.4	27.07 ± 2.8	**26.58 ± 3.0**
	LT	26.39 ± 0.5	23.64 ± 2.0	23.15 ± 1.2	**24.40 ± 1.2**
	BB	27.17 ± 1.6	28.62 ± 3.5	24.34 ± 1.8	**26.71 ± 2.3**
	NCP	23.34 ± 2.0	25.25 ±1.3	13.70 ± 0.8	**20.76± 1.4**
	Mean	**26.00 ± 1.7**	**26.89 ± 2.6**	**23.13 ± 1.8**	**25.34 ± 2.0**
	FPr	0.002			
	Lsd (0.05)	3.288			
	CV (%)	14.0			

Note: LTPRT = Lutembwe parent spreading type, BBPRT = Bubebe parent bush type, LT = LT 11-3-3-12 Lutembwe mutant spreading type, BB= BB 14-16-2-2 Bubebe mutant bush type, NCP = non cowpea, M1 = ZMS 606, M2 = GV 640, M3 = GV 635. Control = mostly purchased by smallholder farmers. ± denotes standard errors of means

The high nitrogen use efficiency (NUE) at the Chisamba site by maize varieties could be due to increased soil nutrient content coupled with high levels of organic matter content. In the present study, soil organic matter was significantly higher at Chisamba with 2.3% than at Batoka that had 1.8% across soil depths of 0-15 cm and 15-30 cm. Due to high organic matter content, the maize crop at Chisamba had more nitrogen access than the crop at Batoka. Carvalho and Lourenço, 2014 reported that increasing soil organic matter from 1 % to 2 % would increase nitrogen-use efficiency from 19.1 to 36.6 kg of wheat per kg of applied nitrogen due to residue retention and cover cropping.

The high NUE in the CF system could be due to crop rotation of maize and cowpeas that contributed to soil chemical properties improvement. On average, the soil organic matter content under the CF system was 2.3% compared to 1.4 % in the CONV system across the sites and this could have enhanced efficient uptake of nitrogen due to reduced leaching (Tables 13 and 17). The study revealed that conventional farming system with non- cowpea treatment significantly ($P<0.001$) produced the lowest nitrogen content of 0.042 % against the available nitrogen content of 0.083 % and 0.071 % for LT 11-3-3-12 and BB 14-16-2-2 cowpea mutants respectively at 0-15 cm soil depth in the CF system. The findings therefore, indicated that the maize crop had higher uptake of available nitrogen in the CF than under CONV farming system. The results agreed with Verhulst et al. (2014) that crop monoculture has adverse effects on yield and NUE and positive impact if legumes are included in the rotation. Habbib et al. (2016) reported a significant increase in N use efficiency, N harvest index, N remobilization and N remobilization efficiency in maize crop after a fouryear trial both under no and high N fertilization conditions. Another factor that could have led to increased NUE in the CF is improved soil surface water storage especially after anthesis. In the current study, the oven- dry soil water content was observed high in treatments with cowpea rotated with maize crop. Some studies have shown that soil water retention under no-till (NT) conditions is beneficial to the crop, notably during the grain filling period after anthesis (Thoms et al, 2007). In line with this information, some reports had indicated that NUE was reduced in wheat when there was shortage of water (Baharani et al., 2011). The findings of the present study are in agreement with Acharya (2018) who reviewed that agronomic N use efficiency (kg/kg) in maize under permanently raised beds (PRB) and conventional tillage (CT) method were found 28% and 16% respectively. Therefore, it is likely that water retention on the soil surface in the conservation farming system under this study could have contributed to the favored post – anthesis N uptake and NUE.

The variations in NUE among the maize varieties could be genetic differences for nitrogen use efficiency among the maize genotypes used in the study. Maize varieties ZMS 606 (M1) and GV 640 which expressed significantly ($P<0.001$) higher NUE of 19.6 % on average than GV 635 (M3) at both sites could be suitable for improved productivity of maize under conservation farming systems. Identification of traits such as nutrient absorption, transport, utilization, and mobilization in maize cultivars should greatly enhance fertilizer use efficiency. Therefore, the development of new cultivars with higher NUE, coupled with best management practices such as conservation farming will contribute to sustainable agricultural systems that protect and promote soil, water and air quality (Baligar et al., 2007).

Cowpea genotypes influenced variations in NUE among maize varieties and this was due to differences in their contribution to soil quality improvement. Under the present study, maize crop grown under cowpea mutant LT11-3-3-12 had significant contribution to NUE mainly due to improved soil organic matter content, available nitrogen and water storage on soil surface exhibited by the genotype. The results agreed with Carvalho and Lourenço, (2014) who reported that increasing soil organic matter will increase nitrogen-use efficiency of the crop.

5.4.2 Soil moisture storage

The results of soil moisture storage (SMS) at Chisamba are represented in soil moisture content tables and graphs. Days after planting of soil moisture measurement was an important factor to consider in the study because of environmental differences of the day when measurement was taken. Soil moisture storage significantly ($P<0.001$) varied among the number of days after planting (DAP) the maize crop of soil moisture measurement at 10 cm, 20 cm and 30 cm soil depths, farming systems, maize varieties and cowpea genotypes. A highly significant interaction ($P<0.001$) were observed between DAP x farming systems at all soil depths, DAP x maize varieties at 20 cm and 30 cm soil depth, farming systems x maize varieties at all soil depth, DAP x farming systems x maize varieties, DAP x cowpea genotypes at all soil depth, cowpea genotypes x maize varieties at all soil depth and DAP x cowpea genotypes x maize varieties at all soil depths (Tables 37 and 38).

Table 37: Mean squares of days after planting, Farming systems and maize varieties on soil moisture storage during 2015/2016 growing season at Chisamba

Variate: Soil moisture depth		10 cm	20 cm	30 cm
Source of variation	**d.f.**	**m.s.**	**m.s.**	**m.s.**
Rep	2	81.99	61.71	49.46
Days after planting	11	2701.27***	1170.23***	1155.58***
Error	22	10.52	14.28	18.33
Farming system	1	1419.75***	287.41***	309.93***
Days after planting x farming system	11	81.62***	87.81***	91.96***
Error	24	21.23	12.35	21.22
Maize variety	2	55.6***	69.29***	342.96***
Days after planting x maize variety	22	16.16ns	95.52***	97.95***
Farming system x maize variety	2	57.46***	94.85***	81.26***
Days after planting x farming system x maize variety	22	55.11***	78.63***	65.23***
Error	96	11.22	13.48	14.57
Total	539			

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Non-significant at P ≤ 0.05

Table 38: Mean squares for combine analysis of variance of days after planting, cowpea genotypes and maize varieties on soil moisture storage at Chisamba

Variate: Soil moisture		10 cm	20 cm	30 cm
Source of variation	**d.f.**	**m.s.**	**m.s.**	**m.s.**
Rep	2	81.99	61.71	49.46
Days after planting	11	2701.27***	1170.23***	1155.58***
Error	22	10.52	14.28	18.33
Cowpea genotype	4	399.88***	217.62***	119.52***
Days after planting x Cowpea genotype	44	54.39***	98.68***	127.75***
Error	96	13.53	15.15	14.3
Maize variety	2	55.6**	69.29***	342.96***
Days after planting x maize variety	22	16.16ns	95.52***	97.95***
Cowpea genotype x maize variety	8	47.96***	160.52***	275.45***
Days after planting x Cowpea genotype x maize variety	88	50.09***	92.68***	125.19***
Error	240	12.85	13.19	16.4
Total	539			

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns = Non-significant at P ≤ 0.05

5.4.2.1 Influence of Days after planting of soil moisture measurement on soil moisture storage

At Chisamba, soil moisture content varied between 17.9 % and 40.58 % at 135 and 44 days after planting (DAP) respectively at 10 cm soil depth. At 20 cm soil depth, moisture changed between 22.65 % at 135 DAP to 38.78 % at 66 DAP. The soil moisture content at 30 cm soil depth varied between 24.24 % at 127 DAP and 40. 99 % at 72 DAP. Generally, soil moisture storage of 31.64 % at 10 cm soil depth was lowest compared to moisture content at 20 cm (32.87 %) and 30 cm (32.57 %). The average wettest dates were at 66 DAP and 72 DAP which had soil moisture content of 38.76 % and 38.66 % respectively between 10 cm and 30 cm soil depth. Therefore, the study showed that the highest soil moisture storage of 40.99 % was attained at 72 DAP at 30 cm soil depth. At 10 cm soil depth, the highest soil moisture storage of 40.38 % was at 44 DAP while at 20 cm soil depth, moisture content of 38.78 % was highest at 66 DAP. The lowest soil moisture storage was generally obtained 127 DAP and 135 DAP at 10 cm, 20 cm and 30 cm soil depth (Table 39).

Table 39: Soil moisture storage at 10 cm, 20 cm and 30 cm soil depths from the twelve dates of moisture measurements during 2015/2016 growing season at Chisamba

Soil moisture storage (% v/v)				
DAP	**10 cm**	**20 cm**	**30 cm**	**Mean**
44	40.58 g	36.01 efg	36.70 de	**37.76**
50	38.33 f	35.60 ef	37.60 ef	**37.18**
57	24.12 c	27.33 b	30.43 b	**27.29**
66	38.73 f	38.78 h	39.07 f	**38.76**
72	37.34 f	37.65 gh	40.99 g	**38.66**
79	31.20 d	34.65 de	31.14 b	**32.33**
94	37.81 f	36.48 fg	33.71 c	**36.00**
100	33.87 e	33.63 d	34.93 cd	**34.14**
108	33.72 e	35.58 ef	31.83 b	**33.71**
115	25.36 c	29.71 c	30.79 b	**28.62**
127	20.93 b	26.41 b	24.24 a	**23.86**
135	17.69 a	22.65 a	25.94 a	**22.09**
Mean	**31.64**	**32.87**	**32.57**	**32.36**
FPr	<0.001	<0.001	<0.001	
Lsd	1.418	1.652	1.872	
CV (%)	11.3	11	12.2	

Note: Mean values followed by different letters within a column for different treatments are significantly different at P<0.01. DAP = Days after planting of measuring soil moisture.

The soil moisture storage (SMS) results at Batoka are represented in soil moisture content tables and graphs. Soil moisture storage significantly (P<0.001) varied among the number of days after planting (DAP) the maize crop of soil moisture measurement at 10 cm, 20 cm and 30 cm soil depths, farming systems, maize varieties and cowpea genotypes. Significant interactions (P<0.05) were observed between DAP x farming systems at 10 cm soil depths, DAP x maize varieties at 10 and 20 cm soil depth, DAP x cowpea genotypes at 10 cm and cowpea genotypes x maize (Tables 40 and 41).

Table 40: Mean squares of days after planting, Farming systems and maize varieties on soil moisture storage during 2015/2016 growing season at Batoka

Variate: Soil moisture		10 cm	20 cm	30 cm
Source of variation	**d.f.**	**m.s.**	**m.s.**	**m.s.**
Rep	2	0.299	0.762	2.685
Days after planting	2	572.923***	424.906***	264.029***
Error	4	0.335	0.929	4.204
Farming system	1	52.803***	139.294***	179.228***
Days after planting x farming system	2	11.315**	2.695ns	0.592ns
Error	6	1.341	1.907	1.185
Maize variety	2	16.764***	4.614**	1.037ns
Days after planting x maize variety	4	6.692**	4.501***	0.608ns
Farming system x maize variety	2	3.746ns	1.623ns	0.308ns
Days after planting x farming system x maize variety	4	1.739ns	1.685ns	0.549ns
Error	24	1.702	1.041	0.697
Total	134			

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Non-significant at P ≤ 0.05.

Table 41: Mean squares of date of planting of soil moisture measurement, cowpea genotypes and maize varieties on soil moisture storage at Batoka

Variate:Soil moisture		10 cm	20 cm	30 cm
Source of variation	**d.f.**	**m.s.**	**m.s.**	**m.s.**
Rep	2	0.299	0.762	2.6846
Days after planting	2	572.923***	424.906***	264.0294***
Error	4	0.335	0.929	4.2041
Cowpea genotype	4	14.928***	37.181***	45.9755***
Days after planting x Cowpea genotype	8	4.875**	2.682ns	2.9934ns
Error	24	1.514	2.782	1.6379
Maize variety	2	16.764***	4.614**	1.0375ns
Days after planting x maize variety	4	6.692***	4.501***	0.6078ns
Cowpea genotype x maize variety	8	3.741***	3.205***	1.6478ns
Days after planting x Cowpea genotype x maize variety	16	2.656**	2.099**	1.0955ns
Error	60	1.164	1.005	0.7734
Total	134			

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns = Non-significant at P ≤ 0.05

At the Batoka site, soil moisture storage (SMS) was significantly (P<0.001) different among the days of moisture measurement. The highest moisture content of 16.44 % was obtained at 76 days after planting (DAP) while the lowest (8.2 %) was at 44 DAP. Soil moisture storage increased by soil depth and at soil surface of 10 cm soil depth, moisture content of 9.93% was -lower than at deep layer of 30 cm soil depth which had soil moisture content of 13.85 %. (Table 42).

Table 42: Influence of days after planting on soil moisture storage at 10 cm, 20 cm and 30 cm soil depths from the three dates of moisture-measurements during 2015/2016 growing season at Batoka

	Soil moisture storage (%v/v)			
DAP	10 cm	20 cm	30 cm	**Mean**
44	8.20 [a]	11.84 [b]	13.48 [a]	**11.17**
64	7.55 [b]	9.57 [a]	11.64 [b]	**9.59**
76	14.03 [c]	15.65 [c]	16.44 [c]	**15.37**
Mean	**9.93**	**12.35**	**13.85**	**12.04**
FPr	<0.001	<0.001	<0.001	
Lsd (0.05)	0.339	0.564	1.2	
CV (%)	13.2	11.6	8.7	

Note: DAP = Days after planting of measuring soil moisture. Mean values followed by different letters within a column for different treatments are significantly different at P<0.01

The differences in soil moisture content on different days of measurement at both sites were affected by several factors: amount and pattern of rainfall, temperature, evapotranspiration, plant physiology, wind speed, relative humidity and drought on a particular day (Whitmore and Whalley, 2009). Tijani et al. (2008) also observed a similar trend of soil moisture changes during the growth period of the crop. They explained that fluctuations were mainly dependent on rainfall and soil profile characteristics. The study showed that soil moisture content increased from topsoil (10 cm) to deeper depths (20 and30 cm) due to evaporation of water from soil surface and infiltration taking during days after rainfall (O'Geen, 2013). The dry spell experienced for seven days between 50 and 57 days after planting maize at Chisamba significantly contributed to the reduced soil water content. During this period, evapotranspiration and air temperatures could have been highest compared to the days when the dry spell between the rainfall and measurement date was shorter than seven days. This is further explained by the observed higher evapotranspiration of 134 mm recorded in March when the dry spell was experienced than 91.3 mm and 93.3 mm in January and February respectively. The maximum temperature of 28.9 °C was recorded highest during March when the longer dry spell was experienced compared to 27.9 °C and 25.9 °C for February and January 2016 (A.2.5). However, the lower soil moisture content at 115, 127 and 135 DAP could be attributed to lack of rains that ended at 105 days after planting with 23. 6 mm towards crop maturity.

At the Batoka site, the highest soil moisture storage was recorded at 76 DAP while the lowest was at 64 DAP. Similar environmental factors as for Chisamba site could have attributed the variations in SMS among the three days of measurement. The lowest

SMS measured at 64 DAP (20th February 2016) was attributed to prolonged dry spell of 12 days after rainfall of 51 mm on the 8th of February 2016 indicating that the site experienced high temperatures and evapotranspiration during this period. On the other hand, soil moisture was highest at 76 DAP due rainfall that measured 49 mm on the 24th February 2016 and continuous rainfall of about 5 mm was received for four days before the measurement took place on the 3rd March 2016 (Appendix E). According to Bonan, (2016) soil moisture content always followed the rainfall patterns and it is high after rainfall events, whether the surface was covered with vegetation or not.

5.4.2.2 Influence of Farming system practice (Conservation and Conventional farming) on soil moisture storage

Farming systems significantly affected the soil moisture storage at 10 cm, 20 cm and 30 cm soil depths at both site. For Chisamba site, total soil moisture content in the CF treatment was significantly higher than in the conventional by 3.6 %. Soil moisture contents at 10 cm and 20 cm soil depths were on average 32.45 % and 33.24 % in the conservation farming system and were significantly ($P<0.001$) higher than moisture content recorded in the conventional farming system by 14.3 % and 5.8 % respectively (Table 41, Figures 17 and 18). However, at 30 cm soil depth, soil moisture content of 34.63 % in the conventional farming system was significantly ($P<0.001$) higher than in the conservation farming system (Table 43, Figure 19).

Table 43: Influence of farming systems on soil moisture storage (%v/v) at 10 cm, 20 cm and 30 cm soil depths from the twelve dates of moisture measurements during 2015/2016 growing season at Chisamba

	Soil moisture storage (% v/v)			
Farming systems	**10 cm**	**20 cm**	**30 cm**	**Mean**
Conservation farming	32.45b	33.24b	32.73a	**32.60**
Conventional farming	28.40a	31.41a	34.63b	**31.47**
Mean	**30.45**	**31.40**	**33.65**	**31.83**
FPr	<0.001	<0.001	<0.001	
Lsd (0.05)	1.023	0.78	1.023	
CV (%)	15.6	20.4	20.6	

Note: Mean values followed by different letters within a column for different treatments are significantly different at $P<0.01$

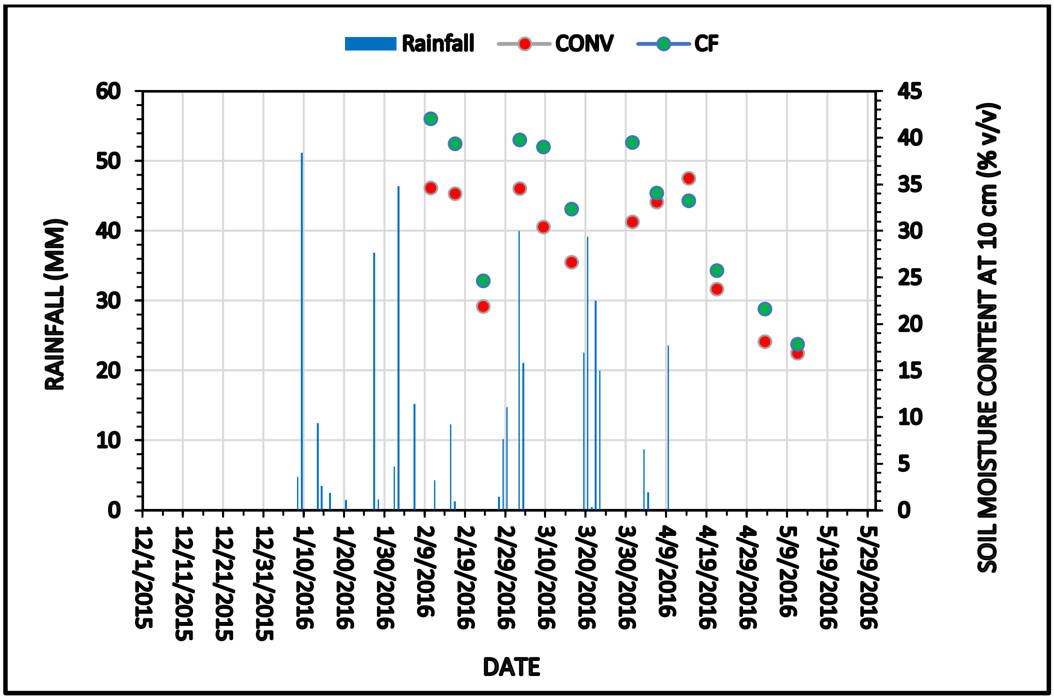

Figure 17: Influence of farming systems on the soil moisture content at 10 cm soil depth under measured rainfall per day

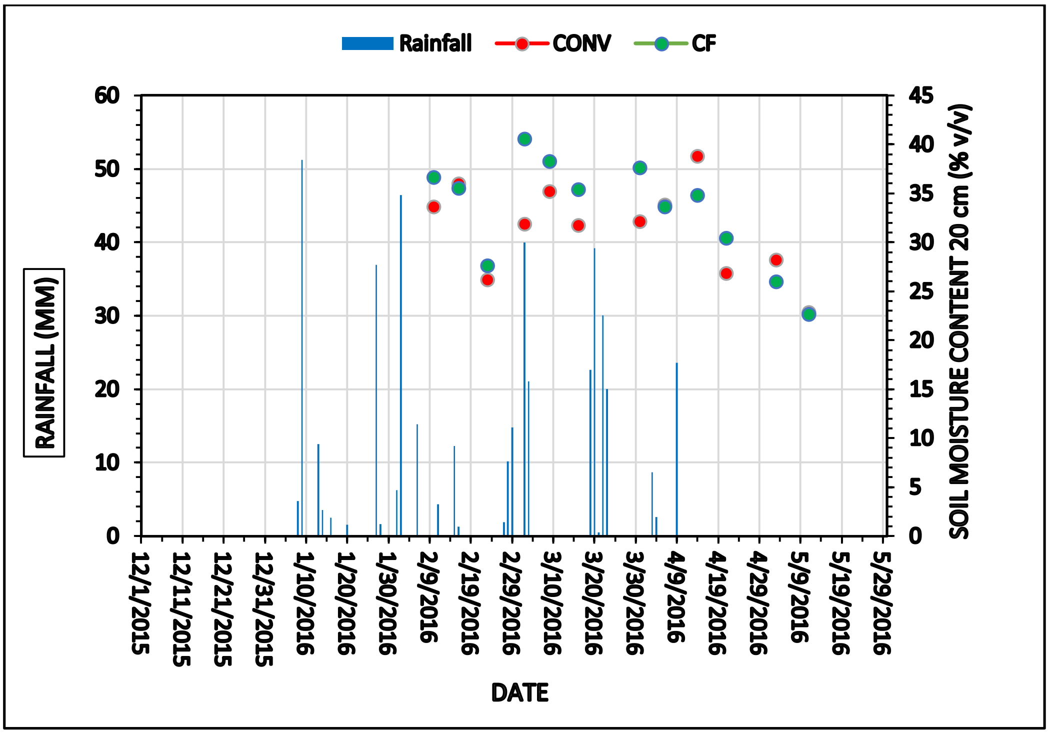

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Figure 18: Influence of farming systems on the soil moisture content at 20 cm depth under measured rainfall per day

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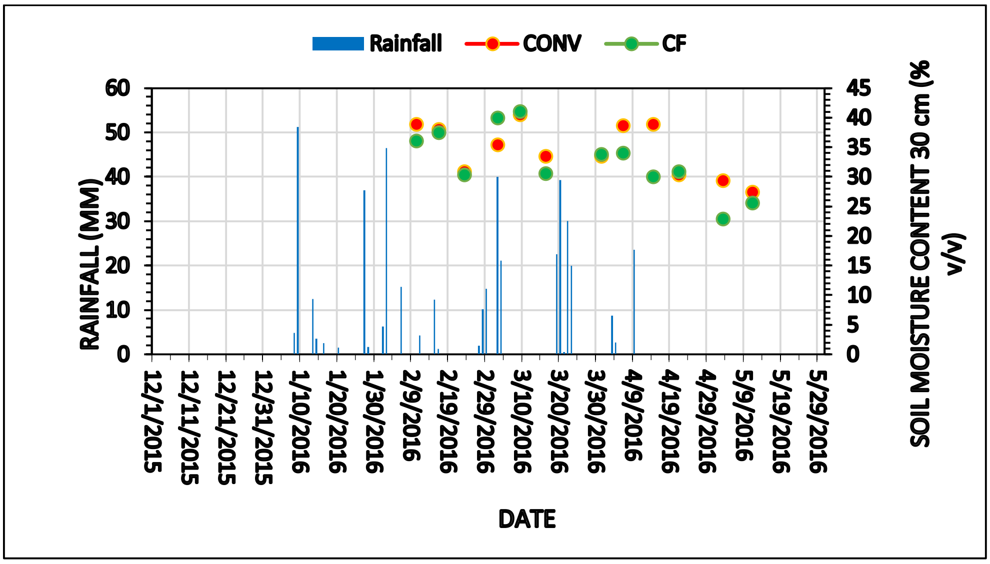

Figure 19: Influence of farming systems on the soil moisture content at 30 cm soil depth under measured rainfall per day

A significant interaction between farming systems and maize varieties was observed for soil moisture storage at soil depth of 10 cm, 20 cm, and 30 cm. Moisture content of 36.89 % was highest at 30 cm soil depth under CONV and maize variety M1 (ZMS 606). The lowest soil moisture content was 26.69 % at 10 cm soil depth under CONV and maize variety M1 (ZMS 606). Under CF variety M2 (GV 640) conserved more soil moisture content of 33.66 % than M3 (GV 635) at 30 cm soil. (Table 44).

Table 44: An interaction between farming systems and maize varieties for soil moisture storage (% v/v) at 10 cm, 20 cm and 30 cm soil depth from the twelve dates of moisture measurements during 2015/2016 growing season at Chisamba

		Soil moisture storage (% v/v)			
		Maize varieties			
		Low N and Drought tolerant			
Farming system	Depth	M1 (control)	M2	M3	Mean
CF	10 cm	32.38 ± 0.8	32.05 ± 0.8	32.92 ± 0.7	**32.48 ± 0.8**
	20 cm	33.53 ± 0.6	33.02 ± 0.7	33.17 ± 0.7	**33.09 ± 0.7**
	30 cm	33.42 ± 0.7	33.66 ± 0.7	31.12 ± 0.8	**32.39 ± 0.7**
	Mean	**33.11 ± 0.7**	**32.91 ± 0.7**	**32.40 ± 0.7**	**32.4 ± 0.7**
CONV	10 cm	26.69 ± 1.5	28.79 ± 1.3	29.7 ± 1.2	**29.25 ± 1.3**
	20 cm	33.80 ± 1.2	30.12 ± 1.3	30.33 ± 1.1	**30.23 ± 1.2**
	30 cm	36.89 ± 1.0	33.78 ± 1.2	33.22 ± 1.0	**34.63 ± 1.1**
	Mean	**32.46 ± 1.2**	**30.90 ± 1.3**	**31.08 ± 1.1**	**31.4 ± 1.2**
	FPr	10 cm = P<0.001	20 cm = P<0.001	30 cm = P<0.001	
	Lsd 0.05)	10 cm =1.415	20 cm = 1.337	30 cm = 1.516	
	CV (%)	10 cm = 15.6	20 cm = 20.4	30 cm =20.6	

Note: CF= Conservation farming, CONV = Conventional farmingM2 (GV 640) and M3 (GV 635) = selected low N and drought tolerant. M1 (ZMS 606) Control = mostly purchased by smallholder farmers. ± denotes standard errors of means

At Chisamba, a significant interaction (P<0.001) between farming system and days after planting was observed at 10 cm, 20 cm and 30 cm. The interaction was at 100 DAP at 10 cm, 57, 100 and 108 DAP at 20 cm, 54,72, 115 DAP at 30 cm (Figures 20, 21 and 22).

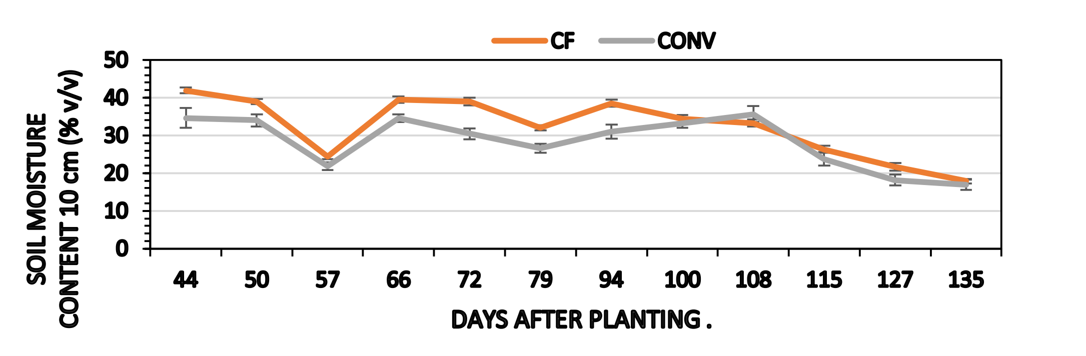

Figure 20: An interaction between farming systems and days after planting of moisture measurement at 10 cm soil depth at Chisamba

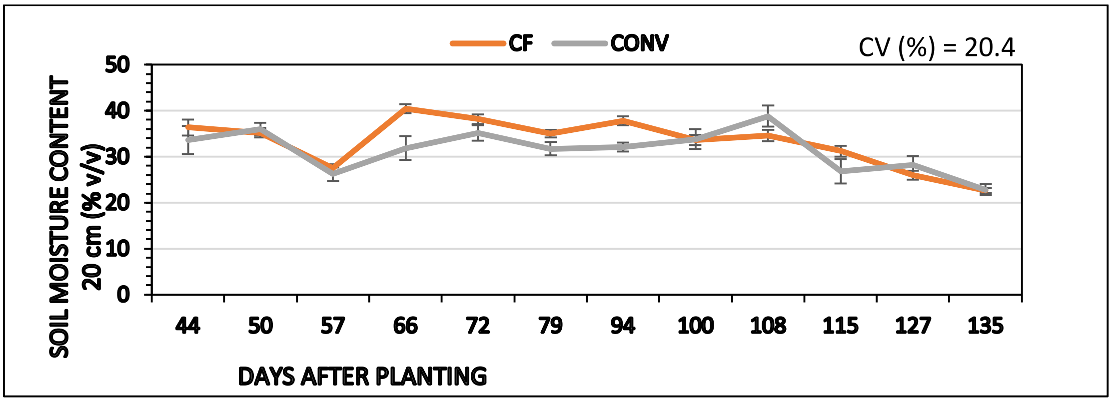

Figure 21: An interaction between farming systems and days after planting of moisture measurement at 20 cm soil depth at Chisamba

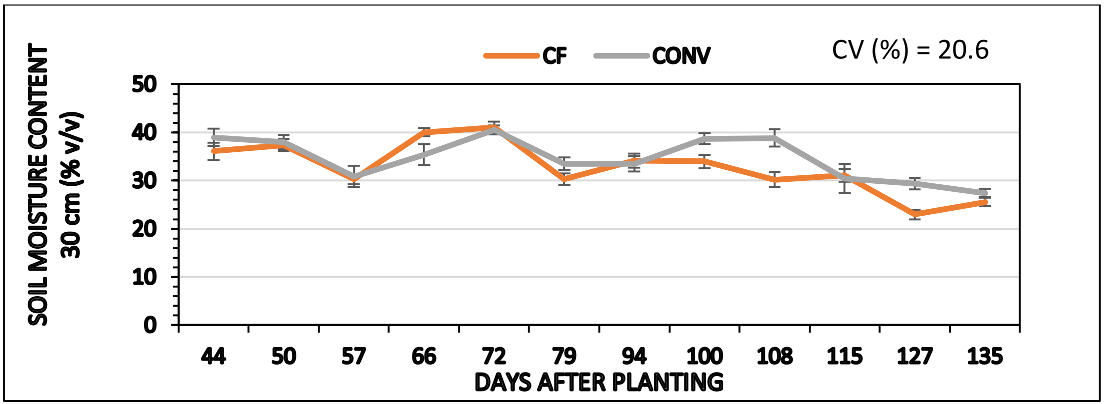

Figure 22: An interaction between farming systems and days after planting of moisture measurement at 30 cm soil depth at Chisamba

The soil moisture storage at Batoka was significantly (P<0.001) lower in the conventional farming system than in the conservation farming system by 22.7 % at soil depth of 10 cm, 20 cm and 30 cm (Table 45). A significant interaction (P<0.05) between days after planting and farming systems was observed at 10 cm soil depth mainly at 64 DAP and 76 DAP. There was high increase in SMS under CF at 64 DAP (18.6%) and 76 DAP (25.3%) compared with 6.6 % at 44 DAP (Figure 23).

Table 45: Influence of farming systems on soil moisture storage (%v/v) at 10 cm, 20 cm and 30 cm soil depths from the three dates of moisture .measurements during 2015/2016 growing season at Batoka

	Soil moisture storage (% v/v)			
Farming systems	**10 cm**	**20 cm**	**30 cm**	**Mean**
Conservation farming	10.24 [b]	12.86 [b]	14.43 [b]	**12.51**
Conventional farming	8.67 [a]	10.38 [a]	11.55 [a]	**10.20**
Mean	**9.46**	**11.62**	**12.99**	**11.36**
FPr	<0.001	<0.001	<0.001	
Lsd (0.05)	0.61	0.727	0.573	
CV (%)	13.2	11.6	8.7	

Note: Mean values followed by different letters within a column for different treatments are significantly different at P<0.01.

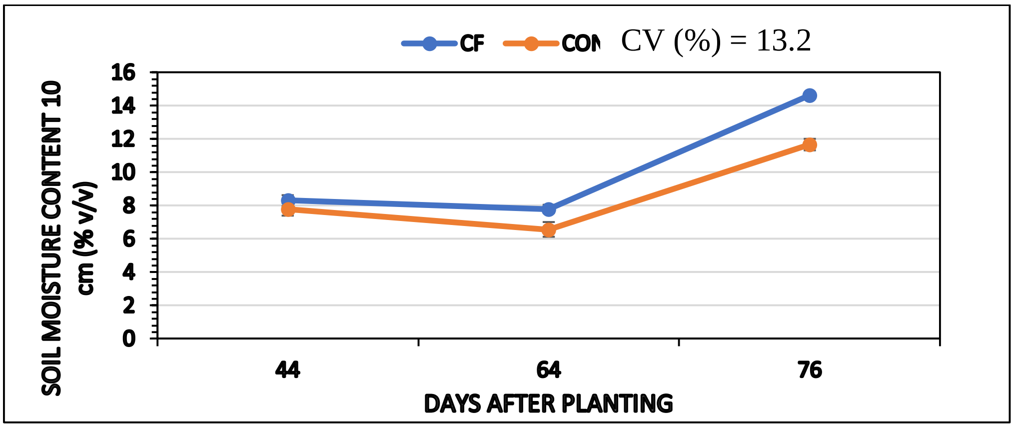

Figure 23: An interaction between farming systems and days after planting of moisture measurement at 10 cm soil depth at Batoka

Soil moisture conservation was significantly higher (P<0.001) under the conservation farming system (CF) than the conventional system (CONV) at 10 cm and 20 cm for the Chisamba site and at 10 cm, 20 cm and 30 cm at the Batoka site indicating that CF is beneficial for crops under drought conditions. Thus, the study is supported by a review of Kopila (2017) who explained that residue retention stores more water on soil surface and will not allow water deficit condition and improves grain yield.

Therefore, the study had indicated that more soil moisture storage was conserved under CF than CONV and mostly at soil surface layer between 10 and 20 cm for Chisamba soils. The higher soil moisture in the CF at 10 and 20 cm for Chisamba sites and at all three-soil depth at Batoka was attributed to mulching effects by cowpea crop residues that remained as soil cover and organic matter input after decomposition. This condition allowed less water evaporation from the soil surface in CF than under CONV. In the present study the soil organic matter was significantly observed lower at $p<0.05$ in the conventional (maize mono- cropping) which had 1.4 % than in the conservation farming systems (maize – cowpea rotation) which measured 2.1 % on average at 0-15 cm soil depth (Simunji et al., 2019). The findings of the study are further supported by oven- dry soil moisture assessment done in this study. The oven dry method's soil moisture assessment showed that conservation farming system that included maize - cowpea rotation significantly stored more water (6.8 %) than conventional system - Non cowpea (NCP), which had 5.8 %. At Batoka site plant available water (PAW) of 16.2% under cowpea mutant LT 11-3-3-12 in the CF system was significantly observed higher than 14.6 % of soils under the non- cowpea treatment (CONV) suggesting that CF had positively impacted to soil structure improvement. The study results agreed with Govaerts et al. (2007) who reported that soil moisture accumulated more with depth and residues than without residues under a zero-tillage system. In another study, VanLoocke et al. (2012) demonstrated that high moisture content on surface depth was due to less evaporation and increased soil organic carbon. Minimum tillage by ripping to a depth of 15 cm with an ox- drawn ripper could have also added to the high soil moisture storage at 10 and 20 cm soil depths. The results agreed with Bradford and Peterson (2000) who revealed that conservation farming practices have proven effective in helping to increase plant-available water under drought and to improve crop water- use efficiency (Govaerts et al., 2007). Liu et al. (2013) indicated greatest soil water storage in No till followed with reduced tillage and the least was conventional tillage in the 30 cm surface. Though amount of soil moisture storage at Batoka was lower than that of Chisamba, the impact of CF on soil moisture storage was more at Batoka than Chisamba due to differences in soil types and fertility status.

Therefore, the study has given evidence that poor and degraded lixisols of Batoka would increase soil moisture storage significantly if CF practices are followed. In the present study the soil organic matter was significantly ($P<0.05$) observed higher at Chisamba with 2.3 % than Batoka which had 1.8 % across soil depths of 0-15 cm and 15-30 cm (Tables 13 and 17).

The lower moisture content in the CF at depth of 30 cm soil depth at Chisamba could be attributed to high water uptake by vigorous growing maize crop. Esser (2017) also reported similar results that moisture content in the CF maize crop was less than CONV. The uptake of water from the soil by the crop is influenced by plant density, plant size and root system volume which means the crop with high biomass and large volume of root system would take up more water and faster than the weaker crop. Similar findings observed by Tijani (2008)., Zougmore et al. (2008) showed that low water storage under organic material treated maize plot was due to higher maize crop biomass and consequent higher water demand by the crop. According to Blum (1984) when the top soil (top 3 cm) was wet (at least above 70 % of field capacity) crown roots initiation and establishment proceeded at potential rates, resulting in a large number (14) of crown roots which grew to a depth of 30–40 cm, at 24 days after emergence. Therefore, findings of the present study, explain that maize crop in the CF had wellestablished root system that enhanced more water extraction than fewer roots suppressed by dry surface soil in the CONV. The modification of soil structure by CF systems might have also contributed to this trend. This might be explained by high water storage in the improved soil structure of top layer under CF compared to initial high water percolation from loosened top layer soil (0-20 cm) to the deeper layer (30 cm) in the CONV (Tijani,2008).

The interaction between farming systems and maize varieties for soil moisture storage implied that soil moisture utilization and water use efficiency vary depending on the farming system and varieties used in the production. In the present study, variety M3 (GV 635) which had taken up more water at a soil depth of 30 cm compared to M1 (ZMS 606) and M2 (GV 640), which had lost more water at a soil depth of 10 cm could suggest that M3 had higher biomass and deeper root system. The maize variety with a large leaf surface area covers the soil surface faster and can prevent excessive loss from the soil surface by evaporation. Maize variety M3 (GV 635) produced a higher biomass yield of 8204 kg ha^{-1} than the average yield of M1 (ZMS 606) and M2 (GV 640) by 7.0 %. Based on the amount of soil moisture storage, maize varieties were more efficient in water use under CF than in the CONV due to high soil moisture conserved in the CF system.

5.4.2.3 Influence of Cowpea genotypes on soil moisture storage

Cowpea genotypes used in the experiment for rotation with maize significantly ($P<0.001$) influenced the uptake of moisture by maize crop in the CF plots. The cowpea genotypes LTPRT, mutants LT 11-3-3-12 and BB 14-16-2-2 conserved significantly higher moisture content of 33.32 %, 32.69 % and 32.25 % than for non-cowpea by 15. 3 % and BBPRT by 3.8 % at 10 cm soil depth mainly due to increased dry biomass yield produced by the genotypes (Table 46 and Figure 24). At 20 cm soil moisture depth, cowpea mutants BB 14-16-2-2 and LT 11-3-3-12 had conserved highest soil moisture content of 34.57 % and 33.72 % more than non-cowpea treatment by 10.1% and 7.4 % respectively (Table 44 and Figure 25). Non-cowpea and cowpea genotype LTPRT treatments with soil moisture content of 34.63% and 33.77 % respectively were significantly higher than for other cowpea genotypes at 30 cm soil depth (Table 46 and Figure 26).

Table 46: Influence of cowpea genotypes on soil moisture storage at 10 cm, 20 cm and 30 cm soil depths from the twelve dates of moisture measurements during 2015/2016 growing season at Chisamba

	Soil moisture storage (% v/v)			
Cowpea genotypes	**10 cm**	**20 cm**	**30 cm**	**Mean**
LTPRT	33.32 ^{d}	33.27 ^{b}	33.77 ^{b}	**33.45**
BBPRT	31.55 ^{b}	31.40 ^{a}	32.67 ^{a}	**31.77**
LT	32.69 ^{cd}	33.72 ^{bc}	32.34 ^{a}	**32.73**
BB	32.25 ^{bc}	34.57 ^{c}	32.17 ^{a}	**33.39**
NCP	28.40 ^{a}	31.41 ^{a}	34.63 ^{b}	**31.48**
Mean	**31.64**	**32.87**	**33.12**	**32.54**
FPr	<0.001	<0.001	<0.001	
Lsd (0.05)	0.994	1.051	1.021	
CV	11.3	11	12.2	

Note: Mean values followed by different letters within a column for different treatments are significantly different at P<0.01. LTPRT = Lutembwe parent indeterminatetype, BBPRT = Bubebe parent cowpea determinatetype, LT = Lutembwe mutant indeterminateand running type, BB 14-16-2-2 = Bubebe mutant determinatetrifoliate type

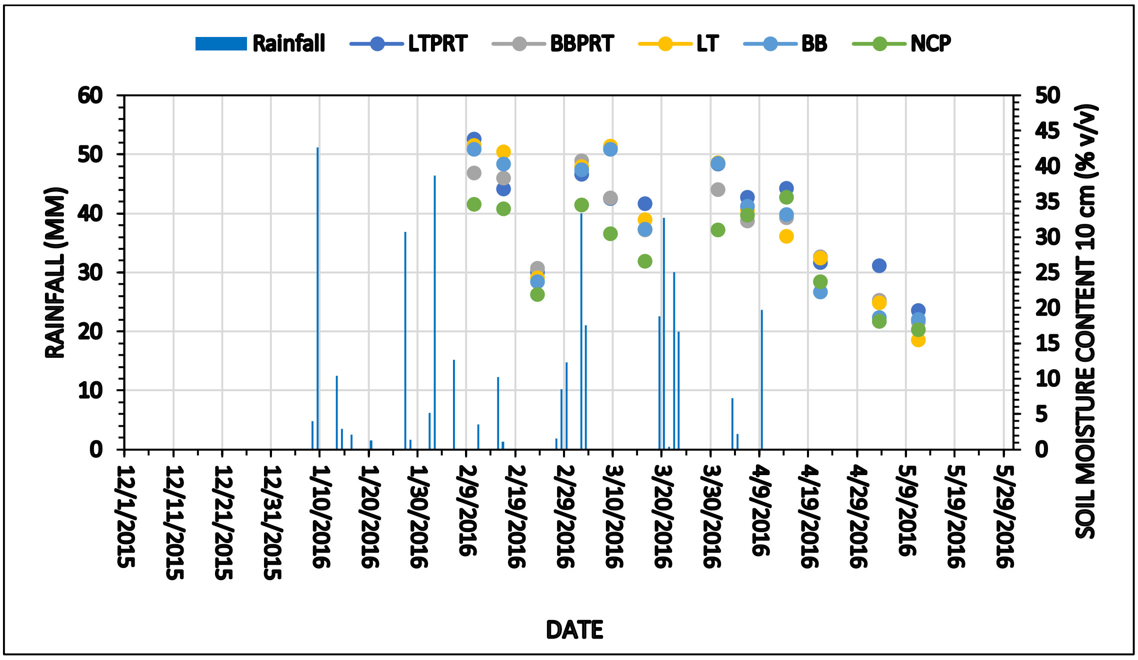

Figure 24: Influence of Cowpea genotypes on the soil moisture content at 10 cm soil depth under measured rainfall per day

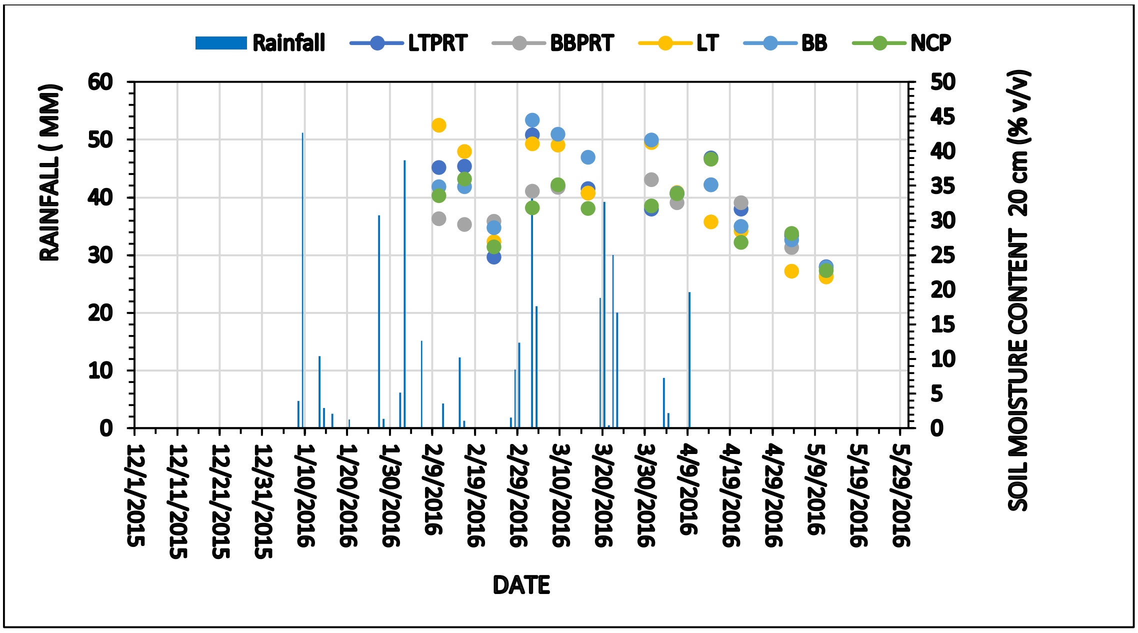

Figure 25: Influence of Cowpea genotypes on the soil moisture content at 20 cm soil depth under measured rainfall per day

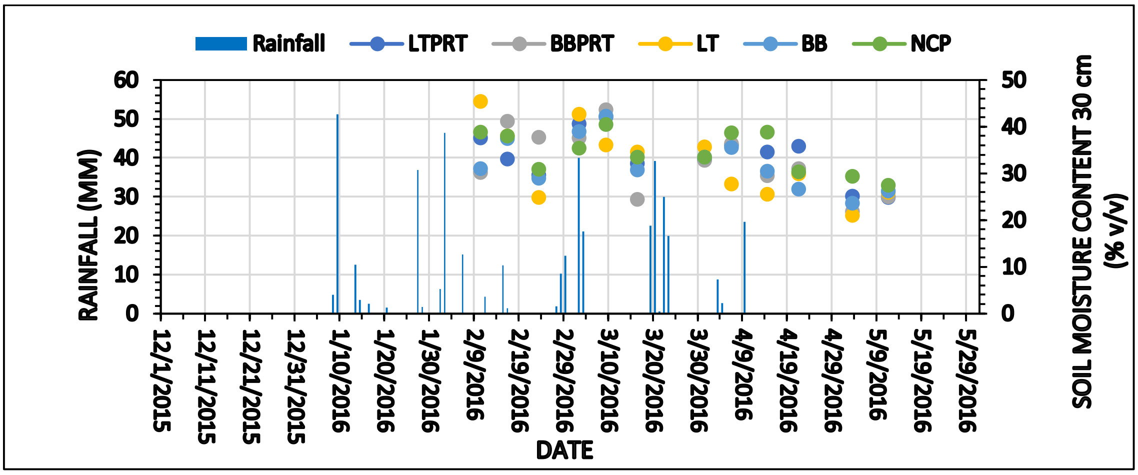

Figure 26: Influence of cowpea genotypes on the soil moisture content at 30 cm soil depth under measured rainfall per day

A significant interaction (P<0.05) of soil moisture storage between days after planting of soil moisture measurement (DAP) and cowpea genotypes was observed at 10 cm, 20 cm and 30 cm soil depth. Generally, non-cowpea treatment had significantly the lowest soil moisture content at 10 cm soil depth throughout the growth period of the maize crop. Cowpea mutants LT 11-3-3-12 and BB 14-16-2-2 had on average expressed significantly higher soil moisture storage at 50, 66, 72 and 94 DAP more than under the non- cowpea treatment (Figure 27).

At 20 cm soil depth a similar trend as at 10 cm was observed where mutants LT 11-3-3-12 and BB 14-16-2-2 exhibited the highest soil moisture content compared to their parents and non–cowpea treatment at 66, 72, 79 and 94 DAP. However, average soil moisture content of 38.89 % was highest for parent LTPRT and NCP at 108 DAP compared to mutants LT 11-3-3-12, BB 14-16-2-2 and parent BBPRT (Figure 28). At 30 cm soil depth, soil moisture storage was highest for NCP at 100 DAP (38.85 %) and 108 DAP (38.85 %) compared to cowpea genotypes while mutant LT 11-3-3-12 had highest moisture content of 45.59 % at 44 DAP (Figure 29).

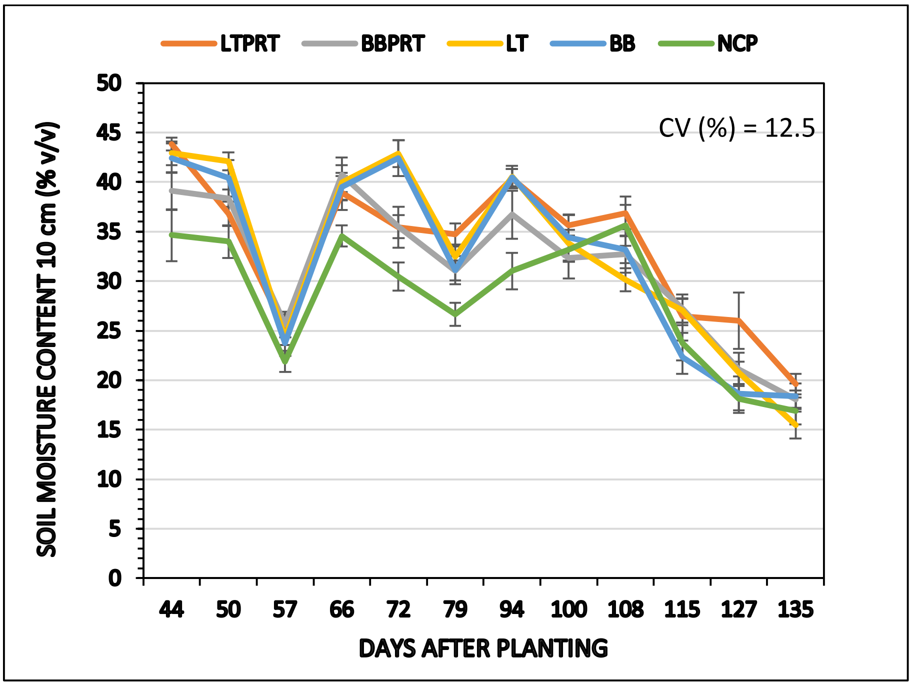

Figure 27: An interaction between Days after planting and cowpea genotypes on the soil moisture content at 10 cm soil depth at Chisamba

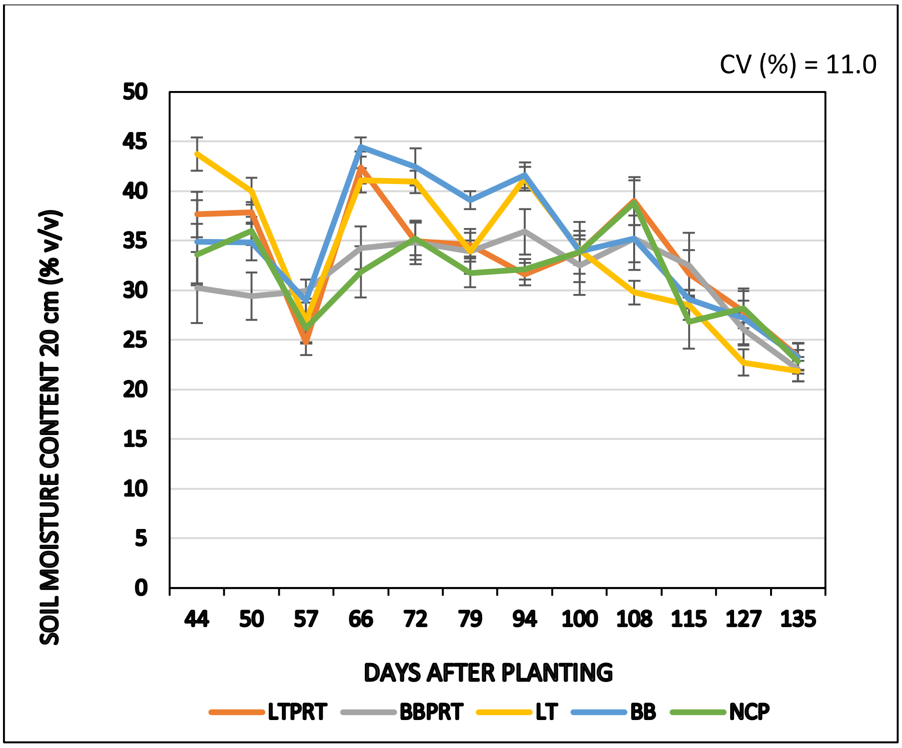

Figure 28: An interaction between Days after planting and cowpea genotypes on the soil moisture content at 20 cm soil depth at Chisamba

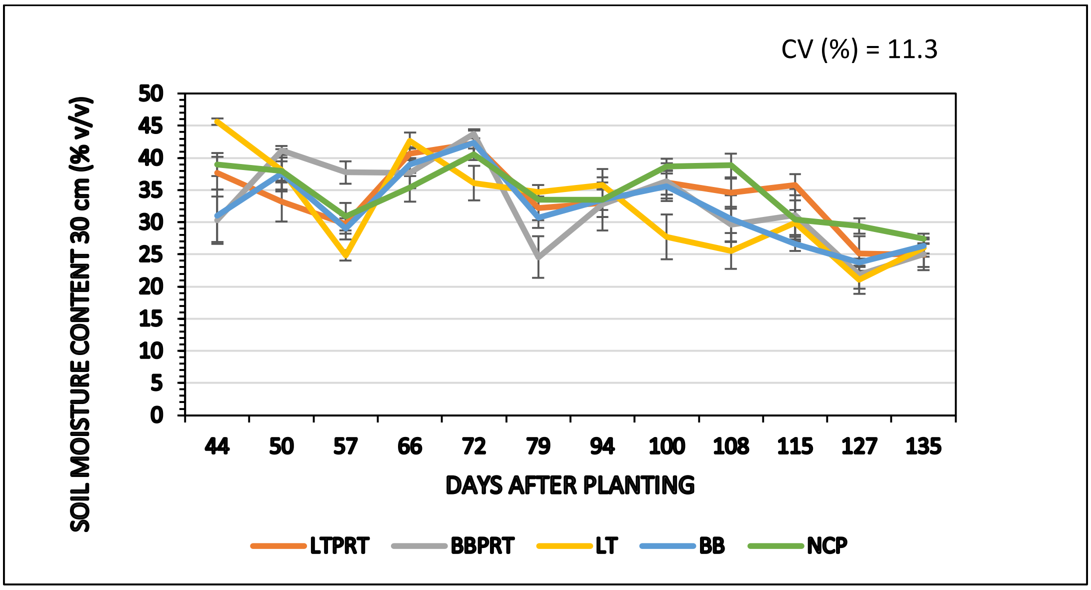

Figure 29: An interaction between days after planting and cowpea genotypes on the soil moisture content at 30 cm soil depth at Chisamba

Compared to the non-cowpea treatments, cowpea genotypes had a significant impact on SMS and utilization by the maize crop at soil depth of 10 cm, 20 cm and 30 cm at the Batoka site. On average SMS under the influence of cowpea genotypes was 12.51 % and was significantly (P<0.001) higher than under conventional (NCP) which had 10.18 % (Table 47).

Table 47: Influence of cowpea genotypes on soil moisture storage at 10 cm, 20 cm and 30 cm soil depths from the three dates of moisture .measurements during 2015/2016 growing season at Batoka

	Soil moisture storage (% v/v)			
Cowpea genotypes	**10 cm**	**20 cm**	**30 cm**	**Mean**
LTPRT	9.86 [b]	12.35 [b]	14.08 [b]	**12.10**
BBPRT	10.43 [b]	13.02 [b]	14.63 [b]	**12.69**
LT	10.50 [b]	12.96 [b]	14.49 [b]	**12.65**
BB	10.16 [b]	13.10 [b]	14.52 [b]	**12.59**
NCP	8.67 [a]	10.32 [a]	11.55 [a]	**10.18**
Mean	**9.92**	**12.35**	**13.85**	**12.04**
FPr	<0.001	<0.001	<0.001	
Lsd (0.05)	0.691	1.1922	0.7189	
CV (%)	10.9	8.1	6.3	

Note: Mean values followed by different letters within a column for different treatments are significantly different at P<0.01. LTPRT = Lutembwe parent indeterminate type, BBPRT = Bubebe parent cowpea determinate type, LT = Lutembwe mutant indeterminate and running type, BB 14-16-2-2 = Bubebe mutant determinate trifoliate type

At Batoka, an interaction between DAP and cowpea genotypes for soil moisture storage and utilization was significantly observed at 10 cm soil depth at P<0.05. The results indicated that some cowpea genotypes conserved considerably more moisture than others on specific soil moisture testing days. Cowpea mutant LT 11-3-3-12 had significantly conserved more moisture content of 9.20% than non- cowpea treatment and other cowpea genotypes that had an average of 8.0 % at 44 DAP. The SMS increased more under the cowpea genotypes by 33.3% than in the NCP which had 11.67 % at 76 DAP (Figure 30).

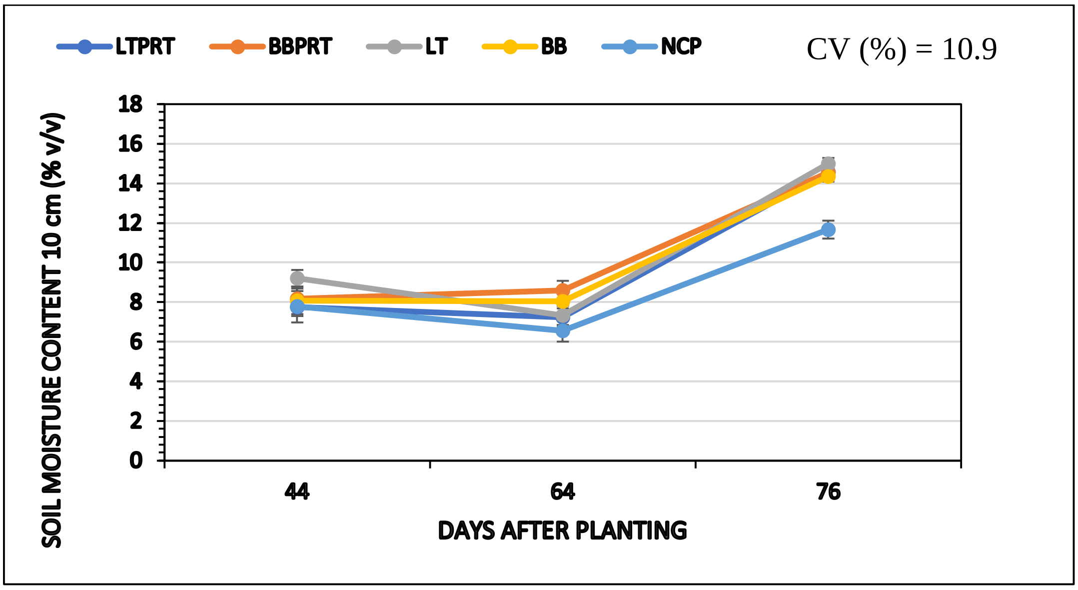

Figure 30: An interaction between Days after planting and cowpea genotypes on the soil moisture content at 10 cm soil depth at Batoka.

Treatments under cowpea genotype BBPRT and non- cowpea had highly significant ($P<0.001$) lowest contribution to soil moisture storage at 10 and 20 cm soil depth due to less soil organic matter content (Johnson., 2016; Blanco-Canqui et al., 2013). At the soil depth of 15-30 cm in the present study, LT 11-3-3-12 mutant which measured 3.2 % organic matter content was significantly ($P<0.05$) highest compared to BBPRT and the non-cowpea treatment (NCP) that had 1.9 % and 1.4 % respectively. Cowpea genotypes used in the experiment for rotation with maize significantly ($P<0.05$) influenced the uptake of moisture by maize crop in the CF plots. On average the cowpea genotypes LTPRT, mutants LT 11-3-3-12 and BB 14-16-2-2 conserved the highest moisture content of 33.1 % than for non- cowpea and BBPRT treatments mainly due to increased dry biomass yield produced by the genotypes. A similar trend was observed at the Batoka site where cowpea mutants generally outperformed other genotypes for soil moisture storage. During the 2014/15 growing season of the present study, the cowpea genotypes LTPRT and LT 11-3-3-12 produced an average of 3650 kg ha^{-1} dry biomass yield. Itwas significantly ($P<0.001$) more than the biomass yield of cowpea genotypes BBPRT and BB 14-16-2-2 by 49 % at Chisamba while at Batoka, cowpea LT 11-3-3-12 and LTPRT had an advantage over BBPRT, BB 14-16-2-2 by 54.1 %. A similar trend was observed during the 2015/2016 growing season where on average mutants BB 14-16-2-2 and LT 11-3-3-12 had higher dry biomass yield of 3293 kg ha^{-1} and 3953 kg ha^{-1} than their parents BBRT and LTPRT which produced 2809 kg ha^{-1} and 3340 kg ha^{-1} respectively. The high dry biomass produced by parent LTPRT, mutants LT 11-3-3-12 and BB 14-16-2-2 genotypes remained on the soil surface as soil cover that saved water by reducing soil water evaporation (Kaspar, 2010) before planting and during part of the growing season (Richard and Marietha, 2007). Similarly, Karukua et al. (2014) indicated that soil moisture storage and water use efficiency in tomato production varied according to residue management of different crop species as soil cover. The differences in crop residue decomposition rate could have also contributed to the variations in soil moisture content under cowpea genotypes. In the present study, the rate of residue decomposition for mutant LT 11-3-3-12 and parent LTPRT with lower nitrogen content (Table 19) could have been lower and hence prolonged the soil surface cover (Talgre, 2017). According to Gwenzi et al. (2009), decomposition rates of soil organic matter are lower with minimal tillage and residue retention eventually organic carbon content increases with time.

Generally, the non-cowpea treatment had less soil moisture conserved than under cowpea genotypes at different days of moisture measurement. Therefore, the present study indicated that cowpea genotypes would influence the soil moisture differently depending on weather condition of the specific day. The changes in soil moisture storage and utilization by maize crop could be attributed to effects of rainfall intensity and distribution, drought, soil surface cover, C/N ratio and mineralization rate of soil organic matter into nitrogen from different cowpea genotypes (Talgre, 2017). The mutant genotypes LT 11-3-3-12 and BB 14-16-2-2 had more advantage for soil moisture conservation at soil depth of 10 cm and 20 cm than their parents and non-cowpea treatment at the early growth stages of maize crop. This was due to the high biomass yield produced by mutants compared to their parents that acted as soil cover to prevent excessive moisture loss through evaporation. The increased soil moisture content exhibited under the non-cowpea treatment at maize grain filling and towards maturity stages compared to the cowpea genotypes at 30 cm soil depth could be attributed to less water demand by less vigorous crop under CONV system than for high water requirement and uptake by vigorous maize crop in maize- cowpea rotation under CF.

5.4.2.3. Influence of maize varieties on soil moisture storage

The maize varieties at the Chisamba site significantly (P<0.001) influenced soil moisture content differently at soil depth of 10 cm, 20 cm and 30 cm. On average soil moisture content of 32.27 % was significantly higher under M3 (GV 635) than for M1 (ZMS 606) and M2 (GV640) at 10 cm soil depth. At 20 cm soil depth, soil moisture storage was significantly (P<0.001) highest under M1 (ZMS 606) with soil moisture content of 33.58 % compared to M2 (GV640) and M3 (GV 635). Soil moisture storage at 30 cm soil depth under GV 635 (31.54 %) was significantly (P<0.001) lower than average soil moisture content under M1 (ZMS 606) and M2 (GV 640) (Table 48, Figures 31, 32 and 33).

Table 48: Influence of maize varieties on soil moisture storage at 10 cm, 20 cm and 30 cm soil depths from the from the twelve dates of moisture .measurements during 2015/2016 growing season at Chisamba

	Soil moisture storage (% v/v)			
Maize varieties	**10 cm**	**20 cm**	**30 cm**	**Mean**
ZMS 606 (M1)	31.24a	33.58b	34.11b	**32.98**
GV 640 (M2)	31.40a	32.44a	33.69b	**32.51**
GV 635 (M3)	32.27b	32.60a	31.54a	**32.46**
Mean	**31.64**	**33.20**	**33.11**	**32.65**
FPr	<0.001	<0.001	<0.001	
Lsd	0.744	0.754	0.841	
CV	11.3	11	12.2	

Note: Mean values followed by different letters within a column for different treatments are significantly different at P<0.01. M2 (GV 635) and M3 (GV 640) = selected low N and drought tolerant. M1 (ZMS 606) Control = mostly purchased by smallholder farmers

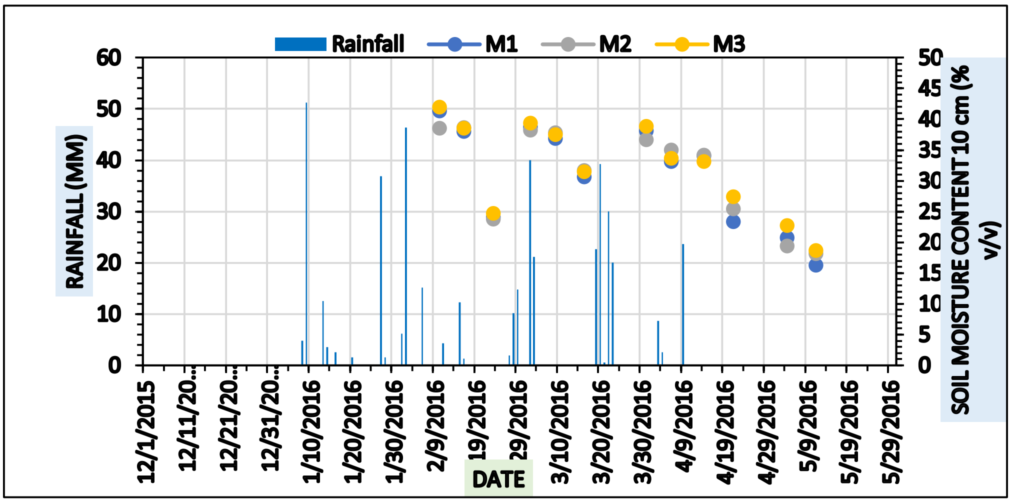

Figure 31: Influence of maize genotypes on soil moisture content at 10 cm soil depth under measured rainfall per day

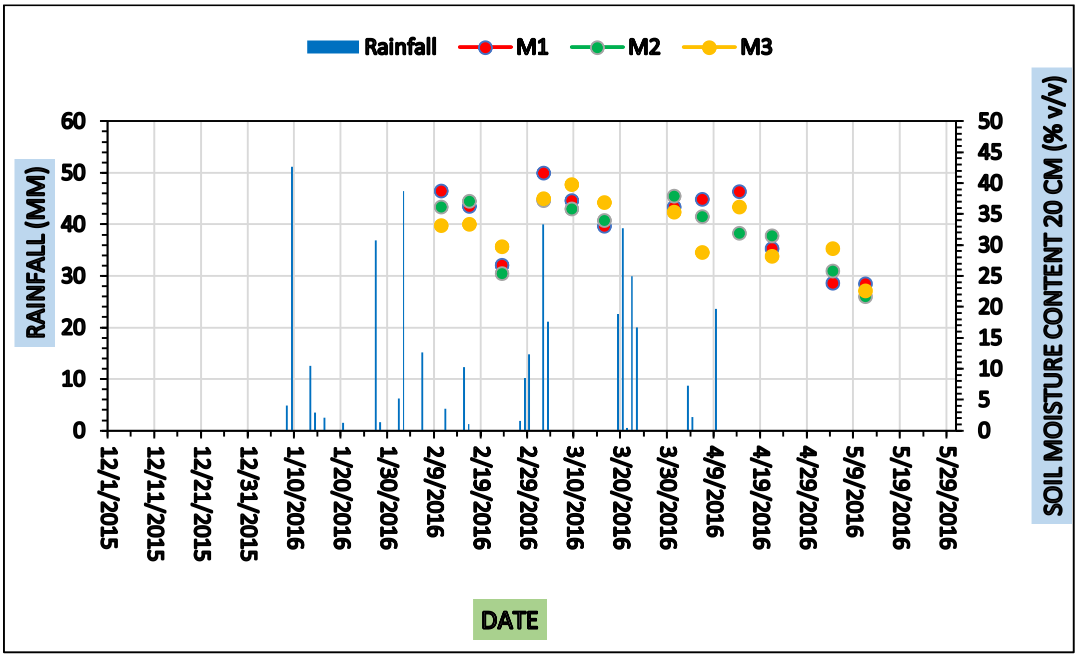

Figure 32: Influence of maize genotypes on soil moisture content at 20 cm soil depth under measured rainfall per day

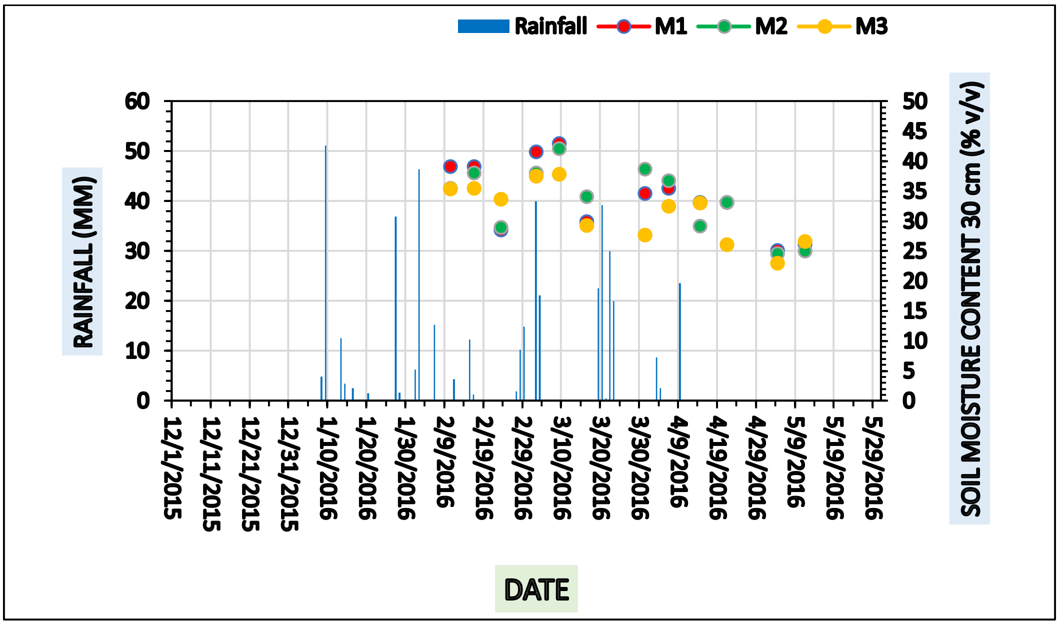

Figure 33: Influence of maize genotypes on soil moisture content at 30 cm soil depth under measured rainfall per day

A significant interaction ($P<0.001$) between days after planting (DAP) and maize varieties for soil moisture storage was observed at 20 cm and 30 cm soil depths. At soil depth of 20 cm, the highest soil moisture content of 41.5 % and 38.65 % was measured under maize variety M1 (ZMS 606) at 66 and 108 days after planting (DAP). a Maize variety M3 (GV 635) on the other hand had the highest soil moisture storage of 29.74 % and 39.80 % at 57 and 72 DAP compared to M1 and M2. Soil moisture storage was generally higher under M1 (ZMS 606) and M2 (GV 640) than M3 (GV 635) at 30 cm soil depth (Figures 34 and 35).

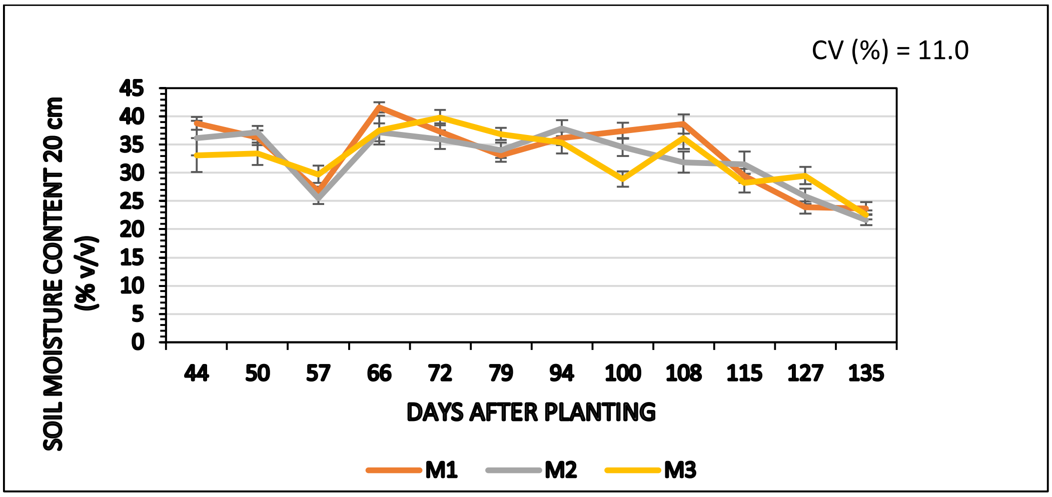

Figure 34: An interaction between days after planting of moisture measurement and maize varieties on soil moisture content at 20 cm soil depth at Chisamba

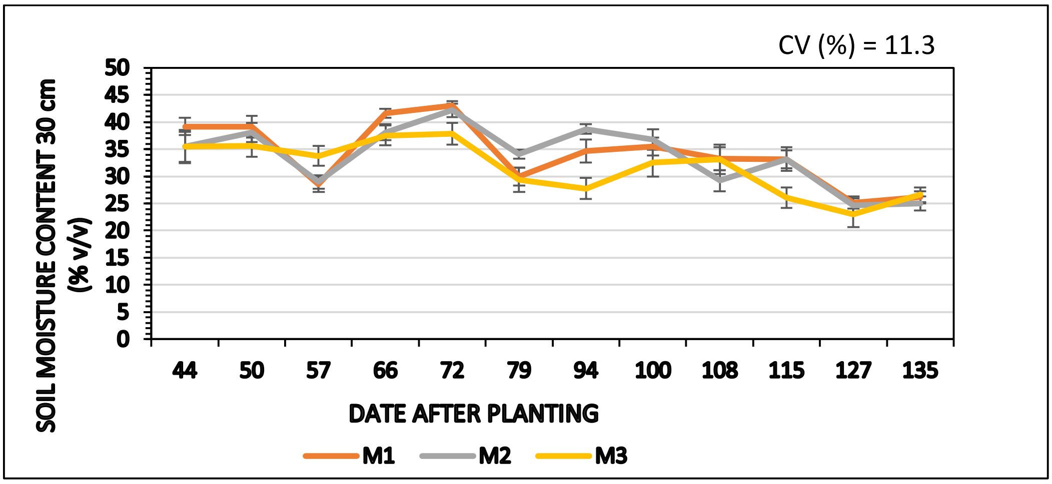

Figure 35: An interaction between days after planting of moisture measurement and maize varieties on soil moisture content at 30 cm soil depth at Chisamba

A significant interaction (P<0.001) between cowpea genotypes and maize varieties for soil moisture storage at Chisamba was observed at 10 cm 20 cm and 30 cm soil depths. Soil moisture storage of 33.32 % under the combination of cowpea genotype LT 11-3-3-12 and maize variety M1(ZMS 606) at 10 cm soil depth. M1 (ZMS 606) had highest soil moisture storage of 36.89 %, 35.81 % and 34.95 % combined with non-cowpea, BBPRT and mutant LT 11-3-3-12 at 30 cm soil depth respectively. Maize variety M2 (GV 640) had the highest moisture storage of 35.62 % in combination with mutant LT 11-3-3-12 at 20 cm soil depth. Maize variety M3 (GV 635) conserved the highest soil moisture content of 34.42 % with combination of cowpea genotypes LTPRT at soil depth of 10 cm. The combination of maize variety M3 (GV 635) with cowpea mutant BB 14-16-2-2 had the significantly highest soil moisture content of 36.76 % at 20 cm soil depth.

The lowest soil moisture content of 26.69 % was however, obtained under combination of non- cowpea treatment (NCP) with maize variety M1 (GV 606) and between cowpea mutant LT 11-3-3-12 with maize variety M3(635) at soil depth of 10 cm and 30 cm respectively. At Chisamba the highest soil moisture conservation was under CF between maize variety M1 (GV 606) and cowpea mutants LT 11-3-3-12, BB 14-16-2-2 and cowpea parent BBPRT (Table 49).

Table 49: An interaction between cowpea genotypes and maize varieties for soil moisture storage (% v/v) at 10 cm, 20 cm and 30 cm soil depth from the twelve dates of moisture measurements during 2015/2016 growing season at Chisamba

		Soil moisture storage (% v/v)			
		Maize varieties			
			Low N and Drought tolerant		
Cowpea genotypes	**Depth**	**M1 (control)**	**M2**	**M3**	**Mean**
LTPRT	10 cm	32.51 ± 1.4	33.02 ± 1.6	34.42 ± 1.2	**33.3**
	20 cm	33.30 ± 1.2	35.62 ± 1.3	30.89 ± 1.3	**33.3**
	30 cm	32.41 ± 1.3	34.27 ± 1.5	34.62 ± 1.2	**33.8**
BBPRT	10 cm	31.89 ± 1.5	29.74 ± 1.4	33.02 ± 1.3	**31.6**
	20 cm	33.94 ± 1.3	30.12 ± 1.2	30.12 ± 1.4	**31.4**
	30 cm	35.81 ± 1.3	32.27 ± 1.5	29.93 ± 2.1	**32.7**
LT	10 cm	33.32 ± 1.7	32.9 ± 1.5	31.86 ± 1.7	**32.7**
	20 cm	32.86 ± 1.3	33.37 ± 1.4	34.91 ± 1.5	**33.7**
	30 cm	34.95 ± 1.4	35.37 ± 1.3	26.69 ± 1.7	**32.3**
BB	10 cm	31.8 ± 1.7	32.57 ± 1.5	32.37 ± 1.6	**32.2**
	20 cm	34.01 ± 1.3	32.94 ± 1.7	36.76 ± 1.3	**34.6**
	30 cm	30.52 ± 1.5	32.74 ± 1.5	33.24 ± 1.2	**32.2**
NCP	10 cm	26.69 ± 1.5	28.79 ± 1.3	29.7 ± 1.2	**28.4**
	20 cm	33.8 ± 1.2	30.12 ± 1.3	30.33 ± 1.1	**31.4**
	30 cm	36.89 ± 1.0	33.78 ± 1.1	33.22 ± 0.9	**34.6**
	Mean	**33.0**	**32.5**	**32.1**	**32.5**
	FPr	10 cm = <0.001	20 cm = P<0.001	30 cm = <0.001	
	Lsd (0.05)	10 cm= 1.677	20 cm = 1.725	30 cm = 1.837	
	CV (%)	10 cm = 11.3	20 cm = 11.0	30 cm = 12.2	

Note: LTPRT = Lutembwe parent indeterminatetype, BBPRT = Bubebe parent cowpea determinatetype, LT = LT 11-3-3-12 Lutembwe mutant indeterminateand running type, BB=BB 14-16-2-2 Bubebe mutant determinatetrifoliate type, NCP = Non cowpea. M2 (GV 640) and M3 (GV 635) = selected low N and drought tolerant. M1 (ZMS 606) control = mostly purchased by smallholder farmers. ± denotes standard errors of means

The soil moisture storage (SMS) at Batoka was significantly affected by maize varieties at soil depth of 10 cm and 20 cm. Maize variety M3 (GV 635) had higher soil moisture storage than M1 (ZMS 606) and M2 (GV 640) at 10 cm soil depth while at soil depth of 20 cm, M1 (ZMS 606) was superior in soil moisture storage over M2 (GV 640) (Table 50).

Table 50: Influence of maize varieties on soil moisture storage at 10 cm, 20 cm and 30 cm soil depths from the three dates of moisture measurements during 2015/2016 growing season at Batoka

	Soil moisture storage (% v/v)			
Maize varieties	**10 cm**	**20 cm**	**30 cm**	**Mean**
ZMS 606 (M1)	9.52 a	12.66 b	13.94 a	**12.04**
GV 640 (M2)	9.63 a	12.02 a	13.94 a	**11.86**
GV 635 (M3)	10.63 b	12.37 ab	13.68 a	**12.23**
Mean	**9.93**	**12.35**	**13.85**	**12.04**
FPr	<0.001	0.023	0.246	
Lsd (0.05)	0.568	0.444	0.363	
CV (%)	11.3	11	12.2	

Note: Mean values followed by different letters within a column for different treatments are significantly different at P<0.05. M2 (GV 640) and M3 (GV 635) = selected low N and drought tolerant. M1 (ZMS 606) control = mostly purchased by smallholder farmers

A significant (P<0.001) interaction between days after planting and maize varieties was observed at soil depths of 10 cm and 20 cm at Batoka. At a soil depth of 10 cm, the interaction was significantly higher for maize variety M3 (GV 635) at 44 DAP than M1 (ZMS 606) and M2 (GV 640) (Figure 36). At soil depth of 20 cm, the significant interaction was observed at 64 DAP where maize variety M1 (ZMS 606) had improved soil moisture storage over M2 (GV 640) and M3 (GV 635) by 20.9 % and 12.9 % respectively (Figure 37).

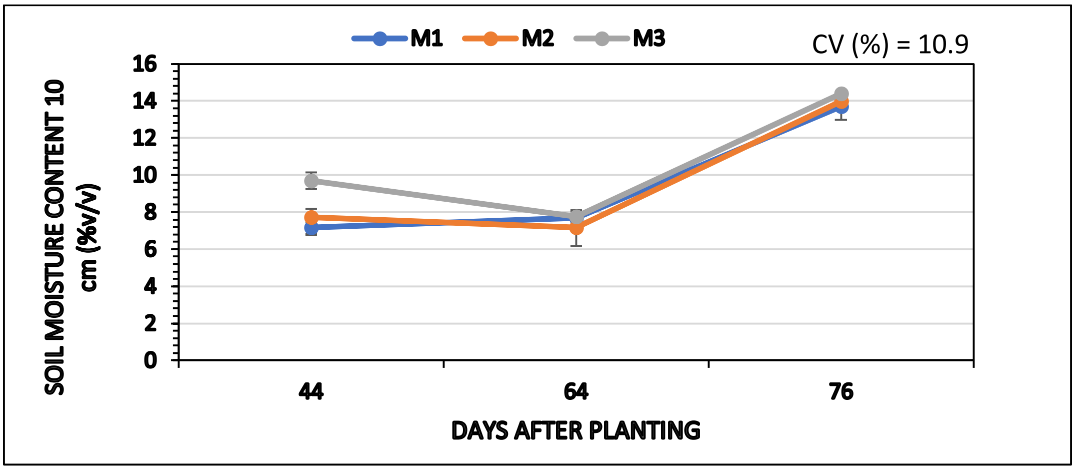

Figure 36: An interaction between days after planting of moisture measurement and maize varieties on soil moisture content at 10 cm soil depth at Batoka

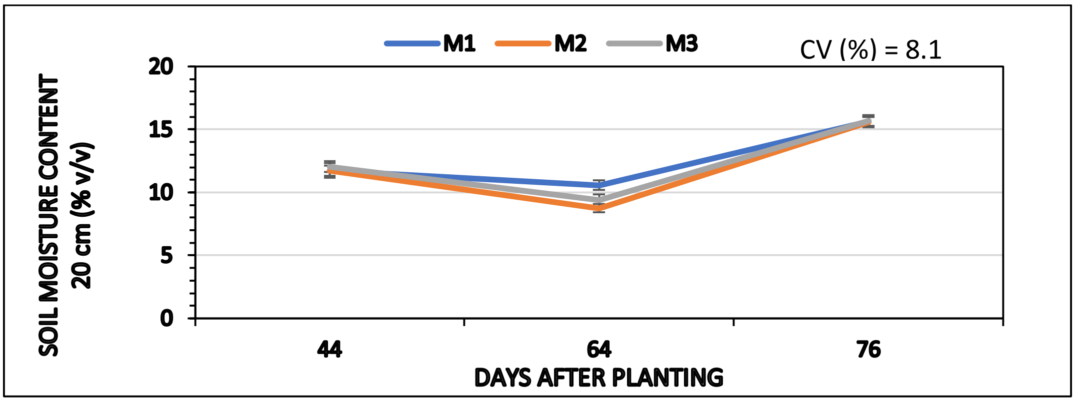

Figure 37: An interaction between days after planting of moisture measurement and maize varieties on soil moisture content at 20 cm soil depth at Batoka

There was a highly significant interaction (P<0.001) between cowpea genotypes and maize varieties at soil depth of 10 cm and 20 cm where some maize varieties had higher soil moisture conservation under rotation with a specific cowpea genotype. At soil depth of 10 cm, maize variety M1(ZMS 606) exhibited highest soil moisture content of 10.64 % in rotational combination with parent BBPRT and 10.33 % with mutant LT 11-3-3-12. Maize variety M2 (GV 640) had higher SMS of 10.17 % combined with cowpea mutant LT 11-3-3-12 and 10.14 % with its parent LTPRT. The highest soil moisture storage of 11.39 % and 11.01 % at 10 cm soil depth was attained when maize variety M3 (GV 635) was combined with cowpea mutants BB 14-16-2-2 and LT 11-3-3-12 respectively.

At soil depth of 20 cm, maize variety M1 (ZM 606) had the highest SMS of 13.93 % in rotation with cowpea mutant LT 11-3-3-12 which increased by 34.5 % compared to the NCP which had soil moisture storage of 10.36 %. Maize variety M2 (GV 640) had the highest SMS of 12.86 % under rotation with cowpea parent BBPRT and 12.46 %

with mutant LT 11-3-3-12 indicating an increase of 23.5 % and 19.6 % compared with the NCP respectively. Maize variety M3 (GV635) had the highest SMS of 13.82 % in rotation with cowpea mutant BB 14-16-2-2 which translated to 35.9 % increase compared to NCP. Based on the findings of the study, the best maize- cowpea combination for soil moisture storage was achieved through use of mutants LT 11-3-3-12, and BB 14-16-2-2 in rotation with maize varieties ZMS 606 and GV 635 under CF at Batoka (Table 51).

Table 51: An interaction between cowpea genotypes and maize varieties for soil moisture storage (% v/v) at 10 cm, 20 cm and 30 cm from the three dates of moisture .measurements during 2015/2016 growing season soil depth at Batoka

		Soil moisture storage (% v/v)			
		Maize varieties			
			Low N and Drought tolerant		
Cowpea genotypes	**Depth**	**M1 (control)**	**M2**	**M3**	**Mean**
LTPRT	10 cm	8.48 ± 1.3	10.14 ± 1.3	10.96 ± 1.2	**9.9**
	20 cm	12.10 ± 1.0	12.06 ± 1.0	12.90 ± 1.0	**12.4**
	30 cm	14.11 ± 0.7	14.02 ± 0.7	14.11 ± 0.9	**14.1**
BBPRT	10 cm	10.64 ± 1.0	9.67 ± 1.2	10.97 ± 1.2	**10.4**
	20 cm	13.70 ± 0.8	12.87 ± 1.1	12.49 ± 1.2	**13.0**
	30 cm	14.29 ± 0.8	14.85 ± 0.9	14.74 ± 0.6	**14.6**
LT	10 cm	10.33 ± 1.0	10.17 ± 1.5	11.01 ± 1.1	**10.5**
	20 cm	13.93 ± 0.7	12.46 ± 1.4	12.49 ± 1.1	**13.0**
	30 cm	14.85 ± 0.6	15.04 ± 0.8	13.58 ± 0.9	**14.5**
BB	10 cm	9.28 ± 1.4	9.81 ±1.2	11.39 ± 0.8	**10.2**
	20 cm	13.2 ± 0.9	12.28 ± 1.1	13.82 ± 0.9	**13.1**
	30 cm	14.61 ± 0.8	14.26 ± 0.9	14.69 ± 0.8	**14.5**
NCP	10 cm	8.86 ± 0.8	8.36 ± 0.8	8.81 ± 1.0	**8.7**
	20 cm	10.36 ± 0.9	10.42 ± 0.8	10.17 ± 0.8	**10.3**
	30 cm	11.82 ± 0.9	11.56 ± 0.7	11.27 ± 0.8	**11.6**
	Mean	**12.0**	**11.9**	**12.2**	**12.0**
	FPr	10 cm = 0.004	20 cm = 0.004	30 cm = 0.046	
	Lsd (0.05)	10 cm = 1.062	20 cm = 1.192	30 cm = 0.97	
	CV (%)	10 cm =10.9	20 cm = 8.1	30 cm = 6.3	

Note: LTPRT = Lutembwe parent indeterminate type, BBPRT = Bubebe parent cowpea determinatetype, LT = Lutembwe mutant indeterminate and running type, BB 14-16-2-2 = Bubebe mutant determinate trifoliate type, NCP = Non cowpea. M2 (GV 640) and M3 (GV 635) = selected low N and drought tolerant. M1 (ZMS 606) control = mostly

The higher soil moisture content exhibited by M3 (GV 635) at 10 cm soil depth at both sites could be attributed to the high biomass of the variety that acted as soil cover to prevent excess water loss from the soil surface. Generally, M1 (ZMS 606) and M2 (GV640) showed more water storage at 20 cm and 30 cm due to increased water use efficiency during water uptake than for M3 (GV 635) especially under conservation farming system. Azeez et al. (2005) reported variations in soil moisture uptake among maize genotypes and found the highest uptake of moisture in drought susceptible hybrid. The results therefore, suggest that GV 635 that depleted more water at 30 cm soil depth compared to GV 640 and ZMS 606 could be less efficient in water use while, GV 640 and ZMS 606 could be recommended for production in areas faced with water limitations under conservation farming system. A significant interaction between maize varieties and cowpea genotypes showed that cowpea genotypes significantly influenced soil moisture storage for maize genotypes utilization. Since high soil moisture storage was mainly observed under the maize varieties M2 (GV 640) and M1 (ZMS 606), it suggests that the uptake of water by maize varieties tend to be more efficient than other varieties at the Chisamba site. On average, the results have indicated that mutant LT 11-3-3-12 could be the most suitable genotype for rotation with maize varieties M2 (GV 640) and M1 (ZMS 606) to ensure improved water storage in conservation farming system at soil depth of 20 and 30 cm (Van Donk et al., 2010). For the Batoka site however, the best maize- cowpea combination for soil moisture storage was achieved through mutants LT 11-3-3-12, BB 14-16-2-2 and parent BBPRT in rotation with maize varieties ZMS 606 and GV 635 under CF at Batoka. The study has further indicated that the amount of water uptake by maize crop depends not only on the farming system but also on the cowpea genotype or maize variety used in the system (Hans and Richard,1996). Considering the high maize grain yield produced by M2 (GV 640) and M1 (ZMS 606) in the CF for two growing seasons, it means that water use efficiency (WUE) could be highest for M2 (GV 640) and M1 (ZMS 606) compared to M3 (GV 635) maize genotypes (Tahar, 2010).

The interaction between days after planting of soil moisture measurement and maize varieties for soil moisture content suggest that water uptake and utilization vary according to maize genotypes and prevailing weather condition during the crop's growth stages Maize variety M3 (GV 635) which consistently showed lower soil moisture at a lower soil depth of 20 cm and 30 cm demands more water than other varieties. It could not be tolerant under high water stress despite having been selected as drought tolerant variety. Therefore, ZMS 606 that is purchased mainly by farmers and GV 640 a drought tolerant variety were identified as most efficient in water utilization. The varieties' water use efficiency (WUE) could be significantly improved when produced under rotation with cowpea mutants LT 11-3-3-12 and BB 14-16-2-2 under conservation farming system.

5.4.3. Rainfall water use Efficiency (RWUE)

5.4.3.1 Maize grain rainfall water use efficiency (RWUEg)

The rainfall water use efficiency of the maize grain yield (RWUEg) was computed as a ratio of total maize grain yield kg ha^{-1} to rain fall (mm) received between planting and maturity. RWUEg was significantly (P<0.001) observed different between the experimental sites, farming systems, among cowpea and maize genotypes during the 2015/2016 growing season. Significant interactions were observed between site x farming systems, site x maize varieties, site x farming systems x maize varieties, site x cowpea genotypes, cowpea genotypes x maize varieties and site x cowpea genotypes x maize varieties (Tables 52 and 53).

Table 52: Mean squares for combine analysis of variance of maize varieties grain rainfall water use efficiency under the influence of farming systems at two sites during the 2015/2016 growing season

Variate: Maize 2015/2016		RWUEg (kg ha^{-1} mm^{-1})
Source of variation	**d.f.**	**m.s.**
Site	1	1459.938***
Rep/Location	4	3.212
Farming system	1	293.502***
Site x Farming system	1	42.653***
Error	4	1.644
Maize variety	2	25.681***
Site x Maize variety	2	4.249**
Farming system x maize variety	2	19.445***
Site x Farming system x.maize variety	2	20.488***
Error	16	1.105

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05, RWUEg = rainfall water use efficiency of maize grain yield.

Table 53: Mean squares for combine analysis of variance of maize varieties grain rainfall water use efficiency under the influence of cowpea genotypes at two sites during the 2015/2016 growing season

Variate: Maize 2015/2016		RWUEg (kg ha^{-1} mm^{-1})
Source of variation	**d.f.**	**m.s.**
Site	1	1459.938***
Rep/Location	4	3.212
Cowpea genotype	4	78.403***
Site x cowpea genotype	4	12.65***
Error	16	1.111
Maize variety	2	25.681***
Site x maize variety	2	4.249**
Cowpea genotype x maize variety	8	11.724***
Site x cowpea genotypex maize variety	8	6.586***
Error	40	1.012

Note: ***Significant at $P \leq 0.01$, **Significant at $P \leq 0.05$, ns Not significant at $P \leq 0.05$, RWUEg = rainfall water use efficiency of maize grain yield.

Chisamba (CH) site had RWUEg of 17.44 kg ha^{-1} mm^{-1}on average and was significantly higher than 7.40 kg ha^{-1} mm^{-1} of Batoka (BK) (Table 56). At Batoka, conservation farming (CF) exhibited significantly higher RWUEg of 10.16 kg ha^{-1} mm^{-1} (than the conventional farming (CONV) RWUEg by 119.4 %.At Chisamba, the value of RWUEg was 18.84 kg ha^{-1} mm^{-1} under the CF and was higher than CONV by 17.4 % during the 2015/2016 growing season.The findings indicated that response of maize crop for RWUEg was higher at BK than at CH by adopting CF and this could be due to inherent lower organic matter and other essential plant nutrients of soils at Batoka (Table 54).

Table 54: Influence of farming systems on grain rainfall water use efficiency (RWUEg) of maize varieties at two sites during the 2015/2016 growing season

		Maize varieties			
		Low N and Drought tolerant			
		RWUEg (kgha^{-1}mm^{-1})			
Site	**Farming system**	**M1 (control)**	**M2**	**M3**	**Mean**
Batoka	**CF**	12.11 ± 0.2	9.38 ± 0.5	8.98 ± 0.5	**10.16 ± 0.4**
	CONV	2.44 ± 0.2	5.89 ± 0.5	5.57 ± 0.5	**4.63 ± 0.3**
	Mean	**7.28 ± 0.2**	**7.64 ± 0.5**	**7.28 ± 0.4**	**7.40 ± 0.4**
Chisamba	**CF**	19.68 ± 0.6	17.89 ± 0.3	18.95 ± 0.3	**18.84 ± 0.4**
	CONV	16.94 ± 0.2	15.48 ± 0.6	15.72 ± 0.6	**16.05 ± 0.5**
	Mean	**18.31 ± 0.4**	**16.69 ± 0.5**	**17.34 ± 0.5**	**17.44 ± 0.5**
FPr	<0.001				
Lsd (0.05)	1.259				
CV (%)	10.8				

Note: CF= Conservation farming, CONV = Conventional farming, M1 = ZMS 606, M2 = GV 640, M3 = GV 635. Control = mostly purchased by smallholder farmers. ± denotes standard errors of means

During the 2016/2017 growing season, the RWUEg was significantly (P<0.001) observed differences between the farming systems, cowpea and maize genotypes at Chisamba. Highly significant interactions (P<0.001) were attained between farming systems x maize varieties and cowpeas x maize varieties (Table 55). The conservation farming system (CF) had RWUEg value of 21.24 kg ha^{-1}mm^{-1} and was significantly higher than for conventional farming system (CONV) by 137.2 % (Table 56).

Table 55: Mean squares for combine analysis of variance of maize varieties rainfall water use efficiency in maize grain (RWUEg) under the influence of farming systems and cowpea genotypes at Chisamba during the 2016/2017 growing season

Source of variation	d.f.	m.s.
Rep	2	1.799
Farming system	1	280.324***
Error	2	1.167
Maize variety	2	34.145***
Farming system xmaize variety	2	24.949***
Error	8	1.416
Variate: 2016/2017		**RWUEg (kg ha^{-1} mm^{-1})**
Source of variation	**d.f.**	**m.s.**
Rep	2	1.799
Cowpea genotype	4	280.324***
Error	8	1.167
Maize variety	2	34.145***
Cowpea genotype x maize variety	8	24.949***
Error	20	1.416

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05, RWUEg = rainfall water use efficiency of maize grain yield.

Table 56: Influence of farming systems on grain rainwater use efficiency (RWUEg) of maize varieties at Chisamba during the 2016/2017 growing season

	Maize varieties			
	Low N and Drought tolerant			
		RWUEg kg ha^{-1} mm^{-1}		
Farming system	**M1 (control)**	**M2**	**M3**	**Mean**
CF	20.06 ± 0.4	23.3 ± 1.2	20.34 ±0.6	**21.23 ± 0.7**
CONV	8.58 ± 0.4	9.35 ± 0.4	8.92 ±0.4	**8.95 ± 0.4**
Mean	**14.32 ± 0.4**	**16.33 ± 0.8**	**15.32 ± 0.5**	**15.09 ± 0.6**
FPr	0.027			
Lsd (0.05)	1.355			
CV (%)	16.3			

Note: CF= Conservation farming, CONV = Conventional farming, M1 = ZMS 606, M2 = GV 640, M3 = GV 635. Control = mostly purchased by smallholder farmers. ± denotes standard errors of means

The RWUEg significantly (P<0.001) varied among the cowpea genotypes used in rotation with maize crop during the two growing seasons. At Batoka all the cowpea genotypes significantly contributed to increased RWUEg of the maize crop more than treatments without cowpeas (NCP) which had RWUEg value of 4.63 kg $ha^{-1}mm^{-1}$. The highest contribution to RWUEg was from parent BBPRT with 10.60 kg $ha^{-1}mm^{-1}$ at Batoka during the 2015/2016 growing season (Table 57). At Chisamba, all cowpea genotypes were superior for RWUEg over NCP which had RWUEg value of 16.05 kg $ha^{-1}mm^{-1}$. Cowpea mutant BB 14-16-2-2 had the highest contribution to RWUEg of 19.66 kg $ha^{-1}mm^{-1}$ at Chisamba during the 2015/2016 growing season (Table 57). A similar trend was observed during the 2016/17 growing season where the RWUEg under the cowpea-genotypes was on average greater than 8.95 kg ha^{-1} mm^{-1} obtained from the NCP. Cowpea parent BBPRT produced the highest RWUEg of 22.39 kg ha^{-1} mm^{-1} followed by mutant BB 14-16-2-2 with a value of 21.99 kg ha^{-1} mm^{-1}. (Table 58).

Table 57: Influence of cowpea genotypes on grain rainwater use efficiency (RWUEg) of maize varieties at two sites during the 2015/2016 growing season

		Maize varieties			
		Low N and Drought tolerant			
		RWUEg kg ha^{-1} mm^{-1}			
Site	**Cowpea genotypes**	**M1 (control)**	**M2**	**M3**	**Mean**
Batoka	**LTPRT**	12.24 ± 0.5	8.85 ± 0.4	10.63 ± 0.2	**10.57 ± 0.4**
	BBPRT	11.72 ± 0.3	10.83 ± 0.2	9.25 ± 0.2	**10.60 ± 0.2**
	LT	12.58 ± 0.2	7.42 ± 0.7	7.11 ± 0.9	**9.04 ± 0.6**
	BB	11.88 ± 0.8	10.41 ± 0.4	8.93 ± 0.7	**10.41 ± 0.6**
	NCP	2.44 ± 0.2	5.89 ± 0.5	5.57 ± 0.2	**4.63 ± 0.3**
	Mean	**10.17 ± 0.4**	**8.68 ± 0.4**	**8.30 ± 0.4**	**9.05 ± 0.4**
Chisamba	**LTPRT**	19.33 ± 0.2	16.82 ± 0.5	19.96 ± 1.3	**18.70 ± 0.7**
	BBPRT	17.88 ± 1.0	18.40 ± 0.3	19.65 ± 0.4	**18.64 ± 0.6**
	LT	19.95 ± 0.5	17.16 ± 0.3	17.96 ± 0.4	**18.36 ± 0.4**
	BB	21.57 ± 1.6	19.20 ± 0.3	18.22 ± 0.3	**19. 66 ± 0.7**
	NCP	16.94 ± 0.2	15.48 ± 0.6	15.72 ± 0.6	**16.05 ± 0.5**
	Mean	**19.13 ± 0.7**	**17.41 ± 0.4**	**18.30 ± 0.6**	**18.28 ± 0.6**
FPr	<0.001				
Lsd (0.05)	1.241				
CV (%)	7.1				

Note: LTPRT = Lutembwe parent cowpea spreading type, BBPRT = Bubebe parent cowpea bush type, LT =LT 11-3-3-12 Lutembwe mutant spreading type, BB= BB 14-16-2-2 Bubebe mutant bush type, NCP = non cowpea, M1 = ZMS 606, M2 = GV 640, M3 = GV 635. Control = mostly purchased by smallholder farmers

Significant variations in the RWUEg among the maize varieties were observed and could be due to the genetic differences among the genotypes used in the study. Maize variety M1 (ZMS 606) that had RWUEg value of 10.17 kg $ha^{-1}mm^{-1}$ and 19.13 kg $ha^{-1}mm^{-1}$ at Batoka and Chisamba respectively was highest compared to M2 (GV 640) and M3 (GV 635) during the 2015/2016 growing season. M1 (ZMS 606) maize variety had however, the lowest RWUEg value of 2.44 kg $ha^{-1}mm^{-1}$ at Batoka under CONV (Table 57). The results showed that RWUEg for M1 (ZMS 606) maize variety could be maximized when planted under CF system. For 2016/2017 growing season, a significant difference was observed under the CF while there was no difference in RWUEg among the maize varieties under CONV at Chisamba (Table 58).

Significant interactions which were observed at $P<0.001$ between sites and farming systems, sites and cowpea genotypes, sites and maize genotypes and between cowpea and maize genotypes for RWUEg in the maize crop could be attributed to genetic differences among the maize and cowpea genotypes, edaphic and climatic conditions. The findings of the present study showed that the benefit of changing farming systems from conventional to conservation farming for RWUEg was more pronounced at Batoka (119.4 %) than at Chisamba (17.4 %) and dependent on different cowpea and maize genotypes interaction. The highest RWUEg value of 21.57 kg $ha^{-1}mm^{-1}$ was attained under cowpea mutant BB 14-16-2-2 combined with maize variety M1 (ZMS 606) at Chisamba and lowest value of 7.11 kg $ha^{-1}mm^{-1}$ under mutant LT in combination with M3 (GV 635) at Batoka. The highest RWUEg value of 12.58 kg $ha^{-1}mm^{-1}$ at Batoka was under the Maize variety M1 (ZMS 606) with cowpea mutant LT (Table 57).

Among the maize genotypes, M1 (ZMS 606) had the highest RWUEg value of 10.17 kg $ha^{-1}mm^{-1}$ when rotated with cowpea genotype LT 11-3-3-12 at Batoka and RWUEg value of 19.13 kg $ha^{-1}mm^{-1}$ when rotated with cowpea genotype BB 14-16-2-2 at Chisamba during the 2015/2016 growing season. However, during the 2016/2017 growing season, maize genotype M2 (GV 640) which had RWUEg value of 27.12 kg $ha^{-1}mm^{-1}$ and 26.31 kg $ha^{-1}mm^{-1}$ under rotation with cowpea genotypes BBPRT and BB 14-16-2-2 respectively outperformed other two genotypes (Table 58).

Table 58: Influence of cowpea genotypes on grain rainwater use efficiency (RWUEg) of maize varieties at Chisamba during the 2016/2017 growing season

		Maize varieties			
			Low N and Drought tolerant		
			RWUEg kg ha^{-1} mm^{-1}		
Site	Cowpea genotypes	M1 (control)	M2	M3	Mean
Chisamba	LTPRT	19.49 ± 0.5	22.44 ± 0.6	19.35 ± 0.3	**20.43 ± 0.5**
	BBPRT	21.04 ± 1.2	27.12 ±1.2	19.02 ± 0.3	**22.39 ± 0.9**
	LT	19.57 ± 0.4	17.35 ± 0.5	23.47± 0.7	**20.13 ± 0.5**
	BB	20.15 ± 0.6	26.31 ± 1.1	19.52 ±0.6	**21.99 ± 0.7**
	NCP	8.58 ± 0.4	9.35±0.4	8.92 ± 0.4	**8.95 ± 0.8**
	Mean	**17.77 ± 0.6**	**20.51 ± 07**	**18.06 ± 0.6**	**18.79 ± 0.6**
FPr	<0.001				
Lsd (0.05)	1.931				
CV (%)	6.3				

Note: LTPRT = Lutembwe parent cowpea spreading type, BBPRT = Bubebe parent cowpea bush type, LT = LT 11-3-3-12 Lutembwe mutant spreading type, BB= BB 14-16-2-2 Bubebe mutant bush type, NCP = non cowpea, M1 = ZMS 606, M2 = GV 640, M3 = GV 635. Control = mostly purchased by smallholder farmers. ± denotes standard errors.

The differences in the RWUEg were attributed to variations in maize grain yields and rainfall received between planting and harvesting date and due to improved soil fertility status at CH compared to BK. The amount of rainfall during the crop growth period from planting to maturity was generally lower at Chisamba (435 mm) than of Batoka (491.9 mm), which increased RWUEg for CH more than for BK. The results were supported by Huang et al. (2019). They indicated that the average WUE of wheat genotypes varied according to levels of soil moisture and fertility status of the soil and that the grain yields were significantly and linearly positively correlated with the WUE ($R^2 = 0.8231 - 0.937$).

The difference in RWUEg between the conservation farming system and the conventional farming system could be as a result of improved soil nutrients and soil water storage of maize crop in the CF as compared to low nutrients and water storage in the CONV system. Since the crop was thriving in the CF treatment, this indicated that most of the rain water received was effectively utilized for grain yield as compared to CONV. Cowpea residues left on the surface in the CF plot contributed to improved soil moisture storage in the soil profile and could have increased water use efficiency of maize grain production. A review by Hatfield et al. (2001) showed that soil management practices such as residue, tillage and nutrient management could increase WUE by 25 to 40%. These practices facilitate more water storage in the soil profile, improve roots ability to extract water effectively, reduce losses of nutrients by leaching, to add nitrogen to the soil which has a positive impact on WUE. In contrast the lower yields in conventional farming were due to leaching of plant nutrients and loss of water through evaporation and drainage (Guzha,2004)., (Hartkamp et al. 2004). The high response of maize crop (122.2 %) for RWUEg at BK compared to 18.8 % at CH by changing from CONV to CF could be due to inherent lower organic matter and other essential plant nutrients of soils at BK.

The variations in RWUEg among the cowpea genotypes could be attributed to differences in Biological Nitrogen Fixation (BNF). Cowpea genotype BB 14-16-2-2 that had more BNF had greater potential to increase RWUEg in maize grain than cowpea genotype with lower BNF (Simunji et al., 2019). Similar findings were observed by Kopila. (2017) that soybean yield increased by 14 % and WUE by 13 % with cover crop treatment compared to non-cover crop treatment. Therefore, the present study suggests that RWUEg in the maize crop cannot only be increased by soil moisture but also with improved levels of nitrogen content in the soil.

Significant variations in the RWUEg among the maize varieties could be due to the genetic differences among the genotypes used in the study. The improved water use efficiency exhibited by M1 (ZMS 606) and M2 (GV 640) under CF mighty reduce water requirements for a crop by about 30% under rain fed (Bot and Benites, 2005). The study results suggest that maize genotypes M1 and M2 could be considered for promotion at both sites for optimized rainfall maize grain water use efficiency mainly in the rotation with cowpea genotype BB 14-16-2-2 and LT 11-3-3-12.

5.4.3.2 Maize dry biomass rainfall water use efficiency ($RWUE_b$)

The rainfall water use efficiency in the maize dry biomass yield ($RWUE_b$) was computed as a ratio of total maize dry biomass yield (kg ha^{-1}) to rainfall (mm) received between planting and maturity. $RWUE_b$ was significantly ($P<0.001$) observed differences between the experimental sites, farming systems, among cowpea and maize genotypes during the 2015/16 growing season at both Chisamba (CH) and Batoka (BK) (Tables 59 and 60).

Table 59: Mean squares for combine analysis of variance of maize varieties dry biomass rainfall water use efficiency under the influence of farming systems at two sites during the 2015/2016 growing season

Variate: Maize 2015/2016		RWUEb (kg ha^{-1} mm^{-1})
Source of variation	**d.f.**	**m.s.**
Site	1	3.523
Rep/Location	4	1408.956***
Farming system	1	301.426***
Site x Farming system	1	4.269ns
Error	4	0.857
Maize variety	2	13.49***
Site x Maize variety	2	5.47**
Farming system x maize variety	2	3.297ns
Site x Farming system x.maize variety	2	3.463**
Error	16	0.962

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05, RWUEg = rainfall water use efficiency of maize grain yield, RWUEb = Rainfall water use efficiency of maize dry biomass yield.

Table 60: Mean squares for combine analysis of variance of maize varieties rainfall water use efficiency in maize dry biomass (RWUEb) under the influence of cowpea genotypes at two sites during the 2015/2016 growing season

Variate: Maize 2015/2016		RWUEb (kg ha^{-1} mm^{-1})
Source of variation	**d.f.**	**m.s.**
Site	1	1408.9556***
Rep/Location	4	2.0241
Cowpea genotype	4	118.2589***
Sitex cowpea genotype	4	21.0219***
Error	16	0.7415
Maize variety	2	13.4897***
Site x maize variety	2	5.47***
Cowpea genotype x maize variety	8	15.975***
Sitex cowpea genotypex maize variety	8	14.2389***
Error	40	0.8323

During the 2016/2017 growing season, the $RWUE_b$ was significantly (P<0.001) observed differences between the farming systems, among cowpea and maize genotypes at Chisamba (CH). There were highly significant interactions (P<0.001 between farming systems x maize varieties and cowpea genotypes x maize varieties (Table 61).

Table 61: Mean squares for combine analysis of variance of maize varieties rainfall water use efficiency in dry maize biomass (RWUEb) under the influence of farming systems and cowpea genotypes at C during the 2016/2017 growing season

Variate: Maize 2016/2017		RWUEb (kg ha^{-1} mm^{-1})
Source of variation	**d.f.**	**m.s.**
Rep	2	0.951
Farming system	1	261.582**
Error	2	0.552
Maize variety	2	3.722**
Farming system xmaize variety	2	7.148***
Error	8	0.386
Variate: 2016/2017		**RWUEb (kg ha^{-1} mm^{-1})**
Source of variation	**d.f.**	**m.s.**
Rep	2	0.9509
Cowpea genotype	4	73.7687***
Error	8	3.0596
Maize variety	2	3.7219**
Cowpea genotype x maize variet	8	8.8488***
Error	20	0.4139

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05, RWUEb = Rainfall water use efficiency of maize dry biomass yield

Chisamba (CH) site had $RWUE_b$ of 17.69 kg ha^{-1}mm^{-1}and was significantly higher than 8.94 kg ha^{-1} mm^{-1} obtained from Batoka (BK) by 97.9 %). The $RWUE_b$ value of 10.72 kg ha^{-1}mm^{-1} observed in the conservation farming (CF) was significantly higher (P<0.001) than the conventional farming (CONV) of 7.15 kg ha^{-1}mm^{-1} at Batoka during the 2015/2016 growing season. At Chisamba $RWUE_b$ value of 20.24 kg ha^{-1}mm^{-1} under CF was significantly higher than in the CONV by 33.8 % (Table 62). Similar results were obtained at CH in the 2016/2017 growing season where CF that had $RWUE_b$ of 13.27 kg ha^{-1} mm^{-1} was significantly higher than CONV by 83.3 % (Table 63).

Table 62: Influence of farming systems on dry biomass rainwater use efficiency (RWUEb) of maize varieties at two sites during the 2015/2016 growing season

		Maize varieties			
		Low N and Drought tolerant			
		WUEb (kgha^{-1}mm^{-1})			
Site	**Farming system**	**M1 (control)**	**M2**	**M3**	**Mean**
Batoka	**CF**	10.19 ± 0.5	10.52 ± 0.7	11.45 ± 1.0	**10.72 ± 0.7**
	CONV	6.47 ± 0.3	8.38 ± 0.4	6.61 ± 0.5	**7.15 ± 0.4**
Mean		**8.33 ± 0.4**	**9.45 ± 0.6**	**9.03 ± 0.8**	**8.94 ± 0.6**
Chisamba	**CF**	20.28 ± 0.8	19.29 ± 0.3	21.16 ± 1.0	**20.24 ± 0.7**
	CONV	14.37 ± 0.3	14.48 ± 0.4	16.53 ± 1.1	**15.13 ± 0.6**
Mean		**17.33 ± 0.6**	**16.89 ± 0.3**	**18.85 ± 1.1**	**17.69 ± 0.7**
FPr	0.051				
Lsd (0.05)	0.954				
CV (%)	20.1				

Note: CF= Conservation farming, CONV = Conventional farming, M1 = ZMS 606, M2 = GV 640, M3 = GV 635. Control = mostly purchased by smallholder farmers ± denotes standard errors of means

Table 63: Influence of farming systems on dry biomass rainwater use efficiency (RWUEb) of maize varieties at Chisamba during the 2016/2017 growing season

`	Maize varieties			
	Low N and Drought tolerant			
	RWUEb kg ha^{-1} mm^{-1}			
Farming system	**M1 (control)**	**M2**	**M3**	**Mean**
CF	13.99 ± 0.6	12.65 ± 0.7	13.18 ± 0.4	**13.27 ± 0.6**
CONV	6.11 ± 0.4	6.89 ± 0.4	8.73 ± 0.4	**7.24 ± 0.4**
Mean	**10.05 ± 0.5**	**9.77 ± 0.6**	**10.96 ± 0.4**	**10.26 ± 0.5**
FPr	<0.001			
Lsd (0.05)	0.995			
CV (%)	17.4			

Note: CF= Conservation farming, CONV = Conventional farming, M1 = ZMS 606, M2 = GV 640, M3 = GV 635. Control = mostly purchased by smallholder farmers. ± denotes standard errors of means.

The $RWUE_b$ of maize crop dry biomass significantly ($P<0.001$) varied among the cowpea genotypes used in rotation with maize crop during the two growing seasons. All the cowpea genotypes significantly ($P<0.001$) contributed to increased $RWUE_b$ in the maize crop greater than 7.15 kg ha^{-1}mm^{-1} attained from plots without cowpeas at Batoka. At Chisamba, the cowpea genotypes significantly ($P<0.001$) increased $RWUE_b$ in the maize crop greater than 15.13 kg ha^{-1}mm^{-1} attained from plots without cowpeas during the 2015/2016 growing season. The $RWUE_b$ was highest under parent cowpea genotype BBPRT that produced 13.64 kg ha^{-1} mm^{-1} at Batoka while at Chisamba the highest $RWUE_b$ of 21.96 % was obtained from the influence of parent cowpea LTPRT during the 2015/2016 growing season (Table 62). A similar trend was observed during 2016/17 growing season where cowpea genotypes significantly outperformed NCP which had $RWUE_b$ value of 7.15 kg ha^{-1} mm^{-1} Cowpea mutant LT 11-3-3-12 significantly ($P<0.001$) contributed to an improved $RWUE_b$ value of 14.44 kg ha^{-1}mm^{-1} (Table 63).

Significant variations in the $RWUE_b$ among the maize genotypes were observed and could be due to the genetic differences among the genotypes used in the study. Maize genotype M3 (GV 635) that had $RWUE_b$ value of 20.23 kg ha^{-1}mm^{-1} was highest compared to M2 (GV 640) and M1 (ZMS 606) at Chisamba while at Batoka there was no significant difference observed among the maize varieties for $RWUE_b$ during 2015/2016 growing season (Table 62). Maize genotype M1 (ZMS 606)) that had an average $RWUE_b$ value of 12.41 kg ha^{-1}mm^{-1}was higher than M2 (GV 640) by 8.0 % during the 2016/2017 growing season (Table 63).

Significant interactions were observed at $P<0.001$ between sites and farming systems, sites and cowpea genotypes, sites and maize genotypes, farming systems and maize genotypes, and between cowpea and maize genotypes for $RWUE_b$ in the maize crop. The present study's findings showed that dry biomass water use efficiency of the maize crop was more effective at Batoka which had $RWUE_b$ increased by 49.9 % than at Chisamba which had increased 3by 3.8 % for adopting conservation farming system. The interaction between cowpea and maize genotypes showed that M3 (GV 635) with an average of 16.6 kg $ha^{-1}mm^{-1}$ was most efficient in rainfall water use for maize dry biomass yield under crop rotation with BBPRT at Batoka and was 24.57 kg $ha^{-1}mm^{-1}$ under rotation with parent LTPRT at Chisamba during the 2015/2016 growing season (Table 64). Maize variety M1 with $RWUE_b$ of 16.96 kg $ha^{-1}mm^{-1}$ was significantly superior over other varieties under rotation with LT 12-3-3-11 during the 2016/2017 growing season (Table 65).

Table 64: Influence of cowpea genotypes on dry biomass water use efficiency (RWUEb) of maize varieties at two sites during the 2015/2016 growing season

		Maize varieties			
		Low N and Drought tolerant			
		RWUEb kg ha^{-1} mm^{-1}			
Site	**Cowpea genotypes**	**M1 (control)**	**M2**	**M3**	**Mean**
Batoka	**LTPRT**	10.08 ± 0.2	11.46 ± 0.5	10.86 ± 0.2	**10.80 ± 0.3**
	BBPRT	12.10 ± 0.7	12.23 ± 0.3	16.60 ± 0.3	**13.64 ± 0.4**
	LT	10.88 ± 0.5	6.46 ± 0.4	7.60 ± 0.8	**8.31 ± 0.6**
	BB	7.71 ± 0.3	11.94 ± 0.4	10.74 ± 0.6	**10.13 ± 0.4**
	NCP	6.47 ± 0.8	8.38 ± 0.4	6.61 ± 0.5	**7.15 ± 0.6**
	Mean	**9.45 ± 0.5**	**10.09 ± 0.4**	**10.48 ± 0.5**	**10.01 ± 0.5**
Chisamba	**LTPRT**	23.40 ± 0.5	17.92 ± 0.3	24.57 ± 0.4	**21.96 ± 0.4**
	BBPRT	21.50 ± 0.5	18.71 ± 0.4	23.05 ± 0.5	**21.09 ± 0.5**
	LT	18.96 ± 0.9	20.50 ± 0.5	20.61 ± 0.5	**20.02 ± 0.6**
	BB	17.27 ± 0.9	20.04 ± 0.2	16.41 ± 0. 5	**17.91 ± 0.6**
	NCP	14.37 ± 0.3	14.48 ± 0.4	16.53 ± 1.0	**15.13 ± 0.6**
	Mean	**19.1 ± 0.6**	**18.33 ± 0.4**	**20.23 ± 0.6**	**19.22 ± 0.5**
	FPr	<0.001			
	Lsd (0.05)	0.9993			
	CV (%)	3.3			

Note: LTPRT = Lutembwe parent cowpea spreading type, BBPRT = Bubebe parent cowpea bush type, LT = LT 11-3-3-12 Lutembwe mutant spreading type, BB= BB 14-16-2-2 Bubebe mutant bush type, NCP = non cowpea, M1 = ZMS 606, M2 = GV 640, M3 = GV 635. Control = mostly purchased by smallholder farmers. ± denotes standard errors.

Table 65: Influence of cowpea genotypes on dry biomass water use efficiency (RWUEb) of maize varieties at Chisamba during the 2016/2017 growing season

		Maize varieties			
			Low N and Drought tolerant		
			RWUEb kg ha^{-1} mm^{-1}		
Site	Cowpea genotypes	M1 (control)	M2	M3	Mean
Chisamba	LTPRT	13.41 ±0.9	15.78 ±1.2	12.84 ± 0.9	**14.01 ± 1.0**
	BBPRT	12.86 ±0.3	12.10 ± 0.3	11.96 ± 0.1	**12.3 1 ± 0.2**
	LT	16.96 ± 0.4	12.25 ± 0.5	14.10 ± 0.4	**14.44 ± 0.4**
	BB	12.71 ± 0.6	10.46 ±0.7	13.82 ± 0.7	**12.33 ± 0.7**
	NCP	6.114 ± 0.4	6.89 ± 0.4	8.73 ± 0.4	**7.24 ± 0.4**
	Mean	**12.41 ± 0.5**	**11.49 ± 0.6**	**12.3 ± 0.5**	**12.07 ± 0.6**
FPr	<0.001				
Lsd (0.05)	2.0153				
CV (%)	5.3				

Note: LTPRT = Lutembwe parent spreading type, BBPRT = Bubebe parent cowpea bush type, LT = Lutembwe mutant spreading type, BB 14-16-2-2 = Bubebe mutant bush type, NCP = non cowpea, M1 (ZMS 606) = Control mostly purchased by smallholder farmers M2 (GV 640) and M3 = (GV 635) = selected low N and drought tolerant varieties ± denotes standard errors.

The differences in the $RWUE_b$ between the two sites was attributed to variations in maize dry biomass yields and rainfall received between planting date and harvesting (Kwasi et al.,2011). Other factors that led to variations could include the soil's ability to store water, the ability of the maize crop to access the soil moisture and ability of the crop to convert water and nutrients into biomass and grain. The average maize dry biomass yield at CH was significantly (P<0.001) higher than BK due to improved soil fertility status at CH with clay loam soils as compared to lower soil conditions of BK with loamy sand soils. Soils at Chisamba stored more water that could have supported the high water uptake for improved dry biomass and grain. The amount of rainfall during the crop growth period from planting to maturity was generally lower at Chisamba (435 mm) than of Batoka (491.9 mm) and this could have contributed to increased $RWUE_b$ for CH.

The difference in $RWUE_b$ between the conservation farming and conventional farming systems could be attributed to improved soil nutrients and soil water storage of maize crop in the CF compared to low nutrients and water storage in the CONV system. Plant Available water as defined by Ball. (2001) as the amount of water that a plant can use between Field Capacity (FC) and Permanent Wilting Point (PWP) was recorded higher in the CF than CONV in the present study which could have improved $RWUE_b$ in the CF system. At the vegetative stage maize crop had more vigorous growth in the CF plot than in the CONV and hence most of the rainfall water received was taken up by the crop more effectively in the CF compared to CONV which had a lower vigorous crop (Cantero-Martínez et al., 2007). Leaching of plant nutrients and soil moisture loss due to soil surface evaporation could have contributed to lower dry biomass yields and $RWUE_b$ in the conventional farming system. A review by Acharya, (2018) indicated that WUE is also positively correlated with soil fertility status. Fertile soil resulting from conservation farming practices will have higher WUE than less fertile (Deng et al., 2006). The variations among the cowpea genotypes for $RWUE_b$ of the study indicate that cowpea genotypes LTPRT and LT 11-3-3-12 were superior over the BBPRT and BB 14-16-2-2 for $RWUE_b$ mainly due to their ability to produce high biomass yield that improved soil moisture conservation for a more extend period (Cantero-Martínez, 2007).

Therefore, the study revealed that maize genotype M3 (GV 635) was most efficient in using rainfall water for dry biomass production. Kwasi et al. (2011) also found similar variations in maize dry biomass WUE and observed the highest value of 32.0 kg ha^{-1} mm^{-1} from maize cultivar Obatampa at 56 days after emergency.

The high $RWUE_b$ of maize varieties for maize dry biomass yield under rotation with LTPRT and BBPRT as compared to noncowpea treatments could be attributed to increased nutrient levels due to high biological nitrogen fixation and increased organic matter content from cowpea genotypes. The combination of maize varieties and cowpea genotypes could therefore be recommended for farmers to produce maize crop for silage or hay as supplementary feed during the dry season (Turmel et al., 2014).

5.4.4. ^{13}C Isotope discrimination as measurement for intrinsic water use efficiency (WUEi) in Maize and cowpea crops

5.4.4.1 ^{13}C Isotope discrimination ($d^{13}C$) in Maize Grain

There was a significant (P<0.05) variation in the value of $d^{13}C$ of maize grain between the two experimental sites (Table 67). Batoka (BK) site had $d^{13}C$ value of -12.27 ‰ which was significantly lower than the isotope $d^{13}C$ value of -11.67 ‰ at the Chisamba (CH) site (Table 66). The farming systems were significantly different (P<0.01) for $d^{13}C$ discrimination in the maize grain at Chisamba. The $d^{13}C$ value of -11.44 ‰ was higher in the conventional system than -11.86 ‰ in the conservation farming system (CF) at Chisamba. The $d^{13}C$ value of -12.28 ‰ under conservation farming system (CF) was however, not significant (P>0.05) with a $d^{13}C$ value of -12.26 ‰ under conventional system at Batoka. A significant interaction between the sites and farming systems was observed (P<0.01). Chisamba site had the higher $d^{13}C$ value of -11.44 under the conventional farming system while the Batoka site had lowest value of -12.28 ‰ under the conservation farming system. The difference between CF and CONV for $d^{13}C$ at Chisamba was much higher than for Batoka. The maize variety M2 (GV 640) with an average $d^{13}C$ of -12.59 ‰ at Chisamba and -12.39 ‰ at Batoka had the lowest $d^{13}C$. It was superior over M1 (ZMS 606) and M3 (GV 635) for intrinsic water use efficiency in grain under both CF and CONV (Table 66).

Table 66: Influence of farming systems and maize varieties on $d^{13}C$ isotope discrimination in the grain at two sites during 2015/2016 growing season

		Maize varieties			
			Low N and Drought tolerant		
		$d^{13}C$ value in Maize grain (‰)			
Site	**Farming system**	**M1 (control)**	**M2**	**M3**	**Mean**
Chisamba	**CF**	-11.81 ± 0.02	-12.02 ± 0.05	-11.77 ± 0.04	**-11.86 ± 0. 05**
	CONV	-11.34 ± 0.03	-11.59 ± 0.05	-11.41 ± 0.04	**-11.44 ± 0.04**
	Mean	**-11.58 ± 0.03**	**-11.59 ± 0.05**	**-11.67 ± 0.04**	**-11.67 ± 0.04**
Batoka	**CF**	-12.17 ±0.04	-12.35 ± 0.06	-12.32 ± 0.09	**-12.28 ± 0.06**
	CONV	-12.04 ± 0.04	-12.43 ± 0.08	-12.31 ± 0.05	**-12.26 ± 0.06**
	Mean	**-12.11 ± 0.04**	**-12.39 ± 0.07**	**-12.32 ± 0.07**	**-12.27 ± 0.06**
Fpr	0.1722				
Lsd (0.05)	0.1201				
CV (%)	1.6				

Note: CF = Conservation farming system, CONV = Conventional farming system.M1 (ZMS 606) = Control mostly purchased by smallholder farmers M2 (GV 640) and M3(GV 635) = selected low N and drought tolerant varieties. ± denotes standard errors of means.

Cowpea mutant LT 11-3-3-12 significantly (P<0.01) contributed to low value of $d^{13}C$ (-12.54 ‰) in the maize grain compared to other cowpea genotypes and non- cowpea treatment at Batoka. Cowpea parent LTPRT and mutant BB 14-16-2-2 had lowest $d^{13}C$ value of - 11.91 ‰ and -11.89 ‰ respectively compared to non-cowpea treatment (NCP) at Chisamba. On average mutant cowpea LT 11-3-3-12 treatment had lowest $d^{13}C$ value (-12.16 ‰) in the maize grain than the rest of the genotypes, implying that it contributed more to the improved WUEi. The influence of cowpea genotypes for $d^{13}C$ value among the maize varieties was significant. M2 (GV 640) significantly (P<0.001) discriminated lowest $d^{13}C$ value of -12.37 ‰ in the maize grain compared to M1 (ZMS 606) which had -12.14 at Batoka. At Chisamba, M2 (GV 640) significantly (P<0.001) discriminated lowest $d^{13}C$ value of -11.93 ‰ in the maize grain compared to M1 (ZMS 606) and M3 (GV 635) (Table 68).

Table 67: Mean square for combine analysis of variance of farming systems, cowpea genotypes, and maize varieties for $d^{13}C$ isotope discrimination in maize grain at two sites

Variate: $d^{13}C$_ Maize		**$d^{13}C$ Grain (‰)**
Source of variation	**d.f.**	**m.s.**
Site	1	5.50782***
Rep/Location	4	0.02396
Farming system	1	0.69376***
Site x farming system	1	0.57292***
Error	4	0.01702
Maize varieties	2	0.38276***
Site x maize varieties	2	0.09438***
Farming system x maize variety	2	0.02205ns
Site x farming system x maize variety	2	0.01306ns
Error	16	0.01263
Variate: $d^{13}C$_ Maize		**$d^{13}C$ Grain (‰)**
Source of variation	**d.f.**	**m.s.**
Site	1	5.50782***
Rep/Location	4	0.02396
Cowpea genotype	4	0.22795***
Site x Cowpea genotype	4	0.31733***
Error	16	0.02287
Maize variety	2	0.38276***
Site x maize variety	2	0.09438***
Cowpea genotype x maize variety	8	0.03472**
Site x cowpea genotype x maize variety	8	0.04935***
Error	40	0.01218

Note: ***Significant at $P \leq 0.01$, **Significant at $P \leq 0.05$, ns Not significant at $P \leq 0.05$. $d^{13}C$ Grain = ^{13}C discrimination in the maize grain, $d^{13}C$ stv = ^{13}C discrimination in the maize stover.

Table 68: Influence of cowpea genotypes and maize varieties on d^{13}C isotope discrimination in the grain at two sites during 2015/2016 growing season

		Maize varieties			
			Low N and Drought tolerant		
			d^{13}C value in Maize grain (‰)		
Site	**Cowpea genotypes**	**M1 (control)**	**M2**	**M3**	**Mean**
Batoka	**LTPRT**	-12.08 ± 0.04	-12.34 ± 0.04	-12.14 ± 0.04	**-12.19**
	BBPRT	-12.07± 0.06	-12.42 ± 0.11	-12.20 ± 0.06	**-12.23**
	LT	-12.30 ± 0.11	-12.54 ± 0.10	-12.79 ± 0.09	**-12.54**
	BB	-12.21 ± 0.09	-12.09 ± 0.05	-12.17 ± 0.10	**-12.16**
	NCP	-12.04 ± 0.04	-12.43 ± 0.08	-12.31 ± 0.05	**-12.26**
	Mean	**-12.14**	**-12.37**	**-12.32**	**-12.27**
Chisamba	**LTPRT**	-11.76 ± 0.05	-12.06 ±0.04	-11.92 ± 0.11	**-11.91**
	BBPRT	-11.82 ± 0.08	-12.04 ± 0.12	-11.73 ± 0.09	**-11.86**
	LT	-11.83 ± 0.03	-11.85 ± 0.09	-11.70 ± 0.05	**-11.79**
	BB	-11.82 ± 0.04	-12.13 ± 0.08	-11.72 ± 0.03	**-11.89**
	NCP	-11.34 ± 0.03	-11.59 ± 0.05	-11.41 ± 0.04	**-11.45**
	Mean	**-11.71**	**-11.93**	**-11.70**	**-11.78**
	FPr	0.001			
	Lsd	0.1494			
	CV (%)	0.9			

Note: LTPRT = Lutembwe parent spreading type, BBPRT=Bubebe parent cowpea bush type LT = Lutembwe mutant spreading type, BB = Bubebe mutant bush type, NCP = non cowpea, M1 (ZMS 606) = Control purchased mainly by smallholder farmers M2 (GV 640) and M3 (GV 635) = selected low N and drought tolerant varieties. ± denotes standard errors of means.

Significant interactions ($P<0.05$) between sites and cowpea genotypes; sites and maize varieties; site, cowpea genotype and maize varieties for the d^{13}C in the maize grain production were observed (Table 66). The interaction effect showed that the lowest d^{13}C values of -12.79 ‰ and -12.54 ‰ in the maize grain were obtained from combination of cowpea mutant LT 11-3-3-12 and maize varieties M3 (GV 635) and M2 (GV 640) respectively at Batoka. Whereas at Chisamba, the lowest d^{13}C value of -12.13 ‰ in the maize grain was attained from the combination of cowpea mutant BB and maize variety M2 (GV 640).

A significant ($P<0.001$) variation in the values of ^{13}C discrimination (d^{13}C) in the maize grain between the two experimental sites could be explained by differences in edaphic and environmental conditions under which the maize crop was produced. Batoka (BK) site with *Chromic haplic Lixisols* loamy sand soil and had lower d^{13}C value of -12.27 ‰ than at Chisamba (-11.78 ‰) site with *niti-luvic Phaeozems* clay loam soils could therefore be more water-stressed than the maize crop at Chisamba. Total rainfall received at Chisamba during the test season was 726.6 mm while at Batoka the total rainfall was 620.5 mm.

According to Yu et al. (2004) intrinsic water use efficiency (WUEi) is negatively correlated with $d^{13}C$ discrimination and WUE increased with nitrogen supply and with increased water stress in maize crop. Based on the negative relationship between $d^{13}C$ and WUEi shown by Yu et al. (2004) and Dercon et al. (2006), the results suggested that the BK site which measured lower value of $d^{13}C$ had higher WUEi than CH site at maize grain filling growth stage. Therefore, under the present study the maize crop at the Batoka site could have been more water- stressed than the crop at Chisamba. Yu et al. (2004) indicated that water stress improved WUEi implying that higher values of $d^{13}C$ in maize grain at the Chisamba site had plants growing under reduced water stress conditions. The study's findings were in agreement with Tolk et al. (1999) and observed that mulch significantly increased grain yield and grain WUE of the maize crop in the clay loam soil while the dry biomass WUE of the crop was high in sandy loam soil.

The farming systems were significantly different ($P<0.001$) for $d^{13}C$ discrimination among the maize varieties in the grain. Generally, the lower value of carbon discrimination in the CF could have been attributed to the high availability of nitrogen from biological nitrogen fixation by cowpea genotypes decomposition and mineralization. Cowpeas increase nitrogen levels in the soil which enhances improved WUE in the conservation farming system. The results agreed with Zhong and Shangguan, (2014) and reported that nitrogen plays an essential role in improving agricultural water use efficiency. On average mutant cowpea genotype LT 11-3-3-12 that significantly discriminated least $d^{13}C$ in the maize grain than the rest of the genotypes could have contributed more to the improved WUE under the CF system. Therefore, WUE could be considered to vary according to different farming systems applied on the maize crop production and cowpea genotypes used in the rotation (Heisey and Edmeades, 1999).

Among the maize varieties, M2(GV 640) discriminated lower $d^{13}C$ value than M1(ZMS 606) and M3(GV 635). The results showed that GV 640 could have used water significantly ($P<0.001$) more efficiently than ZMS 606 and GV 635 during dry spells and might be recommended for low rainfall areas. Varieties that produce more grain than water use should be grown under limited water areas to increase the water productivity per unit area. The findings of the present study agreed with Chand and

Bham. (2000) and reported that Varsha sorghum variety was distinctly superior in WUE in terms of grain production and dry matter production over CSV 13 and CSV 15. Hakeem et al. (2018) further reported that maturity and physiological traits among crop cultivars have significant effect on WUE. Pennington et al. (1999) reported that substantial genetic variation in $d^{13}C$ of honey mesquite (*Prosopis glandulosa* Torr.) were recorded to determine that a drought- escape mechanism was most important for growth and survival under drought conditions.

Significant interaction ($P<0.05$) between sites and cowpea genotypes on the $d^{13}C$ in the maize grain production of the present study indicated that WUE in the maize grain yield depended on the environmental factors maize crop is produced and cowpea genotype used in the rotation. The study had therefore showed that, cowpea mutant LT made a significant ($P<0.001$) contribution to the improvement of water use efficiency of maize in the grain development at both sites. Based on these findings, maize variety M2 (GV 640) was most consistent in ^{13}C discrimination at both sites (BK and CH) and was most efficient in water use among other maize varieties under test. The results were consistent with the findings of Huang et al. (2006) who stated that WUE of maize varieties is a function of multiple factors, including physiological characteristics of maize, genotype, soil characteristics such as soil water holding capacity, meteorological conditions and agronomic practices. Tolk et al. (1999) also reported similar findings on maize crop that improved grain WUE and dry matter WUE are based on genotypes and soil types. Therefore, to improve WUE, integrative measures should aim to optimize cultivar selection and agronomic practices.

5.4.4.2 ^{13}C Isotope discrimination ($d^{13}C$) in Maize stover

The discrimination of ^{13}C ($d^{13}C$) in the maize stover significantly ($P<0.05$) varied between the two experimental sites (Chisamba and Batoka) of different soil types, soil fertility status and rainfall pattern, farming systems, maize verities and cowpea genotypes. (Table 69 and 70). The Batoka site with loamy sand soil had a more reduction effect on the values of $d^{13}C$ for maize stover than the values obtained from Chisamba with clay loam soil. The value of $d^{13}C$ in the maize stover at Batoka was -12.62 ‰ and was significantly lower than -12.42 ‰ measured at Chisamba. The difference between the two farming systems for ^{13}C discrimination in the maize stover was highly significant at $P<0.001$). On average, the conventional farming system had a lower d^{13}C value of -12.61‰ in the maize stover than the conservation farming system with -12.42 ‰. At Batoka, CONV had a significantly lower d^{13}C value of -12.79 ‰ in the maize stover than under CF. However, farming systems did not show a significant difference ($P > 0.05$) for the d^{13}C in the maize stover at Chisamba (Table 71).

Table 69: Mean square for combine analysis of variance of farming systems and maize varieties for d13C isotope discrimination in maize stover at two sites

Variate: d^{13}C_ Maize		d^{13}C stv (‰)
Source of variation	**d.f.**	**m.s.**
Site	1	0.24586**
Rep/Location	4	0.01041
Farming system	1	0.51537***
Site x farming system	1	0.37556***
Error	4	0.00386
Maize varieties	2	0.15263***
Site x maize varieties	2	0.04117**
Farming system x maize variety	2	0.01824ns
Site x farming system x maize variety	2	0.02406ns
Error	16	0.00742

Table 70: Mean square for combine analysis of variance of cowpea genotypes and maize varieties for d^{13}C isotope discrimination in maize stover at two sites

Source of variation	d.f.	m.s.
Site	1	0.24586**
Rep/Location	4	0.01041
Cowpea genotype	4	0.18499***
Site x Cowpea genotype	4	0.17066***
Error	16	0.01309
Maize variety	2	0.15263***
Site x maize variety	2	0.04117**
Cowpea genotype x maize variety	8	0.04181***
Site x cowpea genotype x maize variety	8	0.06356***
Error	40	0.01044

Table 71: Influence of site, farming systems and maize varieties on $d^{13}C$ values in the maize stover

		Maize varieties			
			Low N and Drought tolerant		
		Maize stover 13 C discrimination (‰)			
Site	**Farming system**	**M1 (control)**	**M2**	**M3**	**Mean**
Batoka	**CF**	-12.47 ± 0.05	-12.43 ± 0.03	-12.43 ± 0.06	**-12.44 ± 0.05**
	CONV	-12.89 ± 0.06	-12.72 ± 0.05	-12.77 ± 0.05	**-12.79 ± 0.05**
	Mean	**-12.68 ± 0.06**	**-12.58 ± 0.04**	**-12.60 ± 0.06**	**-12.62 ± 0.05**
Chisamba	**CF**	-12.54 ± 0.04	-12.36 ± 0.05	-12.31 ± 0.06	**.-12.40 ± 0.05**
	CONV	-12.50 ± 0.05	-12.32 ± 0.03	-12.47 ± 0.04	**-12.43 ± 0.04**
	Mean	**-12.52 ± 0.05**	**-12.34 ± 0.04**	**-12.39 ± 0.05**	**-12.42 ± 0.05**
FPr	0.066				
Lsd (0.05)	0.1201				
CV (%)	1.6				

Note: CF = Conservation farming system, CONV = Conventional farming system.M1 (ZMS 606) = Control mostly purchased by smallholder farmers M2 (GV 640) and M3(GV 635) = selected low N and drought tolerant varieties. ± denotes standard errors of means.

Cowpea genotypes caused significant (P<0.001) variations in the $d^{13}C$ of maize stover. At Batoka, the lowest $d^{13}C$ value of -12.79 ‰ in the maize stover was measured under the non-cowpea treatment (NCP) while at Chisamba the lowest $d^{13}C$ value of -12.46 ‰ was attained under mutant cowpea BB 14-16-2-2. Genetic differences of the maize varieties also influenced the variation in the $d^{13}C$ values in the maize stover. At the Batoka site, there was no significant difference (P> 0.05) observed among the maize varieties for $d^{13}C$ in the maize stover. However, at Chisamba, maize variety ZMS 606 (M1) produced significantly lowest $d^{13}C$ value of -12.54 ‰ compared to GV 640 (M2) and M3 (GV 635) had similar value (Table 70). The study indicated that ZMS 606, with the lowest value of $d^{13}C$ was more drought tolerant than GV 640 and GV 635 and could have high WUEi in the stover (Table 72).

An interaction between the sites, cowpea genotypes and maize varieties was significantly observed at P<0.001 and indicated that the influence of cowpeas and maize varieties on the $d^{13}C$ dependent on the site. The effect of non-cowpea treatment for $d^{13}C$ was more significant at Batoka where it showed a reducing effect for $d^{13}C$ than Chisamba while cowpea genotype LTPRT had an increasing effect at Batoka. Cowpea mutant LT 11-3-3-12 had an increasing impact on maize stover $d^{13}C$ at the Chisamba site but BBPRT and mutant BB 14-16-2-2 were stable across the sites. The $d^{13}C$ values in the maize stover for M2 (GV640 and M3 (GV 635) were higher at Chisamba than Batoka indicating that the two varieties had less water stress during the vegetative growth stage than M1 (ZMS 606) at Chisamba (Table 72).

Table 72: Influence of site, cowpea genotype and maize varieties on d^{13}C values in the maize stover

		Maize varieties			
			Low N and Drought tolerant		
		Maize stover 13 C discrimination (‰)			
Site	Cowpea genotypes	M1 (control)	M2	M3	Mean
Batoka	LTPRT	-12.29 ± 0.06	-12.40 ± 0.04	-12.12 ± 0.02	**-12.27 ± 0.04**
	BBPRT	-12.71 ± 0.05	-12.42 ± 0.07	-12.46 ± 0.06	**-12.53 ± 0.06**
	LT	-12.42 ± 0.09	-12.49 ± 0.02	-12.49 ± 0.03	**-12.47 ± 0.05**
	BB	-12.45 ± 0.03	-12.39 ± 0.10	-12.65 ± 0.04	**-12.50 ± 0.06**
	NCP	-12.89 ± 0.06	-12.72 ± 0.05	-12.77 ± 0.04	**-12.79 ± 0.05**
	Mean	**-12.55 ± 0.06**	**-12.48 ± 0.06**	**-12.5 ± 0.04**	**-12.50 ± 0.05**
Chisamba	LTPRT	-12.52 ± 0.10	-12.24 ± 0.10	-12.57 ± 0.04	**-12.44 ± 0.08**
	BBPRT	-12.69 ± 0.06	-12.40 ± 0.09	-12.17 ± 0.03	**-12.42 ± 0.06**
	LT	-12.42 ± 0.09	-12.31 ± 0.07	-12.13 ± 0.06	**-12.29 ± 0.07**
	BB	-12.55 ± 0.04	-12.48 ± 0.08	-12.36 ± 0.04	**-12.46 ± 0.05**
	NCP	-12.50 ± 0.05	-12.32 ± 0.03	-12.47 ± 0.04	**-12.43 ± 0.04**
	Mean	**-12.54 ± 0.07**	**-12.35 ± 0.07**	**-12.34 ± 0.04**	**-12.41 ± 0.06**
FPr	<0.001				
Lsd (0.05)	0.1721				
CV (%)	0.9				

Note: LTPRT = Lutembwe parent spreading type, BBPRT = Bubebe parent cowpea bush type, LT = LT 11-3-3-12 Lutembwe mutant spreading type, BB= BB 14-16-2-2 Bubebe mutant bush type, NCP = non- cowpea, M1 (ZMS 606) = Control mostly purchased by smallholder farmers. M2 (GV 640) and M3 (GV 635) = selected low N and drought tolerant varieties. ± denotes standard errors.

The significant variation in the discrimination of ^{13}C (d^{13}C) in the maize stover at two experimental sites indicated that intrinsic WUEi in the maize stover is affected by edaphic and environmental factors. The Batoka site with loamy sand soil had a more reduction effect on the values of d^{13}C in maize stover than the values obtained from Chisamba with clay loam soil. Cowpea genotypes contributed to significant ($P<0.001$) variations in the d^{13}C of maize stover. According to Decorn et al. (2006), d^{13}C values in the maize crop decreased with increasing water stress. This indicated that the maize crop at the BK site was more affected by water limitation than at CH. Therefore, the results therefore suggest that the lowest d^{13}C values in the maize stover from the conventional farming system could be attributed to insufficient water supply to the maize crop and reduced nitrogen supply compared to maize crop produced in rotation with cowpeas (Ranajath et al., 1995). Dercon et al. (2006) reported that in C4 plants such as maize, variation in d^{13}C isotopic discrimination, results from changes in the ratio of intracellular to ambient partial pressure of CO_2 (p_i/p_a) and/ or from variation in the 'leakiness' of the bundle sheath. They further explained that under water stress conditions, the ratio of (p_i/p_a) decreases with increasing nitrogen supply, leading negatively to a reduction of the d^{13}C values in maize. However, in this study, the lower values of d^{13}C obtained in the non- cowpea plots could be due to an increase in leakiness (ϕ) and high nitrogen stress experienced in the maize mono-cropping system particularly at the Batoka site. Therefore, when estimating $d^{13}C$ in C4 crops leakiness should be considered because it affects the p_i/p_a ratio (Yang et al., 2017). The results were in line with the findings of Meinzer and Zhu (1998) who showed that leakiness could increase with decreasing nitrogen supply and this mechanism leads to lower $d^{13}C$ values with increasing nitrogen stress. Cowpea genotype LTPRT and its mutant LT 11-3-3-12 could have enhanced soil moisture storage due to high dry biomass yield hence the maize crop in these plots had reduced water stress.

Based on the negative relationship between $d^{13}C$ and WUEi, the results further revealed that intrinsic water use efficiency for stover improved more in the conventional farming system, cowpea genotype BB 14-16-2-2 and BBPRT due to low values of $d^{13}C$ (Dercon et al., 2006). Genetic differences of the maize varieties, also influenced the variation in the $d^{13}C$ values in the maize stover. The study indicated that ZMS 606 with average lowest value of $d^{13}C$ had higher WUEi in the maize stover compared to GV 640 and GV 635 and was more efficient in stover water use efficiency during the dry spells than the other two varieties.

An interaction between the sites, cowpea genotypes and maize varieties was significant, at $P<0.001$and indicated that the influence of cowpeas and maize varieties on the $d^{13}C$ dependent on the site. The effect of the conventional farming system for $d^{13}C$ was more significant at Batoka than Chisamba where it showed reducing the effect of $d^{13}C$. At the same time cowpea genotype LTPRT had an increasing impact at the same site. Cowpea mutant LT 11-3-3-12 had an increasing effect on maize stover $d^{13}C$ at the Chisamba site but BBPRT and mutant BB 14-16-2-2 were stable across the sites. The increase in $d^{13}C$ values of the maize stover for M2 (GV 640) and M3 (GV 635) was higher at Chisamba than Batoka implying that the two varieties were less efficient for water use in the stover than M1 (ZMS) at the Chisamba site. Based on the findings, the study suggests that the maize grain with the mean value of -12.027 ‰ $d^{13}C$ is less efficient in water use than maize stover with a $d^{13}C$ mean value of -12.460 ‰ which indicated that grain is more sensitive to water stress than the stover. The study has further showed that in addition to $d^{13}C$ values measured in the maize, the isotopic composition of the different plant parts at harvest can be used as a historical account of how water availability varied over the crop cycle under different farming systems and varieties.

5.4.4.3 d^{13}C Isotope discrimination in Cowpea Grain

The d^{13}C discrimination in cowpea genotypes for grain varied significantly ($P<0.05$) between the two sites (Table 73). Batoka (BK) site had d^{13}C value of -27.54 ‰ and was lower than of Chisamba (CH) site that had d^{13}C value of -27.04 ‰. The cowpea genotypes varied significantly ($P<0.05$) in the d^{13}C values of the grain. Among the cowpea genotypes, the mutant LT 11-3-3-12 with lowest d^{13}C of -27.65 ‰ and -27.77 ‰ was the most efficient genotype in carbon fixation followed by mutant BB 14-16-2-2 which discriminated -27.43 ‰ of ^{13}C and -27. 59 ‰ at Batoka and Chisamba respectively (Table 74)

Table 73: Mean squares of combine analysis of variance of d^{13}C isotope discrimination in Cowpea grain at two sites during 2015/2016 growing season

Variate: d^{13}C Cowpea		d^{13}C Grain (‰)
Source of variation	**d.f.**	**m.s.**
Site	1	1.4844***
Rep/Location	4	0.0486
Cowpea genotype	3	0.9129***
Site x cowpea genotype	3	2.3539***
Error	12	0.1218

Note: ***Significant at $P \leq 0.01$, **Significant at $P \leq 0.05$, ns Not significant at $P \leq 0.05$. d^{13}C Grain = ^{13}C discrimination in the cowpea grain, d^{13}C stv = ^{13}C discrimination in the cowpea stover.

A significant interaction ($P<0.001$) between the sites and cowpea genotypes for d^{13}C value discrimination in the grain are presented in Table 68. The discrimination of d^{13}C in the cowpea grain of mutants BB 14-16-2-2 and LT 11-3-3-12 was lower at Chisamba than at Batoka while cowpea parent LTPRT was lower at Batoka than at Chisamba. The study has suggested that cowpea genotypes could be selected for d^{13}C discrimination to improve cowpea grain yield under specific environmental conditions. Therefore, mutants BB 14-16-2-2 and LT 11-3-3-12 would produce high grain yield at Chisamba while parent LTPRT would give more grain yield at Batoka under water stress conditions.

Table 74: Influence of cowpea genotypes on ^{13}C isotope discrimination ($d^{13}C$) values in the cowpea grain

	$d^{13}C$ value in Cowpea grain				
Site	**LTPRT**	**BBPRT**	**LT**	**BB**	**Mean**
Batoka	-28.04 ± 0.20	-27.02 ± 0.17	-27.65 ± 0.05	-27.43 ± 0.15	**-27.54 ± 0.14**
Chisamba	-25.67 ± 0.24	-27.14 ± 0.30	-27.77 ± 0.17	-27.59 ± 0.12	**.'-27.04 ± 0.21**
FPr	<0.001				
Lsd (0.05)	0.5612				
CV (%)	1.3				

Note: LTPRT = Lutembwe parent spreading type, BBPRT = Bubebe parent cowpea bush type, LT = LT 11-3-3-12 Lutembwe mutant spreading type, BB= BB 14-16-2-2 Bubebe mutant bush type. ± denotes standard error of means

The $d^{13}C$ discrimination in cowpea genotypes for grain varied significantly ($P<0.05$) between the two sites. Batoka (BK) site had lower $d^{13}C$ value of -27.534 ‰ than of Chisamba (CH) site that had $d^{13}C$ value of -27.040 ‰. The low $d^{13}C$ value at BK could be attributed to the limitation of soil moisture at the reproductive growth stage due to the high rate of water drainage of loamy sand soils for the BK site.

This condition of reduced moisture led to the closure of stomata that limited the diffusion of CO_2 from the atmosphere into the plant epidermis causing reduced partial pressure of CO_2 inside the grain intercellular (Oner, 2014). The reduction of the CO_2 concentration in the intercellular space of cowpea grain reduced the $d^{13}C$ value more than the cowpea crop at CH. The results agreed with Dercon et al. (2006) who indicated that genetic and Environment interaction for $d^{13}C$ can have large effect on the values of $d^{13}C$ measured in plant part, especially under declining soil moisture. The study showed more improved transpiration efficiency (TE) and carbon assimilation on cowpea grain during the photosynthesis process at Batoka than at Chisamba. This could have contributed to increased grain yield of cowpea grain of 608 kg ha^{-1} and reduced cowpea grain yield of 481 kg ha^{-1} at Chisamba. Rebetzke et al. (2002) reported the strong negative correlation between TE and $d^{13}C$ in wheat (*Triticum aestivum* L.), suggesting that progeny selection with low $d^{13}C$ may improve TE and biomass under limited water conditions. Mohammad (2001) also stated that plants with high TE will show less $d^{13}C$ values and that moderate drought can cause an increase in TE up to 100 % but extreme droughts could substantially reduce TE.

The cowpea genotypes varied significantly (P<0.05) in the $d^{13}C$ values of the grain. The mutant LT 11-3-3-12 with the lowest $d^{13}C$ of -27.7 ‰ was the most efficient genotype in carbon fixation followed by mutant BB 14-16-2-2 which discriminated -27.51 ‰ of ^{13}C. However, the parent cowpea genotypes LTPRT and BBPRT which discriminated at -26.86 ‰ and -27.08 ‰ respectively were significantly higher than their mutants. The results have therefore revealed that the selection of cowpea genotypes for low $d^{13}C$ could improve adaptation to drought conditions (Dercon, 2006). Based on these results Mutants LT 11-3-3-12 and BB 14-16-2-2 could be more drought tolerant and with higher WUEi for grain yield than their parents. The mutants could therefore be recommended for planting in drought- prone areas to improve the grain yield. According to Rebetzke et al (2017), grain yield advantage for the low $d^{13}C$ in C3 crop increased with reductions in the environment mean grain yield ($r = -0.89$, $P < 0.01$) and total seasonal rainfall ($r = -0.85$, $P < 0.01$). This indicated the benefit of low $d^{13}C$ and therefore high TE for genetic improvement of grain yield in lower rainfall environments.

A significant interaction (P<0.001) between the sites and cowpea genotypes for $d^{13}C$ value discrimination in the grain was observed. This implied that variation in the discrimination of ^{13}C among the cowpea genotypes dependent on the environmental differences. The discrimination of $d^{13}C$ in the cowpea grain of mutants BB 14-16-2-2 and LT 11-3-3-12 was generally the same across the two sites. The study has suggested that cowpea genotypes could be selected for $d^{13}C$ discrimination to improve cowpea grain yield under specific environmental conditions.

5.4.4 ^{13}C discrimination ($d^{13}C$) in Cowpea Stover

The results showed significant difference (P<0.05) between sites and among the cowpea genotypes (Table 75). The discriminated $d^{13}C$ value at Batoka was -28.16 ‰ and was significantly lower than -27.87 ‰ at Chisamba indicating that cowpea genotypes at Batoka had more water stress compared to Chisamba. The $d^{13}C$ value among the cowpea genotypes stover varied significantly at P<0.05(Table 75). The mutant BB 14-16-2-2 that discriminated -28.14 ‰ value of $d\ ^{13}C$ was significantly lower than its parent BBPRT which had -27.83 ‰ at Batoka. However, mutant LT 11-3-3-12 with $d^{13}C$ value of -28.15 ‰ was not significantly (P>0.05) different from the parent LTPRT at Batoka. At Chisamba, cowpea mutant LT 11-3-3-12 had a significantly lower d^{13}C value of -28.03 ‰ than the parent LTPRT (Table 76). The results showed that mutant LT 11-3-3-12 could be more efficient for intrinsic water use in the stover at Chisamba than the parent while mutant BB 14-16-2-2 stover would be more efficient than a parent at Batoka.

Table 75: Mean squares of combine analysis of variance of d13C isotope discrimination in Cowpea stover at two sites during 2015/2016 growing season

Variate: d^{13}C Cowpea		d^{13}C stv (‰)
Source of variation	**d.f.**	**m.s.**
Site	1	0.563392***
Rep/Location	4	0.014676
Cowpea genotype	3	0.031048**
Site x cowpea genotype	3	0.460006***
Error	12	0.008123

Note: ***Significant at P ≤ 0.01, **Significant at P ≤ 0.05, ns Not significant at P ≤ 0.05. d^{13}C Grain = ^{13}C discrimination in the cowpea grain, d^{13}C stv = ^{13}C discrimination in the cowpea stover.

A significant (P<0.001) interaction between sites and cowpea genotype for d^{13}C discrimination in the stover was observed. The environmental conditions of the sites influenced variations in d^{13}C among the cowpea genotypes. Cowpea genotypes BB 14-16-2-2, LT 11-3-3-12 and LTPRT with d^{13}C values of -28.14 ‰, -28.15 ‰ and -28.52 ‰ respectively had significantly less discrimination at the Batoka site than at the Chisamba site. The parent cowpea genotype BBPRT however, discriminated less d^{13}C value (-28.08 ‰) at Chisamba than at Batoka (Table 76).

Table 76: Influence of cowpea genotypes on d13C isotope discrimination values in the cowpea stover

	d^{13}C value in Cowpea stover				
Site	**LTPRT**	**BBPRT**	**LT**	**BB**	**Mean**
Batoka	-28.52 ± 0.06	-27.83 ± 0.28	-28.15 ± 0.08	-28.14 ± 0.07	**-28.16 ± 0.12**
Chisamba	-27.35 ± 0.21	-28.08 ± 0.07	-28.03 ± 0.17	-28.02 ± 0.11	**-27.87 ± 0.14**
FPr	<0.001				
Lsd (0.05)	0.1722				
CV (%)	0.3				

Note: LTPRT = LT 11-3-3-12 Lutembwe parent spreading type, BBPRT = Bubebe parent cowpea bush type, LT = Lutembwe mutant spreading type, BB= BB Bubebe mutant bush type. ± denotes standard error of means.

The results showed significant difference ($P<0.05$) between sites in the discriminated $d^{13}C$ value of cowpea stover and was lower at Batoka with -28.16 ‰ than at Chisamba (-27.87 ‰). According to YU et al. (2004) water use efficiency (WUEi) is negatively correlated with $d^{13}C$ discrimination and WUEi increased with nitrogen supply and with increased water stress. This indicated that the Batoka site with loamy sand soil type and poor soil fertility status was more efficient for water use in the cowpea stover than Chisamba site with clay loam soil during photosynthesis. Between the two sites, Batoka could be more prone to water stress than Chisamba due to lower plant available water (PAW). The study found that Chisamba site with clay loam soils had significantly higher plant available water of 18.3 % than the Batoka site with loamy sand soils that had 14.5%. Bulk density can influence the water holding capacity (WHC) and it was reported by Abu-Zreig et al. (2004) that the WHC decreased by 10 % from non-compacted (Clay loam soils) soil to compacted soil (sandy soil) as like soils of Batoka with higher soil bulk density of 1.83 g cm^{3-1} than Chisamba soils with a bulk density of 1.44 g cm^{3-1}. Therefore, the high-water use efficiency in the cowpea genotypes stover at Batoka could be attributed to the high transpiration efficiency experienced during the moderate water limitation conditions. The results agree with Rebetike et al. (2002) and observed a strong negative correlation between transpiration efficiency (TE) and $d^{13}C$ in wheat crop and further suggested that selection of genotypes for low $d^{13}C$ may increase TE and biomass under water- limited conditions. Abdlbagi and hall. (1992) found Significant genotypic and drought-induced effects on WUE, and drought increased WUE by 29 % due to biomass being reduced less than water use.

Kirchhoff et al (1989) found Significant differences in ^{13}C discrimination for leaves sampled from field-grown cowpea plants and led to the prediction that plants in a drier treatment had higher intrinsic water-use efficiency than well-watered plants. Therefore, under this study, there is a high potential to select cowpea genotypes for low $d^{13}C$ and drought tolerance traits at Batoka.

The $d^{13}C$ value that significantly ($P<0.05$) varied among the cowpea genotypes stover showed that cowpea genotypes could be selected for their water use efficiency during vegetative growth. The present study suggests that on average mutant BB 14-16-2-2 with the lowest $d^{13}C$ (-28.10 ‰) was most efficient in the water use during Carbon dioxide fixation in the stover development. Based on these findings mutant BB 14-16-2-2 could be recommended for drought - prone areas mainly for rotation with maize crop. In contrast to the present study, Kirchhoff et al. (1989) in their study indicated that cowpea mutant had significantly greater ^{13}C discrimination than the parent. However, leaf gas exchange data revealed no significant differences in intrinsic water-use efficiency.

A significant ($P<0.001$) interaction between sites and cowpea genotype for $d^{13}C$ discrimination in the stover indicated that performance of cowpea genotypes for stover carbon fixation depends on the Genetic and Environmental interactions (G x E). According to Derco et al. (2006), G x E interactions for $d^{13}C$ are potentially large because environmental influences can have very large effect on the $d^{13}C$ values measured in in plant dry matter, especially under the declining water content and rising evaporate demand. Cowpea genotypes BB, LT and LTPRT could therefore be more efficient for carbon assimilation and water use when produced at Batoka than Chisamba.

More importantly, the study has also revealed that the cowpea grain with the mean value of -27.29 ‰ $d^{13}C$ is less efficient in water use than cowpea stover with $d^{13}C$ mean value of -28.02 ‰ suggesting that cowpea grain is more sensitive to water stress than the stover. Compared to maize crop with a mean $d^{13}C$ value of -12.24 ‰, the study has given evidence that cowpea crop with a mean $d^{13}C$ value of -27.65 ‰, is more efficient in carbon assimilation during photosynthesis and is more tolerant to water stress than maize crop.

5.5 Conclusion

1) The nitrogen use efficiency (NUE) was significantly ($P<0.001$) higher under the conservation farming system (CF) with mean value of 20.2% than in the conventional system (CONV) at both Chisamba and Batoka sites by 36.2%. The interaction between the farming system and maize variety indicated highest NUE of 21.5% for ZMS 606 in the CF followed by GV 640 with mean value of 20.2% and was enhanced mainly by cowpea mutant LT 11-3-3-12 and BBPRT compared to other genotypes.

2) The soil moisture storage under CF was higher than in the CONV at Chisamba and Batoka sites at soil depth of 10 cm and 20 cm. The soil moisture storage was on average 32.45 % and 33.24 % in the conservation farming system and were higher than moisture content under conventional farming system by 14.3 % and 5.8 % respectively at Chisamba while at Batoka CF had soil moisture storage higher than CONV by 18.5 %. The increased soil moisture under CF at 10 cm and 20 cm soil depth was attributed to water conservation in the ripped furrows and soil cover by crop residues that reduced evapotranspiration. The cowpea genotypes LTPRT, mutants LT 11-3-3-12 and BB 14-16-2-2 conserved significantly higher moisture than non- cowpea by 15.3 % at 10 cm soil depth while at 20 cm soil depth, cowpea mutants BB 14-16-2-2 and LT 11-3-3-12 had conserved highest soil moisture content more than non-cowpea treatment by 10.1% and 7.4 % respectively. The increase in soil moisture storage for maize varieties GV 640 and ZMS 606 was 0.26 % over GV 635 at Chisamba indicating that the two varieties were more efficient for water use. At Batoka the highest soil moisture storage at 10 cm soil depth was attained when maize variety M3 (GV 635) combined with cowpea mutants BB 14-16-2-2 and at 20 cm when ZMS 606 was rotated with mutant LT 11-3-3-12.

3) Conservation farming (CF) exhibited significantly higher RWUEg than the conventional farming (CONV) RWUEg at both sites by 57.9 % mainly attributed to cowpea mutant BB 14-16-2-2 which outperformed other genotypes. The findings indicated that response of maize crop for RWUEg was higher at BK 119.4 %) compared to CH (17.4 %) by adopting CF and this could be due to inherent lower organic matter and other essential plant nutrients of soils at Batoka. The

grain rainfall water use efficiency (RWUEg) of GV 635 was lower than ZMS 606 and GV 640 by 10.2 % and 35.3 % respectively. However, maize variety GV 635 had the highest dry biomass water use efficiency (RWUEb) of 15.36 kg $ha^{-1}mm^{-1}$. Therefore, combination of maize varieties ZMS 606 and GV 640 with cowpea mutant BB 14-16-2-2 under CF could contribute to increased rainfall water use efficiency of the maize grain.

4) The ^{13}C isotope discrimination in the maize grain at Batoka and Chisamba was significantly higher than in the maize stover by 2.9 % and 5.4 % respectively suggesting that maize grain is more sensitive to water stress than the stover. The study has further showed that the isotopic composition of the plant parts at harvest could be used as a historical account of how water availability varied over the crop cycle under different farming systems and varieties.

5) The maize variety GV 640 with an average grain $d^{13}C$ value of -12.37 ‰ at Batoka and -11.93 ‰ at Chisamba had the lowest $d^{13}C$ compared to ZMS 606 and GV 635 by 1.2 % at Batoka and 1.9 % at chisamba. GV 640 exhibited the lowest ^{13}C discrimination under conservation farming system compared to conventional by 0.9 % at Batoka and 4.7 % at Chisamba in combination with mutants LT 11-3-3-12 and BB 14-16-2-2 used for rotation. Therefore, results showed that the maize variety GV 640 combined with cowpea mutants LT 11-3-3-12 and BB 14-16-2-2 was most efficient for intrinsic water use and could be selected for high adaptation in water-limited areas.

CHAPTER SIX

6.0 GENERAL CONCLUSIONS

The study focused on three specific objectives: (i) To evaluate the yield performance of selected drought and Low N tolerant maize varieties in conventional and conservation farming systems. (ii) To assess the performance of cowpea genotypes for Biological Nitrogen Fixation in the conservation farming system. (iii) To identify maize – cowpea combinations with high water use efficiency (WUE) and nitrogen use efficiency (NUE) for high maize productivity in the CF system. The following general conclusions of the study were made:

6.1 Response of selected maize genotypes for low nitrogen and drought stress

- The study findings revealed that agronomic yield performance of the selected drought and low N tolerant maize varieties varied according to sites, farming systems, cowpea genotypes due to differences in soil types and nutrient dynamics in the farming systems. Maize yield from CF system was significantly ($P<0.05$) higher than from conventional farming system. These results were consistent with high BNF, improved soil properties, high nitrogen use efficiency, water use efficiency and high moisture storage mainly contributed by cowpea genotypes LT 11-3-3-12 and BB 14-16-2-2.

- Among the maize varieties, Maize yield of GV 640 selected for drought and low N tolerance was highest under CF followed by the control (ZMS 606) which is mostly purchased by smallholder farmers in Zambia.

6.2 Evaluation of selected cowpea genotypes for Biological Nitrogen Fixation

- Among the cowpea genotypes, mutants LT 11-3-3-12 and BB 14-16-2-2 exhibited the highest Biological Nitrogen Fixation sites which contributed to increased maize productivity under CF at both Chisamba and Batoka. The high BNF exhibited by the mutants could improve productivity of maize among smallholder farmers at low input management. However, BNF is higher in areas with sufficient plant nutrients such as phosphorus, potassium and calcium t enhancing productivity of Brady Rhizobia responsible for nitrogen fixation.

6.3 Evaluation of the productivity of cowpea-maize combinations

- Maize varieties ZMS 606 and GV 640 were superior over GV 635 in grain yield, nitrogen use efficiency (NUE) and rainfall water use efficiency in the maize grain (RWUEg). The high maize productivity in the study was due to good water storage and improved soil chemical and physical properties mainly contributed by cowpea mutants BB 14-16-2-2 and LT under conservation farming system.

- Maize variety GV 640 and cowpea genotype LT 11-3-3-12 were surrogated as most efficient for intrinsic water use efficiency because they exhibited lowest ^{13}C isotope discrimination ($d^{13}C$). The genotypes could therefore be recommended for use among smallholder farmers in drought and water limited areas of Zambia.

- Two maize varieties (ZMS 606 and GV 640) with traits of high maize grain yields, Nitrogen Use Efficiency (NUE), Water use efficiency (WUE) were found compatible in combination with cowpea mutants BB 14-16-2-2 and LT 11-3-3-12 in a rotation.

- The study therefore, suggests that ZMS 606 and GV 640 could be the most superior maize varieties for combination (rotation) with cowpea genotypes BB 14-16-2-2 and LT 11-3-3-12 to ensure increased Nitrogen and Water use efficiency under conservation farming system.

CHAPTER SEVEN

7.0 RECOMMENDATIONS

Based on the findings of this study, the following recommendations could be made: Through the ministry of agriculture, CF should be strongly promoted among all categories of farmers particularly the resource poor smallholder farmers for production of maize especially on poor soils and in areas with erratic rainfall. This is because the indicators of crop productivity that were measured and evaluated (nue, water storage in soil profile and wue) show that they were greater in conservation farming (CF) than in Conventional farming(CONV).

1) There are several legumes such as cowpeas, soyabeans velvet beans and sunhemp that are used in legume- cereal rotation under conservation farming systems in Zambia. Cowpea is commonly grown by smallholder farmers in Zambia and often in rotation with cereals. Local unimproved varieties of cowpea likely contribute little nitrogen (N) to soil through Biological Nitrogen Fixation. This study has shown that mutation derived varieties of cowpea fix up to 86 kg per ha. Therefore, adoption of mutation derived varieties such as LT 11-3-3 -12 can improve maize productivity in smallholder conservation farming systems. The system would reduce nitrogen fertilizer requirement currently costing the US $ 33.0 by about 50 % translating into 50% reduction in fertilizer importation. This genotype has also characteristic of stay green making it dual purpose for grain (human consumption) and fodder (livestock production). The adoption of this genotype as climate smart technology in rotation with maize varieties could mitigate the climate change because of reduced nitrogen lost into the atmosphere through volatilization and nitrification from synthetic fertilizers. This would permit the country transit into a low carbon trajectory in agriculture production.

2) Many small holder farmers in Zambia produce maize crop as stable food for Zambians. However, productivity of maize is too low due to poor farming practices like conventional and inadequate improved maize varieties that are tolerant to drought and low N. From this study, combinations of maize varieties ZMS 606 and GV 640 with cowpea genotypes BB 14-16-2-2 14-16-2-2 and LT 11-3-3-12 as evidenced by their higher NUE and drought tolerance should be promoted in the cowpea-maize rotation system for enhanced food security among smallholder farmers in Zambia. To ensure availability of the improved cowpea varieties on the market, genotypes BB 14-16-2-2 and LT 11-3-3-12 are recommended for accelerated release by Seed Control and Certification Institute (SCCI).

3) This study was not able to evaluate many developed maize and cowpea genotypes for drought tolerance, Water use efficiency, Nitrogen use efficiency and biological nitrogen fixation. Therefore, it is recommended that further studies be conducted to evaluate more improved cowpea genotypes and maize varieties which have been developed. The productivity of improved cowpea-maize genotype combinations should also be assessed to select best combinations for improved maize productivity among smallholder farmers in Zambia.

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9.0 APPENDICES

APPENDIX A: WEATHER DATA

A.1. 2014/2015 Seasonal Rainfall at Chisamba- GART

	MONTH							
	SEPT	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
DATE								
1	0	0	0	0	0	8.6	0	0
2	0	0	0	0	9.1	9.6	25.5	0
3	0	0	0	0	0	3.7	0.6	0
4	0	0	0	0	7.6	2.8	0	30
5	0	0	0	0	0	0	0	17.2
6	0	0	0	0	4.2	0	0	0
7	0	0	0	0	0	0	0	4.6
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	19.8	0	0	0
11	0	0	0	21.6	0	4.6	0	0
12	0	0	0	22.4	0	0	0	0
13	0	0	0	43.4	0.8	3.9	0	0
14	0	0	0	0	60.4	4.4	0	2.7
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	5	0	0	0	0	0
18	0	0	48.3	30.3	20.2	0	0	0
19	0	0	0	0	24.4	0	0	3
20	0	0	0	0	6.5	0	0	0
21	0	0	0	14.2	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0.4	0	7.5	0	0
24	0	0	0	17.5	0	32.5	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	30.4	1.9	36.2	0	0
27	0	0	0	0	0	5.3	0	0
28	0	0	0	10	37.2	5.6	0	0
29	0	0	0	4.6	28.6		16.7	0
30	0	0	0	0	3.6		0	0
31		0		16.5	9.2		13.8	
Totals	**0**	**0**	**53.3**	**211**	**233.5**	**124.7**	**56.6**	**57.5**
CUMM.	**0**	**0**	**53.3**	**265**	**498.1**	**622.8**	**679**	**736.9**
Rain days	0	0	2	10	13	12	3	4

A.2. 2015/2016 Seasonal Rainfall at Chisamba- GART

	MONTH							
	SEPT	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
DATE								
1	0	0	0	11.4	0	6.2	0	0
2	0	0	0	16.5	0	46.4	0	0
3	0	0	0	0	0	0	40	8.7
4	0	0	0	17.4	0	0	21.1	2.6
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	15.2	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	4.8	0	0	0
9	0	0	0	0	51.2	0	0	23.6
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	4.3	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	4.7	12.5	0	0	0
14	0	0	0	3.1	3.5	0	0	0
15	0	0	2.6	23	0	12.3	0	0
16	0	0	0	0	2.5	1.3	0	0
17	0	0	0	5	0	0	0	0
18	0	0	0	7	0	0	0	0
19	0	0	0	83.8	0	0	22.6	0
20	0	0	0	7	1.5	0	39.2	0
21	0	0	18	10.1	0	0	0.5	0
22	0	0	81.6	0	0	0	30	0
23	0	0	0	0	0	0	20	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	36.9	1.9	0	0
28	0	0	0	0	1.6	10.2	0	0
29	0	0	0	0	0	14.8	0	0
30	0	0	0	0	0		0	0
31		0		0	0			
M/TOTAL	**0**	**0**	**102**	**189**	**114.5**	**112.6**	**173**	**34.9**
CUMM.	**0**	**0**	**102**	**291**	**405.7**	**518.3**	**692**	**726.6**
Rain days	0	0	3	11	8	9	6	3

A.3. 2016/2017 Seasonal Rainfall at Chisamba- GART

	MONTH							
	SEPT	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
DATE								
1	0	0	0	0	3.7	0	0	0
2	0	0	0	0	6.5	11.3	15.4	0
3	0	0	0	0	0	10.8	0	0
4	0	0	0	7.5	0	34.2	0	0
5	0	0	0	3	0	16.9	29.3	0
6	0	0	0	0	0	11.8	2.6	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	3.9	0
9	0	0	0	5.6	0	0	22.3	0
10	0	0	0	9.2	14.9	0	0	0
11	0	0	3.2	3.1	0	0	0	0
12	0	0	0	26.7	12.1	0	0	0
13	0	0	29.6	5	0.3	21.5	0	0
14	0	0	0	5.3	9.1	10.2	0	0
15	0	0	0	0	16.3	0	0	37.3
16	0	0	0	8.6	7.2	67	0	0
17	0	0	0	4.2	10.9	37.1	0	0
18	0	0	0	14.2	20.2	6.3	0	0
19	0	0	0	0	27.5	0	0	0
20	0	0	3.2	0	18.9	7.5	0	0
21	0	0	0	0	0	8.3	0	0
22	0	0	0	0	0	17.1	0	0
23	0	0	8.3	0	0	0	0	11.2
24	0	0	0	0	0	0	0	30.7
25	0	0	0	25.3	2.8	21.1	0	0
26	0	0	32.6	0	9.8	20.5	0	0
27	0	0	11	0	0	15.4	0	0
28	0	0	0	22.4	0	0	0	0
29	0	0	0	0	15.8	0	0	0
30	0	0	0	0	7.8	0	0	0
31	0	0	0	0	0	0	0	0
M/TOTAL	**0**	**0**	**87.9**	**140**	**183.8**	**317**	**73.5**	**79.2**
CUMM.	**0**	**0**	**87.9**	**228**	**411.8**	**728.8**	**802**	**881.5**
Rain days	0	0	6	13	15	16	5	3

A.4. 2014/2015 Seasonal Rainfall at BATOKA-LDC

	MONTH							
	SEPT	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
DATE								
1	0	0	0	0	22	18	10	12
2	0	0	0	5	0	7	15	0
3	0	0	0	0	0	38	7	0
4	0	0	0	0	1	3.5	0	15
5	0	0	0	0	3.5	2	0	1
6	0	0	0	0	0	0	0	3
7	0	0	0	0	0	0	0	17
8	0	0	0	0	3.5	0	0	7
9	0	0	0	3	0	10	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	3	0	0	0	0
12	0	0	0	14	7.5	8	0	0
13	0	0	3.5	13	15	0	0	0
14	0	0	0	0	3.7	90.5	0	0
15	0	0	5	11	26	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	5	19	0	0	0	6
18	0	0	1.5	1.5	0	0	0	0
19	0	0	0	1.7	40	0	0	4
20	0	0	0	0	18	0	0	0
21	0	0	0	1.5	0	0	0	0
22	0	0	0	1.5	0	15	0	0
23	0	0	0	0	3.5	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	50	0	26	0	0
26	0	0	0	5	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	40	20	8	0
29	0	0	12	0	62		24	0
30	0	0	0	22	0		0	0
31		0		29	2		30	
M/TOTAL	**0**	**0**	**27**	**180.2**	**247.7**	**238**	**94**	**65**
CUMM.	**0**	**0**	**27**	**207.2**	**454.9**	**692.9**	**786.9**	**851.9**
Rain days	0	0	5	15	14	11	6	8

A.5. 2015/2016 Seasonal Rainfall at BATOKA - LDC

	MONTH							
	SEPT	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
DATE								
1	0	0	0	0.2	0.2	2.8	0	0
2	0	0	4	36	6.8	0	0	0
3	0	0	0.5	0	0	5.8	0	8
4	0	0	0	9	0	0	0	1.3
5	0	0	0	0	0	0	40	0
6	0	0	0	0	0	0	30	1.2
7	0	0	0	0	0	0.1	31	0
8	0	0	0	0	0.8	51	0	4
9	0	0	0	0	5.8	0	1	3
10	0	0	0	0	0	0	2	3
11	0	0	0	0	0	4.5	0	0
12	0	0	0	0.6	0	0	0	0
13	0	0	0	0	13	4.5	0	0.8
14	0	0	0	4.1	34	0	2	0
15	0	0	0	0	10	0	11	0
16	0	0	0	15	30	0	0.6	0
17	0	0	3.4	0	0	5.8	0.1	0
18	0	0	0	0.6	0	0	0	0
19	0	0	0	1.4	0	6	0	0
20	0	0	0	17	0	0	3	0
21	0	0	26	8.1	0	0	0	0
22	0	0	0	0	0	5.1	5.1	0
23	0	0	2.7	0	14	0	0	0
24	0	0	0	0	0	49	0	0
25	0	0	0	0	17	5.9	0	0
26	0	0	0	0	0	5.1	0	0
27	0	0	0	0	0.7	4.1	0	0
28	0	0	0	0	20	6.1	0	0
29	0	0	0	0	36	0.2	0	0
30	0	0	0	0	0.5		0	0
31		0		0	0		0	
M/TOTAL	**0**	**0**	**36.6**	**92**	**188.8**	**156**	**125.8**	**21.3**
CUMM.	**0**	**0**	**36.6**	**128.6**	**317.4**	**473.4**	**599.2**	**620.5**
Rain days	0	0	4	7	10	13	6	6

A.6. 2016/2017 Seasonal Rainfall at BATOKA-LDC

	MONTH							
	SEPT	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**
DATE								
1	0	0	0	0	10	0	0	0
2	0	0	0	0	0	10	11	0
3	0	0	0	0	0	3	4	0
4	0	0	0	0	4	5	4	0
5	0	0	0	0	9	21	4.5	0
6	0	0	0	0	0	2	1	0
7	0	0	0	1	8	4	3	0
8	0	0	0	2	0	0	0	0
9	0	0	0	0	10	32	0	0
10	0	0	0	7	1	3	0	12.5
11	0	0	1.4	7	27	0.8	0	0
12	0	0	5	31	4.8	1.2	0	0
13	0	0	0.6	16	6.7	0	0	0
14	0	0	0	26	7.7	0	0	0
15	0	0	0	0	9.6	13.5	0	0
16	0	0	0	0	8	8	0	0
17	0	0	1	28	10	0	0	0
18	0	0	0	1.5	5	4	0	0
19	0	0	6	2.8	5	1	0	1.5
20	0	0	26	0	36	5.5	5.5	0
21	0	0	0	0	10	52	5	0
22	0	0	0	0	4.5	11	5.5	0
23	0	0	0	2	5.2	4	0	0
24	0	0	18	1.6	2.1	0.3	0	4.8
25	0	0	21	44	1.8	27	0	0
26	0	0	24.5	2	29	9.5	0	0
27	0	0	4.2	0.5	42	26	0	0
28	0	0	0	0	4.9	2.6	0	0
29	0	0	0	30	27.1	0	0	0
30	0	0	0	8.5	3	0	0	0
31	0	0	0	0	0	0	0	0
M/TOTAL	**0**	**0**	**108**	**210.9**	**291.4**	**246.4**	**43.5**	**18.8**
CUMM.	**0**	**0**	**108**	**318.6**	**610**	**856.4**	**899.9**	**918.7**
Rain days	0	0	9	16	26	21	9	3

A.7. 2014/2015 Seasonal Rainfall, Temperature and evapotranspiration at Kabwe

Temperature, Rain fall, Evapotranspiration

	Tmax ^oC	Tmin ^oC	Rain fall	Evap
Sep	29.3	14.8	0.7	236.3
Oct	33.3	18.9	3.6	281.5
Nov	32.9	19.6	0	239.9
Dec	30.1	19.1	188.8	115.9
Jan	27.9	18.1	191	91.3
Feb	25.9	16.3	146.6	93.5
Mar	28.9	17.1	95	134.5
Aprl	24.6	15.4	70.4	88.5
May	25.9	11.8	0	134.8
Jun	23.8	10.3	0	135.4
Jul	26.3	10.8	0	166.5
Aug	28	12.5	0	200.6
Totals	**336.9**	**184.7**	**696.1**	**1918.7**

A.7. 2014/2015 Seasonal Rainfall, Temperature and evapotranspiration at Kabwe continued

Temperature, Rain fall, Evapotranspiration

	Tmax ^oC	Tmin ^oC	Rainfall	Evap
Sep	30.5	15.7	0	240.6
Oct	33.5	19.4	4	283.3
Nov	31.4	18.6	49	204
Dec	30.5	19.2	113.8	143
Jan	29.4	19.2	204.5	143
Feb	28.1	17.8	84	118
Mar	29	18.8	116.2	108.3
Aprl	26	14.9	32.6	126.6
May	25.3	11.9	0	141
Jun	23.4	9.5	0	128.5
Jul	24.5	10	0	137
Aug	27.2	12.9	0	210.9
Totals	**338.8**	**187.9**	**604.1**	**1984.2**

APPENDIX B: PUBLICATIONS, SEMINARS AND CONFERENCES

B1. Publications

1. Simunji, S., Munyinda, K., Lungu, O., Mweetwa, O. A., & Phiri, E. (2018). Optimizing Soil moisture and Nitrogen Use efficiency of Some Maize (*Zea mays*) Varieties under Conservation Farming system. *Sustainable Agriculture Research, 7*(4), 42-50. https://doi.org/10.5539/sar.v7n4p42

2. Simunji Simunji, Kalaluka L. Munyinda, Obed I. Lungu, Alice M. Mweetwa & Elijah Phiri (2019).Evaluation of Cowpea (*Vigna unguiculata L.walp)* Genotypes for Biological Nitrogen Fixation in Maize-cowpea Crop Rotation. URL: https://doi.org/10.5539/

B2. Seminars

1. Seminar week held on the 14th August, 2017. The University of Zambia. Directorate of Research and Graduate studies. **Optimizing Water and Nitrogen Use efficiency of Maize in Conservation Farming system.**

2. Seminar week 3rd October, 2019.The University of Zambia. School of Agricultural Sciences. **Optimizing Water and Nitrogen Use Efficiency of Maize in Conservation Farming system.**

B3. Conferences

1. 10th International Conference on Agriculture & Horticulture. October 02-04, 2017, London, UK. **Optimizing Water and Nitrogen Use Efficiency of Maize in Conservation Farming system.**