EFFECT OF RIDGING AND MULCHING ON SOIL MOISTURE, RAINWATER USE EFFICIENCY AND MAIZEYIELD IN LUNDAZI, ZAMBIA

BY

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DECLARATION

I, Mabvuto Lungu, hereby declare that this master's dissertation was written by me and that I did not use any other sources and means than those specified. This master's dissertation has not been submitted to any other university for acquiring an academic degree.

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Signature   **Date**

APPROVAL

This dissertation of Mr Mabvuto Lungu is approved as fulfilling part of the requirements for the award of the degree of Master of Science in Agronomy of the University of Zambia

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DEDICATION

I dedicate this dissertation to my wife Ketty and children Benjamin, Dorcas, and Catherine for their endurance while I was away.

ABSTRACT

Agricultural practices that conserve soil moisture are inevitable in the face of erratic rains and constant droughts. Mulching can improve water productivity through increase in water retention and reduction in surface evaporation. The studywas conductedinLundazi District of Eastern Province of Zambia (latitude: 12.8°S longitude: 35.18° E and 1080m above sea level). Theobjective ofthestudywas toevaluatetheeffects ofridging andsurface soil mulching on maize growth and rain-water use efficiency (RWUE). The specific objectives were to determine the effect of ridging and mulching on rain-water useefficiency, root-zone soil moisture regime and yield in maize (*ZeaMays* L). The experimental design was aRandomized Complete Block Design (RCBD) with three replications and four treatments andmaize as the test crop.The treatments were:(i) Ridged field without mulch, (ii)ridged field with mulch, (iii) flat field without mulch and (iv) flat field with mulch. Hyperrhenia grass (*Hyperrheniahirta*) was used as mulch, a common grass species in the study site. The aboveground biomass varied from9.5 to 12.3 tons/ha with an average of 11.1 tons/ha. There were nosignificant differences in aboveground biomass among the treatments ($p>0.05$) of either mulching orridging. The stoverbiomass varied from5.9 to 7.8 tons/ha with an average of6.8 tons/ha. Stover biomass was significantly ($p<0.05$) affected byboth mulching andridging. The significant differencesin stoverbiomass was observed betweenflat field with mulch,flat field with ridges when compared with flat field withoutmulch and ridgedfield withmulch. The grain yield varied from3.5 to 4.8tons/ha with an average yield of4.3 tons/ha. Significantdifferences ($p<0.05$) were observed among the treatments. The ridged field with mulch was significantly highercompared with flat fieldwith mulch. The harvest index (HI) varied from36.2%to 44.1%with an average of39.3%.There were significant differences in HI among the treatments ($p<0.05$). The rain-water use efficiency (RWUE) of the grain varied from4.5 to 6.0 kg DM $mm^{-1}ha^{-1}$. The significant differences were observed between ridge field withoutmulch and flat field with mulch. Soil moisture storage in the root-zone varied from 129.1mm to 236.8mm with an average of 181.5mm. However, there were nosignificantdifferencesamongthe treatments in soil moisture storage.The results showed that ridging greatlyimproved yield during the studiedseason which hadnormal rainfall,hence farmers benefited from ridging as it helpedto drain excess water and and improved aeration in the root zone. On the otherhand, mulching would be useful in seasons with water stress conditions. In view of climate change and variability, it can be said that water scarcity will be a burning problem for the future and its most probable solution can be useof mulching and ridging for quality agricultural production.

Keywords: Ridging, Mulching, Soil Moisture, Rainwater use efficiency, Maize yield

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ABBREVIATIONS OR ACRONYMS

B	-	Biomass
BD	-	Bulk Density
C	-	Carbon
cm	-	Centimetre
cm^2	-	Square centimetre
cm^3	-	Cubic centimetre
DAP	-	Days After Planting
DM	-	Dry Matter
FP	-	Flat Plot with no mulch
FPM	-	Flat Plot with Mulch
GY	-	Grain Yield
Ha or ha	-	Hectare
HI	-	Harvest Index
Kg	-	Kilo gram
Ks	-	Saturated hydraulic conductivity
K	-	Potassium
LAI	-	Leaf Area Index
mm	-	millimetre
M^2	-	Square meter
M^3	-	Cubic meter

N	-	Nitrogen
OM	-	Organic Matter
PAR	-	Photosynthetic Active Radiation
P	**-**	Phosphorus
ppm	**-**	parts per million
RH	-	Relative Humidity
RWUE	-	Rain Water Use Efficiency
S	-	Sulphur
T	-	Temperature
WUE	**-**	Water Use Efficiency
θ_{fc}	-	Water content content at field capacity
θ_{wp}	**-**	Water content at permanent wilting point
ZMK	-	Zambian Kwacha

CHAPTER ONE: INTRODUCTION

1.1 Background

Mulching is an agricultural practice which is commonly used in Zambia in orchards and vegetable gardens in the dry season to conserve soil moisture. This practice is not commonly used on field crops like maize grown under rainfed conditions despite the potential to mitigate soil moisture stress due to uneven and unpredictable rainfall. Mulching has the potential to reduce direct evaporation of water from the soil.

Some studies have shown that mulching can increase crop yields by providing favorable soil moisture and temperature (Guo and Gu, 2000; Li et al., 2004; Wang et al., 1992).The increase in soil moisture and temperature has been observed as one of the primary drivers of increased crop yield globally (Allasir et al., 2001), Hansure and Umrai, 1945;Zhou et al.,2009; Chakraborty et al., 2010, Zhang et al., 2012; and Song et al., 2013). Soil microclimate under mulching favors root proliferation (Osuji, 1990) and suppresses weed growth (Lalitha et al., 2001). It has widely been reported that both grain yield and water use efficiency are increased under mulches (Li et al., 2001).

Mulching helps to promote stable soil aggregates as a result of increased microbialactivityin the soil and better protection of soil surface. Mulching also reduces water and wind erosion. The grass mulch decomposes and helps to increase the amount of organic matter in the soil. In addition, mulching can be an efficient and cheaper way of conserving rain-water. Evaporation can be significantly reduced if rain-water is stored in the soil to make it readily available to plants rather than in structures with open water surfaces. Such a practice would be economically feasible to resource poor farmers (Gabriel and Georgis, 1988). The results on soil moisture recharge, soil moisture use patterns, and soil moisture, crop yield relationships indicate a critical dependence of the crop growth on stored soil moisture (Li et al., 2004).

Mulching increases available soil moisture by reducing surface runoff. Most of the water from rainfall can infiltrate into the soil thereby improving soil moisture retention. This increases water use efficiency. Water use efficiency is a comprehensive index that represents the overall efficiency of the plant water use (Turner, 1987). It is commonly used to develop and evaluate optimum water management strategies to ensure the most efficient use of water resources. Therefore, mulching is a water management practice that can be used to increase water use efficiency and yield in areas of low rainfall (semi-arid areas or areas that are drought prone).

Mulching can be auseful practice to improve water harvesting in semi-arid areas (Zhou et al., 2009). The ridges made can direct water to the furrow where it can collect. The water infiltrates into the ground and rises by capillary action. This ensures a good moisture supply in the soil near the plantrootzone. In China, mulching is widely used in crop production in semi-arid areas. Mulching has proved usefulin improving the soil moisture regime and topsoil temperature (Wang et al., 2001).

The practice of ridging, on the other hand, helps to remove excess water from the root zone to enable the roots to grow correctly as the shedding off of excess water makes air available to the root zone. Ridging can be used in water harvesting. The ridge directs the water to the furrow and collects in the furrow or flows to the edge of the field where it collects. A micro basin can be dug to collect the water.

This research focuses on both effect of ridging and mulching on maize yield andrain water use efficiency (RWUE).

1.2 Statement of the Problem

Zambia has been faced with constant droughts, short duration, and uneven rainfall pattern. This has resulted in reduced production of the staple food, maize, due to inadequate soil moisture in the soil to meet the crop water requirement of the maize plant. This problem can be attributed to climate change and has led to food insecurity and high poverty levels on the rural population.

1.3 Objectives

1.3.1 Main Objective

The main objective of the study was to assess the effect of ridging and mulching on rain water use efficiency and maize yield.

1.3.2 Specific Objectives

1. To assess the effect of ridging and mulching on root zone soil water balance components;
2. To assess the effect of ridging and mulching on maize yield; and
3. To assess the effect of ridging and mulching on rainwater use efficiency of maize.

1.4 Research Hypotheses

1. There are significant differences in root zone soil moisture balancebetween the ridged and un-ridged treatments, as well as between the mulched and un-mulched treatments.
2. There are significant differences in maize yield between the mulched treatments and the unmulchedtreatments and between the ridged and the un-ridged treatments.

1.5 Justification

Mulching is widely being used in countries like China as an adaptation to water scarcity and increase agricultural production. The practice if adopted in Zambia can help increase maize production and reduce poverty on the rural populations. The study was therefore conducted if water use efficiency and maize yield could be improved under grass mulching and ridging. The recurrent droughts and erratic rainfall being experienced the country calls for other agronomic measures that can be adopted to increase food production. There has not been much research in this country to determine the effect of mulching and ridging on soil moisture content, rainy water use efficiency and yield in maize. It is therefore important to assess the root zone soil moisture content and rain water use efficiency brought about by mulching and ridging. If proved to improve these parameters, then it can be adopted and be used to improve crop production.

CHAPTERTWO: LITERATURE REVIEW

2.1State of Rain fed Agriculture in Zambia

Zambia's agriculture is mainly rain fed. Recurrent droughts and unusually heavy rains at times result in wide spread crop failure. This has impacted negatively on food security. Crop failures have also been attributed to land degradation and poor field practices and low usage of hybrid seed varieties among small holder farmers (MoFED, 1999). The majority of Zambian farmers lack capacity and resources to overcome climate change. Agricultural production is dominated by small holder farmers who produce about 80% of maize (Ngoma, 2013).The major crops grown are maize, groundnuts, cotton, sorghum, sunflower, millet, tobacco, cassava, soya beans and vegetables. There has been an increase in growing of crops like groundnuts, beans and sorghum as these require less inputs and lower production costs to produce them. The government is supporting the growing of maize through the farmer input support program (FISP).

Maize production has improved in recent years though yields are still as low as 1.5 to 2.0 tons/ha (CSO, 2014) in most provinces. The improvement in yield among small holder farmers is due to adoption of improved technologies such as use of improved seed, early planting and application of fertilizers to improve soil fertility. Adoption of conservation farming technologies has also played a role.

The planting season for maize starts in November. The seed bed is prepared by conventional methods of tillage that is hand hoeing and use of ox-drawn implements. Maize is usually grown on ridges in areas which receive higher rainfall (Zambia's ecological region (II) and (III) to avoid flooding of the maize fields. In Zambia's ecological region (I) which is Southern province and the valleys, maize is planted on flat ground.

2.2 Ridging

Ridging as a land preparation is meant to improve aeration (http://cropwatch.unl.ed). Crops are planted on the ridge to control weeds which grow in between the rows. Myburgh et al., (1991) define ridging as the heaping up of topsoil in a continuous band to create favorable rooting conditions above restrictions in the subsoil. Ridges can be made by using a hoe or an ox-drawn plow. Ridging reduces soil erosion if made across a slope by reducing the force of water. Ridging also reduces erosion by covering the soil. Two cultivations are requiredto prepare ridges according to (http://cropwatch.unl.ed). One is to loosen the soil and control weeds. The second provides additional weed control and rebuilds the ridges. Areas of high rainfall and poorly drained soils are highly suited to ridging.

Water logging creates soil conditions which restrict root penetration and functioning (Elvis and Payne, 1970; Russel, 1977; Kramer, 1983). Root growth is also slowed down due to lack of enough oxygen for root respiration. Also, water-logging causes leaching of plant nutrients and low soil temperatures (Russel, 1977). Plants such as grapevine are sensitive to excessive soil water during periods of active root growth (Weaver, 1976; Pongracz, 1978; Saayman, 1981). Maize is no exception. Optimal air is required for normal growth and functioning of plants. Grape vines favor optimal air composition. Kobayashi et al., (1963), measured root length with increasing oxygen levels. They observed that root length increased with increasing soil oxygen levels. Iwasaki, et al., (1966) found a drastic reduction in mass of the entire grapevine at oxygen concentrations of 15% and below. Hence in such circumstances ridging would be beneficial to remove excess water from the root zone and improve aeration. There is also production of ethylene gas in water logged soil conditions. The gas is detrimental to the growth of some plants (Ishii and Kadoya, 1984).

Ridging is used as a soil preparation of wet soil in South Africa (Van Zyl, 1985). This helps to keep the roots away from the water and poor aeration. If pore spaces in the soil are completely filled with water, diffusion of oxygen is restricted to a large extent. Ridges are also used in water harvesting in semi-arid areas. The ridge directs the water to the furrow where water infiltrates through capillaries to inside the ridge. Planting in the furrows ensures a good moisture supply in the soil near the plant (Wang et al., 2005). Ridging also complements furrow irrigation. It is easier to irrigate crops using the furrows. Furrows improve irrigation efficiency more especially on soils with high infiltration rates.

2.3 Tillage Practices

Tillage includes a wide range of practices ranging from reduced tillage and no-till for conservation systems in which a substantial part of the soil remains covered by previous crop residues (Holland, 2004) to mould board plowing as in conventional tillage systems.

Tillage systems are often classified by the amount of surface residue left on the soil surface (Magdoff, 2006). Conservation tillage systems leave more than 30% of the soil surface covered with crop residue. The amount of surface residue covered isata level where erosion is significantly reduced (Magdoff, 2009). Magdoff, (2009) further said it is easier to grow high yielding crops if high levels of organic matter are maintained in the soil. Higher levels of organic matter in the soil lessen the need to use more fertilizer, lime, and pesticides. Plants can withstand drought conditions and resist pest attack if the soil has high levels of organic matter.

Tilling the soil helps to prepare a seedbed, kills weeds and disrupts dormant insects and plant pathogens, incorporate nutrients and manage crop residues (http://cropwatch.unl.ed, 2017). The yield benefits of a tillage system are specific to each field and production practices. Each tillage system has advantages and disadvantages.The mechanical perturbation aiming at achieving desirable soil conditions for a seedbed and establishing a specific surface configuration for planting, irrigation, drainage or harvesting operation can have a considerable impact on soil hydraulic functions (Kepner et al., 1978).

Farmers and agronomists have debated the pros and cons of no-till versus other tillage systems for decades.No-till systems have performed better in some areas than convention tillage practices. No-tillsystem do not perform well where drainage is a problem (http://cropwatch.unl.ed, 2017).There are three type stillage systems according to (http://cropwatch.unl.ed): conventional tillage, conservation tillage and no-till system.

Conventional tillage can be defined according to http://cropwatch.unl.ed as a tillage system that involves 100% soil disturbance at the surface and leaves less than 15% residue on the surface of the soil. Convention tillage can be further classified as ridge tillage, plowtillage where implements such as a disc, chiseldriven by a tractorare used and a mold boardplow driven by oxen are used and strip tillage. In Zambia, there is also have hoe tillage which is common among peasant farmers. Ridge tillage is a primary tillage where ridges are built during row cultivation. Strip tillage is a minimum tillage cultivation system where the soil is left un disturbedexcept for strips where the soil is tilled, and residue removed to facilitate planting. Conventional tillage exposes the soil to wind erosion, and the loosened soil lose most of its moisture by evaporation

In conservation tillage which is being encouraged in Zambia, there is minimum disruption of soil and therefore helps to prevent soil erosion. Specialized equipment is used to plant seed leaving most of the residue from the previous crop intact. Conservation tillage adds organic matter to the soil andprevents the soil from being eroded. It also prevents loss of soil moisture by evaporation.

In no-till systems there is much less disruption of the soil. No crop residue from the previous crop is turned over. Crops are planted in a narrow strip opened by a special tool. This system also reduces evaporation of water from the soil and also reduces soil erosion by water or wind. The system increases infiltration of water in the soil. Herbicides are used to control weeds. No-till has been said to increase calcium, magnesium, manganese in soils and zinc in soils compared to convention tillage. Continuous cropping affects soil nutrient status. The results are inconsistent and vary with location. Hickman, (2002) found that 16 years of continuous soya been cropping did not affect the levels of ions such as potassium, calcium, phosphorus, magnesium, and zinc when compared to rotating with maize.

Field tillage systems have their disadvantages. They can help overcome certain problems such as compaction and high weed density (Magdoff, 2009). Secondary tillage crushes soil aggregates that make the soil to crust easily during the rainy season thereby increasing runoff. Intensely cultivated soils readilyform hard crusts after drying and make root penetration in the soil to be difficult (Magdoff, 2009).

The effectiveness of conservation tillage depends on the type of soil, climate and land types (Tolketal., 1999; Lampurlanes et al., 2006; Zhang et al., 2007 and Xie et al., 2008). Review of available research results, conservation tillage,gives increased crop yield or similar yield to convention tillage according to 89% of the studies over the past decade in China and decreased crop yields according to about 11% of the studies. Nevertheless, under conservation tillage there is less energy input, soil water is conserved, and soil quality and other ecological benefits like control of soil erosion could be achieved (Blanco- Canqui and Lal, 2008, Govaets et al., 2009; Li et al., 2009; Morris et al., 2010).

Convention tillage practices including intensive soil cultivation, crop residue removal, and burning have exacerbated soil erosion and degradation thus contributing to the development of soils with low organic matter content and fragile structure (Bi,1993; Tong, 2004). In an attempt to control the severe erosion and ensure food security, conservation tillage is being encouraged as a means of conserving soil water resources and increasing crop yields.

Differences in climate, soil physio-chemical properties, historical management, crop type, residues and in space-time variation can overwhelm tillage effects (Logdorm and Jaynes, 1966; Allerto et al., 2010). Also the impact of tillage depends on intrinsic soil properties on tillage characteristics such as tillage type, depth and speed and level of mechanical stress. Tillage has an effect of mechanical stress applied to soils. This reduces the porosity of soils. Primary and secondary tillage both have an effect on flow and transport of solutes in the soil (Jarvis, 2007). The nutrient distributions in the soil profile changes as no-till practices are adopted (Flenzluebbers and Hons, 1996). Tillage affects decomposition of surface residue and residue incorporated in the soil. It also affects mixing in tilled fields affecting the timing of nutrient release as well as soil water content, temperature and vertical movement of water. The factors contribute to nutrient stratification between tillage and no-till practices (Chen and Mead, 2005). Often no-till system results inmore significant amounts of potassium and phosphorus in the surface horizon (Dick, 1983; Howard et al, 1999; Fernandez et al., 2008) resulting from an incorporated fertilizer (Shear and Moschler, 1969; Scheimer and Lavado, 1988) and recycling of potassium from the deeper horizons (Jobaggy and Jackson, 2011).Throughout history, humans have tilled the land, and land degradation has occurred. Many civilizations have collapsed due to unsustainable land use (Magdoff, 2009). The United Nations estimates that 2.5 billion acres of land have suffered erosion since 1945 and 38% of the global cropland have become severely degraded since then (Magdoff, 2009).Most of the farmers in Lundazi follow convention farming methods of plowing using a hoe and mouldboardplow. Few use tractors, and also few use conservation tillage practices.

2.4 Soil Water Management`

Many of the cultural practices used in crop production have considerable-effects on crop production, its structure, and its biological life. Tillage breaks up soil structure, destroys biological life, buries residue cover and reduces soil moisture (http://cropwatch.unl.ed) Corrective crop management practices have focused on above ground problems. Research, however, has discovered that what appear to be subtle difference below the soil surface may have profound effects on productivity and sustainability (http://cropwatch.unl.ed).Farmers must manage their tillage systems, crops, and residue to build healthier soils with improved structure to better manage water resources. Improving soil structure and biological activity while maintaining residue cover will, reduce runoff, erosion,evaporation and the related environmental impacts (http://cropwatch.unl.ed).

Crop management continues to impart water use. Zhang et al., (2010) measured a substantial effect of cultivar genetics on grain yield and water use efficiency (WUE). Chen et al., (2010) investigated the effect of raw spacing in winter wheat on soil evaporation and other factors affecting WUE under irrigated conditions. Evaporation increases with an increase in soil desiccation. Li et al., (2014), measured soil moisture in long-term experimental plots. It was found that soil water in a persistent dry layer (below 2m) was recharged during a wet year with a return period of approximately ten years. Indices of crop water requirement (CWR), irrigation water requirement (IWR) and crop water stress index (CWSI) developed using energy balance measurements can be used for agricultural water management. Sun et al., 2010, showed that different ranges of IWR for wheat and maize despite similar values of CWR.

Precipitation is one of the most critical factors affecting agricultural production, especially in arid and semi-arid regions. The annual amount of precipitation and its seasonal distribution are crucial for agricultural production because precipitation directly affects water balance, irrigation requirements and water use efficiency of the different crops (Sun et al., 2010). Kang et al., 2002 and Deng et al., (2006), reviewed water saving in China by focusing on agronomic options and Kang et al., (2004) discussed the technology and theory of agricultural and ecological water saving engineering. Other recent reviews on comprehensively improving WUE under limited waterconditions are the molecular plant breeding and agronomic management of high WUE (Passioura, 2006).

2.5 Mulching and Soil Moisture Conservation

The practice of mulching has been usedas a means of conserving moisture and has been used as a management tool in many ancient civilizations (Das et al., 2014). It is now commonly used in the growing of field crops like maize in the rainy season in semi-arid regions of some countries like China. Mulch is a cover on the soil surface. Mulches take different forms. Itcan be a vegetative cover, manure or plastic mulch or a cover crop grown in the field with another crop. The cover crop acts as a mulch to the other. Some mulching practices are used in water harvesting insome countries and farmer scan practice double cropping. A season's crop is grown under natural rainfall with mulch on it and after the rains and after harvesting, a second crop is grown, mulched and grows successfully without rainfall using soil moisture conserved in the soil in the rainy season. Mulches are helpful in reducing water inputs for successful crop production, water conservation and increased kernel yield in rice or other crops and this can be employed to achieve food security (Xu et al., 2007; Zhang et al., 2008), for example straw mulch applied in non flooded rice, aided rice plants to maintain dry matter and grain yield (Qin et al., 2010). In rice cultivation without the need for continuous flooding, the use of plastic sheets as soil cover reduces evaporation, suppresses weeds, regulates air temperature, and this increases crop yields (Lin et al., 2002; Tao et al., 2006; Qin et al., 2006). Zambia experiences high temperatures during the rainy season, and this leads to high evaporation of water from the ground. If this practice of mulching can be adopted in Zambia in seasons of less rainfall or precipitation, it can help to conserve soil moisture and increase crop production. Thus, mulching can be a barrier to surface evaporation loss and enhance soil water conservation (Qin et al., 2010).

Mulching reduces evaporation of water from the baresoil, and the soil acts as an excellentstorage of water than in free open surfaces (Daset al., 2014). The surface mulch influences soil moisture regime by controlling evaporation of water from the soil surface (Raene- Sarjaz and Barthacur, 1997; Wang et al., 2009), improving infiltration and soil water retention, decreasing bulk density and facilitating condensation of water at night due to temperature reversals (Acharya et al., 2010).The results of soil moisture recharge, moisture use patterns, and soil moisture maize yield relationships indicate the critical dependence of the crop on stored soil moisture (Holt et al., 1964). In Zambia, the growing of maize is highly dependent on rainfall. Moisture conservation techniques like mulching will be highly necessary due to uncertain weather pattern and drought.

Mulching reduces soil erosion. The plant cover on the surface of the soil reduces the speed of runoff water and its capacity to carry soil particles. Thus, mulching can also be used as a soil conservation technique (preventing soil erosion by water) as well as well as a water conservation technique. The surface mulch reduces the impact of a direct rain drop on soil particles. This reduces soil compaction and aggregate disintegration (Mbagwu, 1991). Wind erosion is also prevented in a field which is mulched than the other which is not mulched. Mulching prevents direct contact between the soil with the wind. Physical conditions of the soil are improved under mulching. There is improved infiltration of water in the soil by preventing runoff water from escaping the field (Gosh et al., 2006) and increasing topsoil temperatures. Solar energy passes through the mulch and heats up soil and air beneath the mulch. The heat is trapped by a greenhouse effect (Wang et al. 2005). Soils without mulch receive solar radiation more directly converting liquid into gas. Mulching suppresses this and returns soil moisture to provide more water to the plants. Mulching has performed well in areas with high elevation and low accumulated temperatures (Wang et al.2005) because mulching is said tohave a buffering effect on the soil as it dampens the influence of negative environmental factors on the soil (Bristow and Abrechit, 1989). The magnitude of this buffering effect depends on the quality, quantity, and durability of the mulch material. Maize does not grow well at low temperatures, and the crop can even fail to mature or mature slowly and consequently give low yields. If grass mulch is used, it later decomposes thereby improving the fertility of the soil and reducing the soils bulk density. The decomposed mulch increases the organic matter content of the soil thus improving other soil physical and chemical properties.

2.6 Mulching and Water Use Efficiency

Carbon dioxide acquisition by plants through photosynthesis results in more water loss through the stomata in the leaves. More water is transpired compared to small amounts of carbon dioxide that is fixed for photosynthesis. Tropical plants transpire 200-1000g of water per gram of carbon assimilated (Martin et al., 1976). With diminishing water supplies, the threat of more frequent droughts due to climate change and increasing demand for food crops, the possibility of increasing agricultural water productivity through agronomic and genetic means has received much attention (Arausetal., 2008; Reynolds and Tuberose, 2008; Passioura and Angus, 2010). Although conservation agriculture has improved irrigation management, other agronomic practices have made significant contributions to improving yields under water limited conditions (Anderson et al., 2005; Turner and Asseng 2005). Genotypes that are better marched to their target environments are needed. One theoretical avenue for improving yields is through manipulation of the relationship between carbon gain (photosynthesis) and water loss (transpiration). The ratio between the two parameters is what is referred to as water use efficiency (Bramley et al., 2013).

One of the problems associated with WUE in the field or evapo-transpiration includes water lost by evaporation as well as by plant transpiration. It is not easy to measure soil evaporation within the crops in the field as it will differ from bare soil even when measured nearby. Canopy architecture, organ morphology and anatomy influence plant water uptake capacity, transport efficiency and water loss. These in turn influence plant water status (Bramley et al., 2013). Canopy architecture will influence WUE through its effects on evaporation. More closed canopies have higher humidity and hence lower rates of transpiration. This conserves water but reduces light penetration and lowers photosynthesis. Canopy size and architecture in the field affects evapo-transpiration through soil moisture evaporation. Agronomic methods such as stubble retention and application of mulches can help reduce evaporation from the soil (Yunasa et al., 1994; Richards et al., 2002; Gregory 2004). Soil moisture evaporation is also prevented by crop canopy that shades the soil surface (Siddique et al., 1990). Soil moisture evaporation from the soil surface may be greater early in the season before the canopy has fully established, depending on temperature and humidity.

Mulching suppresses weed growth by covering the weeds. This also reduces the loss of water from the weeds through transpiration. Weed density is greatly reduced in mulched plots than in plots which are not mulched. Slow decomposing mulches, usually cereals with high C/N ratio can smoother weeds for a very long period (Murungu et al., 2010). Disease pathogens are also inhibited under mulch. The surface mulch reduces crop water requirements by reducing evaporation. This in turn results in improved water use efficiency (Hou et al., 2010). Mulching can help the sustainability of a cropping system by increasing water storage, leaf area index, and biomass and grain yield of a crop (Zhang et al., 2011). There are other additional benefits of soil cover in addition to soil water conservation. Mulches improve soil water interception and reduce runoff (Garcu-Moreno et al., 2015). Microbial activity is increased as a result of increased temperature. The temperature increase under plastic mulches accelerates organic matter decomposition thereby improving the nutrient status of the soil. The type and quantity of mulch affects the effectiveness of that mulch to return soil moisture and increase crop productivity (Li et al., 2001; Cook et al., 2006). Since the 1990s, use of chemical fertilizers, mulching, and rainfall harvesting have been adopted in some countries to increase crop yields through ridge and furrow rain waterharvesting. This is yet to be seen happening in Zambia.

2.7 Leaf Area Index (LAI)

LAI characterizes the canopy- atmosphere inter phase. It is important in assessing growth and vigour in vegetation. It is also fundamental as a parameter in land surface processes and parameterization in climate models and controls the link between the biosphere and atmosphere through various processes such as photosynthesis, respiration, transpiration, and rain interception (Breda, 2003). It drives both the within and below canopy micro-climate, determines and controls canopy water interception, radiation extinction, water and carbon dioxide exchange and is therefore a key component of bio-geochemical cycles in the ecosystem. Any change in LAI is accompanied by modifications in stand productivity (Breda, 2003). LAI is used in simulation models that are often required to produce quantitative analyses of productivity. LAI is being used in ecosystem management, forestry, climate change studies and changes occurring in the biosphere.

2.8 Biomass

Above ground biomass represents crops accumulated photosynthesis products. Biomass is an essential factor in the environment and climate modelling. It is also an essential participant in global carbon cycle. Biomass can be considered as a strategic resource because: it is renewable, it is accessible to any area, it provides products of vital interest (e.g. food, feed, raw materials for various industries, bio-fuels, and others).Maize as a C4 crop has less water requirement for plant dry matter production (Dubrovsk, 2010). However, the water stress affects significantly the maize biomass production. There is a wide response of maize plant to drought according to the cultivated hybrid, respectively according to the capacity of genotype to adapt to the environmental conditions and to tolerate water stress. Nevertheless, the maize varieties behaviour to specific climatic and soil conditions must be well known in view to be cultivated the right variety and the farmers to take the appropriate technological decisions.

2.9 Rain Water Use Efficiency (RWUE)

In agriculture, efficiency is a relationship between output and input (Sadras et al., 2011). Output, including measured total biomass or grain yield. These can be expressed as kg/ha or in monetary units ZMK/ha. Input, include water, materials such as seed, fertilizers, radiation, energy, labour and capital. In this case the input is rain water (precipitation) measured in millimeters.

The evaporative demands of the atmosphere are driven by vapour pressure deficit and net radiation. The efficiency of water use becomes increasingly crucial because water is a limiting factor for increased food production to supply an ever-increasing world population. Rain water harvesting is increasingly used to overcome water constraints more especially in semi-arid regions of the world but only a limited amount of water is harvested which can be used to irrigate crops. With diminishing water supply the threat of more frequent droughts due to climate change and the increasing demand for more food crops, the possibility of increasing agricultural water productivity through agronomic and genetic means has received much attention (Aurus et al., 2008; Reynolds and Tuberosa 2008, Passioura and Angus 2010). Conservation agriculture, irrigation management and other agronomic practices have made significant contributions to improving yields under water limited conditions (Anderson et al., 2000; Turner and Asseng, 2003). One avenue for improving yields with less water is through manipulation of the relationship between carbon gain (photosynthesis) and water loss (transpiration). The ratio between the two parameters also called the water use efficiency describes how efficient the plant is at optimizing carbon gain while at the same time minimizing water loss. Plants that are drought tolerant or have evolved in environments with limited available water tend to have higher water use efficiency (WUE) than plants adapted to freely available water (Smith et al 1989). It is therefore not surprising that different plants vary in their WUE (Briggs and Shantz, 1913; Rawson and Begg, 1977; Siddique et al., 2001). Many species of crop plants also display plasticity in their WUE (Smith et al., 1989), acclimating to drier conditions. Identification that there is intra-specific genetic variation for WUE has encouraged plant breeders to develop selective programs for improving WUE to improve drought resistance (Farquhar and Richards, 1984; Condon et al., 1990; Bonhomme et al., 2009; Barbour et al., 2010; Galmes et al., 2010; Devi et al., 2011). However, traits associated with a high WUE are often associated with low yield potential.

2.10 Harvest Index

Harvest Index (HI) represents the proportion of dry plant biomass allocated in grains or economically harvestedpart of the plant (Ion et al., 2015).HI can be relatively constant for a given species of a crop in a given climate and can be used to compare between crops.HI is influenced by different environmental factors and management practices. Variations in HI can be attributed to differences in crop management (Yang et al., 2004; Guo et al., 2004; Kemanian et al., 2007; D’ Andrea et al., 2008; Peltonen- Sainio et al., 2008).HI represents the efficiency of a crop to convert photosynthetic products into economically valuable form (Kawano K., 1990). It describes the plant capacity to allocate biomass (assimilates) into formed reproductive parts of the plant (Wnuk et al., 2013). This HI is the partitioning of dry matter by parts of the plant between biological and economic yield (Shafi et al., 2009). Also,HI can also be be defined as the physiological efficiency and ability of a crop for converting total dry matter into economic yield (Shafi et al., 2012). Among cereals, maize has the highest yield potential. A good water management system such as mulching can help to increase growth in plants and enhance the mobilization of assimilates from vegetative tissues to grain during the grain filling period. This leads to a higher HI within the crop (Xue et al., 2006; Zhang et al., 2008; Bueno and Lafarge, 2009; Fletcher and Jameison, 2009; Ju et al., 2009). In many situations, HI is closely associated with WUE.

Grain filling is the final stage in growth in cereals when fertilized ovaries develop into caryopses and depend on carbon from two sources. One source is current assimilates redistributed from reserve pools in vegetative tissues either pre or post-anthesis period (Kobata et al., 1992; Schnyder, 1993; Samonte et al., 2001). Remobilisation of reserves to the grain is critical for grain yield. If the plants are subjected to water stress or if the yield potential is largely based on the high biomass accumulation (Yoshida, 1972; Ehdaie and Wanes, 1996; Asseng and VanHerwaarden, 2003; Plaut et al., 2004). Remobilisation and transfer of stored assimilate in vegetative tissues to the grain in monocarpic plants require the initiation of whole plant senescence (Gan and Amasino, 1978; Nooden et al., 1977). Delayed whole plant senescence (i.e., plant remains green when grain is due to ripen) results in non-structural carbohydrates left in .the straw and leads to low HI. The slow filling can often be associatedwith the delay in whole plant senescence (Zhu et al., 1997; Mi et al., 2002; Gong et al., 2005). Overuse of nitrogen fertilizers ca delay plant senescence (Buresh et al., 2004; Peng et al., 2006). Usually water stress at grain filling stage can induce early senescence and shortens the grain filling period but increases the re-mobilisation of assimilates from the straw to the grain (Kobata and Takami, 1981; Nicolas et al., 1985; Palta et al., 1990; Asseng and VanHerwaaden, 2003; Plaut et al., 2004).

CHAPTER THREE: MATERIAL AND METHODS

3.1Location and Climate

The study was conducted in Lundazi District of Eastern Province of Zambia during the 2016/2017 farming rain season (longitude 33.18° E and latitude 12.8° S, at an altitude of1080m above sea level). The climate of the area is subtropical with annual mean temperature of 22° C. The rainy season for the area is from November to April, this is followed by cold, dry season (May to July) and a hot, dry season (August to October). The highest temperatures are experienced in December with the mean maximum temperature of 31°C and the coldest month is July with a mean minimum temperature of 10°C. The people in the area grow maize, groundnuts, sweet potatoes, pumpkins, sunflower and beans as food crops as well as for sale while cotton and soya beans are grown for sale. Maize is the dominant crop grown in the area, and it is the main food crop. It is usually grown on ridges, the tradition tillage system in the area, made using hoes or ox-drawn implements. Most tillage and weeding operations are done using human labor and animals (cattle). The dominant soils in the area according to the soil map of Zambia are Acrisols. The soil texture in the field where the experiment was doneissandy loam according to USDA classification (hydrometer method) and soil bulk density of 1.59g/cm^3 (core ring method).

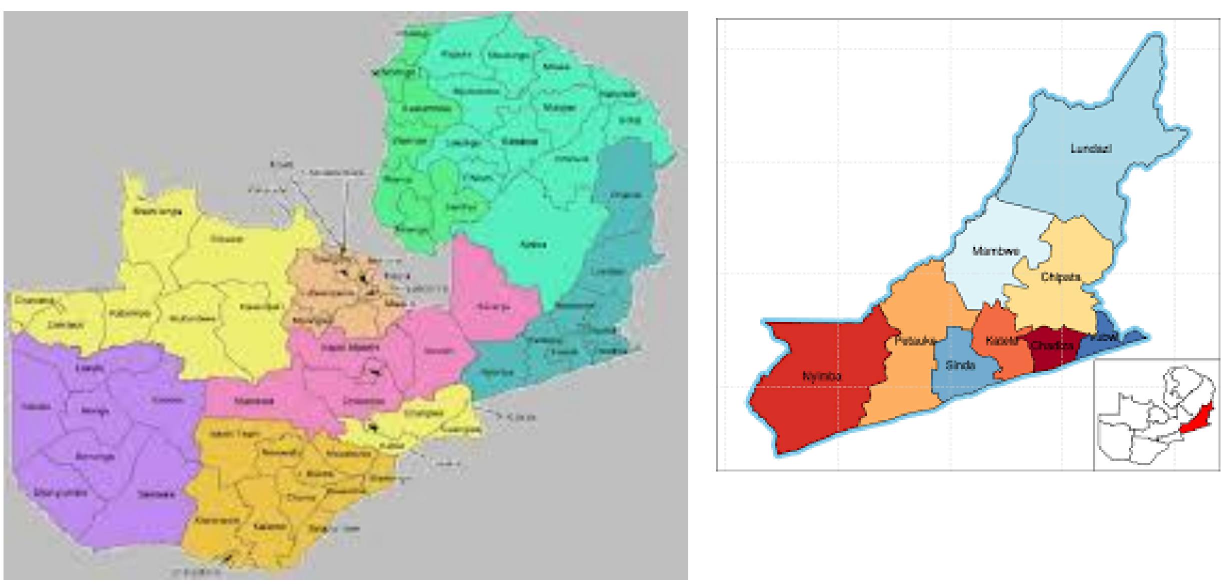

Figure 1: Location of Lundazi District (Source: http://wwwgoogle.com/search**)**

Figure 1 above shows a map of Zambia and Eastern Provence to the location of Lundazi district. The coordinates of the site of the experimental study are11.6˚S and 33.31˚E.

3.2 Experimental Setup

The experimental design was a Randomized Complete Block Design (RCBD) involving four treatments which were replicated three times. The treatments were: (i) ridged plot without mulch (RP), (ii) ridged plot with mulch (RPM), (iii) flat plot without mulch (FP) and, (iv) flat plot with mulch (FPM). Hybrid maize (variety SC 513)was used in the experiment.

3.3 Land Preparation

The site was cleared before the onset of the rains and cultivated using hoes. The size of the field was 25m x 25m which was demarcated into three blocks. The total number of plots was twelve with a plot size of 5m x6m. The distance between each block was 2m and between each plot was 1m. A mini weather station was set up close to the site to record temperature, relative humidity, and rainfall.

Maize was planted on 8thDecember 2016 at a spacing of 50cm between rows and 30cm between plants leading to a density of 69,667plants per hectare. Compound D (10% N, 20% P_2O_5, 10% K_2O and 6% S) and Urea fertilizer (46%N) was applied at a rate of 300kg/ha as basal and top dressing, respectively. The treatment effects were imposed a month after sowing on 11thJanuary 2017. Hyperrhenia grass (*Hyperrheniahirta*) was used as mulch. In the ridged plots, the mulch was placed in the furrows, and in the flat plots, the mulch was placed between the rows. A pre-emergent herbicide (glyphosate) was applied at a rate of 5 litres/ha to suppress weeds during early plant growth. The temperature data during the maize growing season is shown in figure 5 below.

3.4 Data Collection

3.4.1 **Determination of days to 50% tasseling and 50%silkingin Maize**

Maize growth was monitored on a daily basis, and the number of maize plants tasseling and silking wasphysically counted and recorded on a daily basis, and time taken for 50% and 100% of the maize to tassel and silk was counted and recorded.

3.4.2 Soil sampling and measurement of parameters

Soil samples from a depth of 0-20cm were randomly collected from each plot to characterize physical and chemical properties of the soil. The soils were mixed to form a composite sample of the experimental field. The soil was air dried and sieved using a 2mm sieve. Soil pH was measured in 0.01M calcium chloride using a soil solution ratio of 1: 2.5 (McLean 1982). Organic matter content was determined by using the Walkley and black method (1934). Exchangeable potassium was extracted by using 1N ammonium acetate (1N NH_4OAc). The concentration was determined by using the Absorption Atomic Spectrometer (AAS) as explained by Bashour and Sayegh (2007). Available phosphorus was determined by the Bray I method for acid soils (Bray and Kurtz, 1945). The amount of total nitrogen was determined using macro Kjeldahl procedure adapted from Bremner, (1960).Bulk density was determined by use of a core ring, a method described by Tan (2005). The soil properties were measured to determine the soil properties and the nutritional status of the soil before planting.

3.4.3 Determination of Leaf Area Index

Leaf area index (LAI) was determined fortnightly from three randomly sellected plants in each plot. This was done by measuring the length and width for leaf surface area which was multiplied by a factor of 0.75 (leaf shape factor) empirically determined (McKee, 1964) to obtain the surface area of each leaf. The average of leaf area was multiplied by plant density and dividing by area to give LAI (equation 1).

Leaf Area Index (LAI) represents the amount of leaf material in a field or forest or ecosystem. It is a dimensionless quantity that characterizes the plant. It is defined as one-sided area of photosynthetic tissue per unit area of ground (Breda, 2003).

$$LAI = \frac{LA}{GA} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. [Equation\ 1]$$

Where LA is leaf area and GA ground area

3.4.4 Plant Biomass Sampling

One plant was sampled randomly from each plot every two weeks by cutting the shoot at ground level and chopped. The chopped shoot was air dried then later oven dried for twenty-four hours at 65° C. This was expressed as kg DM/ha. The final above ground biomass was determined at harvest which included Stover and grain yield.

3.4.5. Particle size analysis

Soil texture was determined from soil samples collected to a depth of 80cm.Some samples were collected in each plot which were oven-dried for 48 hours at 105°C. Particle size analysis was done following a procedure for mechanical analysis and the settling sequence of the particles was determined using standardized Bouyoucus Hydrometer (Bouyoucus, 1962). The textural class was determined using the United States of America Department of Agriculture (USDA) textural triangle. Soil water retention properties at field capacity, wilting point and available water content including saturated hydraulic conductivity were obtained using Soil Water Characteristics-Hydraulic Properties Calculator developed by Sexton and Rawl(2004).

3.4.6 Measurement of Weather Data

Weather data during the study season was collected from a mini weather station set up close to the site. Weather elements recorded at the station included rainfall (mm) using a rain gauge, minimum and maximum temperatures (ºC) using a digital thermometer and relative humidity (%) using a digital hydrometer.

3.4.7 Soil Moisture Measurement

Soil moisture content of the soil profile during plant growth was determined by gravimetric method (Peters, 1965). Soil samples were collected every fortnightly using an auger at intervals of 10 cm up to a depth of 80cm. These soil samples were oven dried at 105°C for 24 hours. Soil moisture content was expressed as the ratio of mass of water to the mass of oven dry soil.

Gravimetric water content was calculated by:

$$\theta g = \frac{Mw}{Ms} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [\textit{Equation 2}]$$

Where θg is the water content (%), Mw is the mass of water and Ms is the mass of oven dry soil

Volumetric water content was obtained by multiplying the gravimetric water content by bulk density:

$$\theta v = \rho * \theta g \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [\textit{Equation 3}]$$

where θv is the volumetric water content, ρ is the soils bulk density

Soil moisture storage:

Soil moisture storage (*S*) was the integral of volumetric water content soil profile.

$$S = \int_{i=z}^{i=1} \theta * dz (\textit{Equation4})$$

Where θ is the volumetric water content and *dz* is the soil thickness

3.5DataAnalysis

3.5.1 Harvest Index

Harvest index (HI)is influenced by different environmental factors and management practices.HI is fairly constant for a given species of a crop in a given climate and can be used to compare between crops and can be calculated as a percentage fraction grain yield to total aboveground biomass.(Huehn, 1993).

$$HI = \frac{Y}{B} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [\textit{Equation 5}]$$

where *B* is biomass in kg/ha and *Y* is grain yield (kg/ha)

3.5.2 Rainwater Use Efficiency (RWUE).

Rain Water Use Efficiency (RWUE) is a ratio of yield to the amount of rainwater used during the whole growing season and it is expressed in kg/ha/mm

$RWUE_b = \frac{Y}{R}$ ……………………………………………[*Equation 6*]

$RWUEs = \frac{S}{R}$ … … … … … … … … … . . … … … [$Equation$ 7]

$$RWUEg = \frac{GY}{R} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots [Equation\ 8]$$

Where S is stover weight and GY is grain yield and R is rainfall

Rainfall or precipitation needs to be measured for the whole growing season. Higher water use efficiency leads to higher productivity, and higher water use efficiency also lowers the amount of water required to produce each unit of biomass. Higher water use efficiency also reduces evapotranspiration and increases latent heat (i.e., warmer temperatures in the canopy).

3.6 Statistical Analyses.

The effects of the treatments on the measured parameters were evaluated by one-way ANOVA using R software. When F values were significant, the least significant difference test (LSD) was used for comparing the means. In all cases, differences were deemed significant at ($p<0.05$).

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Soil Chemical Properties of surface soil

The results for chemical properties of the top 20cm of soil at the experimental field are presented in table 1. The soils in the experimental field were strongly acidic as was observed from the pH of 4.1. The organic matter content was low (1.52%) but within a range a soil should have. The total nitrogen content was very low in this soil (0.019%) and that of exchangeable potassium was at 139mg/kg of soil. The concentration of available phosphorus was 20mg/kg of soil. The texture of the soil was classified as sandy loam.

Table 1: Soil characterization of study site at 0-20 cm before planting.

VARIABLE	UNIT	VALUE/NAME
pH ($CaCl_2$)		4.1 ± 0.4
Bulk density	g/cm^3	1.59 ± 0.068
Organic matter	%	1.52 ± 0.023
Organic carbon	%	0.76 ± 0.0115
Total Nitrogen	%	0.019 ± 0.0016
Phosphorus	mg/kg	20 ± 4.36
Potassium	mg/kg	139 ± 21.04

4.2 Soil Physical properties of the surface and sub-surface soil

Selected physical properties of the soil as well as water retention properties from the experimental field are presented in Table 2. The soil texture in the upper 40cm was sandy loam, 50 to 70cm was loam and 70 to 80cm, silt loam. Water content at field capacity was highest in the lower 70 to 80cm layer and lowest in the 10 to 20cm layer. Available water was highest in the 10 to 20cm layer and lowest in the 70 to 80cm layer. The saturated hydraulic conductivity was highest in the upper 10 to 20cm layer and lowest in the 70 to 80cm layer.

Table 2: Soil Physical Properties at different depth measured in the field

Depth	Sand (%)	Clay (%)	Silt (%)	Texture	Bd (g/cm^3)	θ_{FC}(v/v)	θ_{WP}(v/v)	AWC (mm/m)	K_S(mm/hr)
10	70.8	13.9	15.3	SL	1.59	0.170	0.095	0.08	29.32
20	72.8	13.6	13.6	SL	1.59	0.166	0.094	0.07	30.37
40	62.8	17.6	19.6	SL	1.59	0.208	0.118	0.09	17.13
60	38.8	21.6	39.6	L	1.59	0.272	0.142	0.13	5.23
80	25.8	23.9	50.3	SiL	1.59	0.304	0.153	0.15	2.70

Bd = Bulk density, SL = Sand loam, L= loam, SiL = Silt loam, v/v= volume/volume, AVC= Available Water Content, FC= field Capacity, WP= wilting Point, Ks = Saturated hydraulic conductivity

4.3 Rainfall

The amount of rainfall received during the season was 907mm which was well above the estimated long-term average of 707mm. The rainfall was above normal by 21%. The highest rainfall in the season was in January, and the lowest was in March. The primary season started in December and ended in April. The rainfall intensity and distribution throughout the season was fair. The number of days without rainfall during the season ranged from 1 to 6 days. The most prolonged period without rains was towards the end of the season in April for twelve days from 3rd April to 14thApril 2017. The rainfall intensity ranged from light to heavy. High-intensity rainfall lasted from 15 to 30 minutes, and low-intensity rainfall could go over an hour. The total number of rain days was 68 against an estimated long-term average of 88 days. Figure 2 and 3 show the rainfall and RH during the studied season and the long-term averages respectively.

The rainfall pattern shows that in the past, rains used to come early. The long-termaverage rainfall for November was 57mm and in the year of study there was none. This means that the rainy season in the year of study did not start in November. The number of rain days was 7. In December the long-term average rainfall was 171mm with 16 rainy days. The amount of rainfall recorded during the studied season was180mm with 11 rainy days. The long-term average rainfall was less by 5%. The long-term average rainfall for January was 202mm with 18 rainy days and for the studied season was 290mm with 18 rainy days. The long-term average rainfall was less by 43%. The long-term average rainfall for February was 195mm with 17 rainy days where as the amount for the studied season was 184mm with 15 rainy days. It was less by 5.6%. The long-term average for March was 124mm with 13 rainy days. The rainfall for March during the studied season was low (71mm) with 7 rainy days. It was less by 42%. April had more rains during the studied season at 145mm with 8 rainy days where as the long-term average was 35mm with 4 rainy days. It was higher by 300%. This shows that rains used to withdraw early in the past than the current season. Figure 2 shows rainfall and RH data during the study season and Figure 3 shows long-term rainfall and humidity data.

Relative humidity was higher in the studied season than the long-term average result throughout. The mean maximum temperatures were higher in the months December to May in the studied season than the long-term average. The mean minimum monthly temperatures for long term average were lower almost throughout the year than those of the studied season. Figure 4 shows the mean maximum monthly temperatures in the study season and Figure 5 the long- term average. The higher humidity and higher temperatures during the study season explain why the season had more rainfall than the long-term average which was well distributed throughout the season.

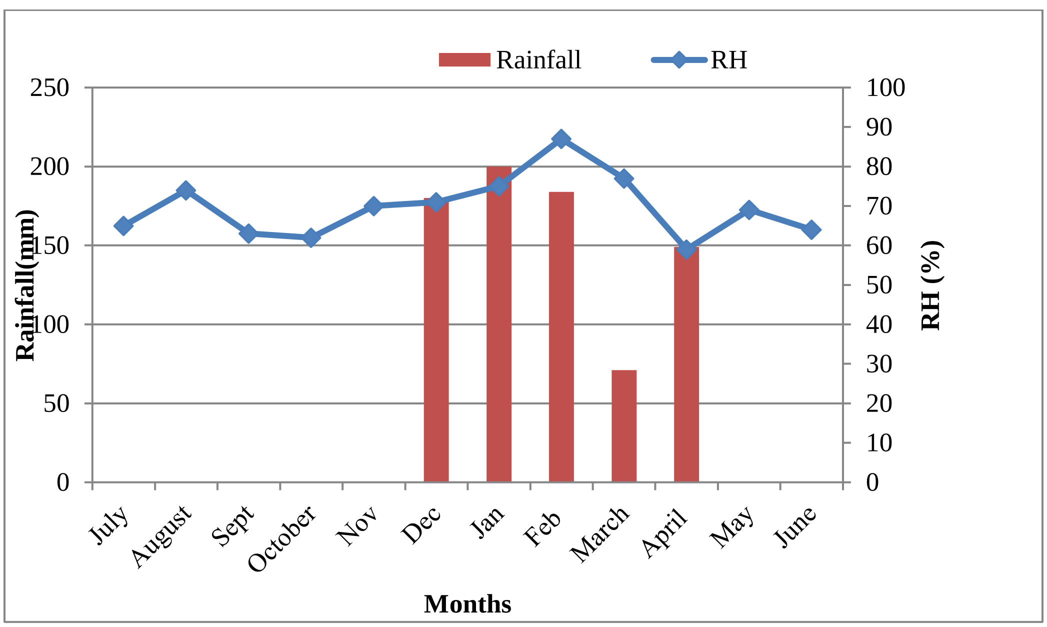

Figure 2: Rainfall and RH data measured at the site during 2016/2017 rainfed season

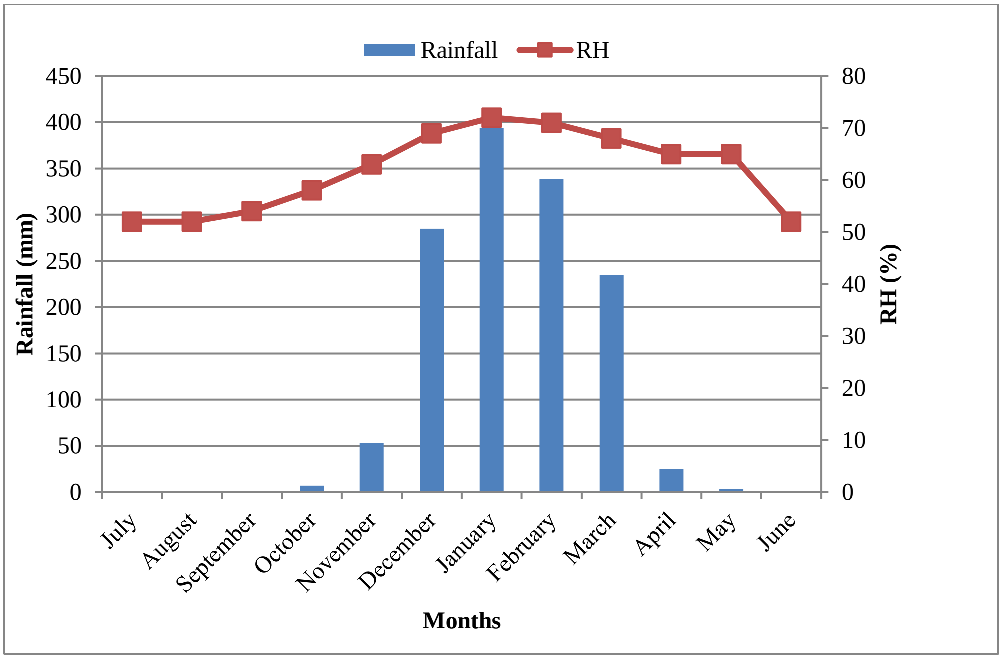

Figure 3: Rainfall and RH data at the station (Long-term averages). Source: New Local Climate.

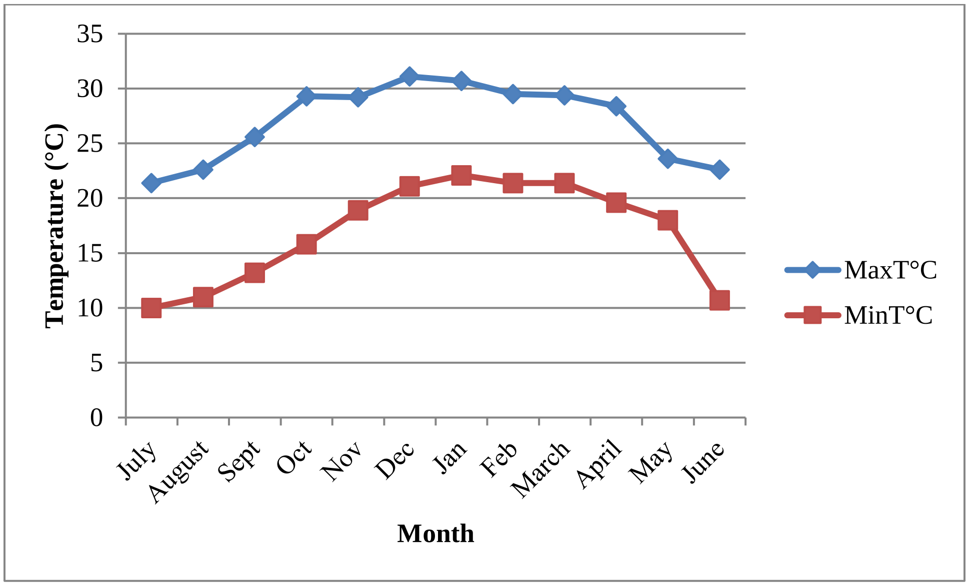

Figure 4: Maximum and minimum temperatures measured at the station during the 2016/2017 farm rainy season

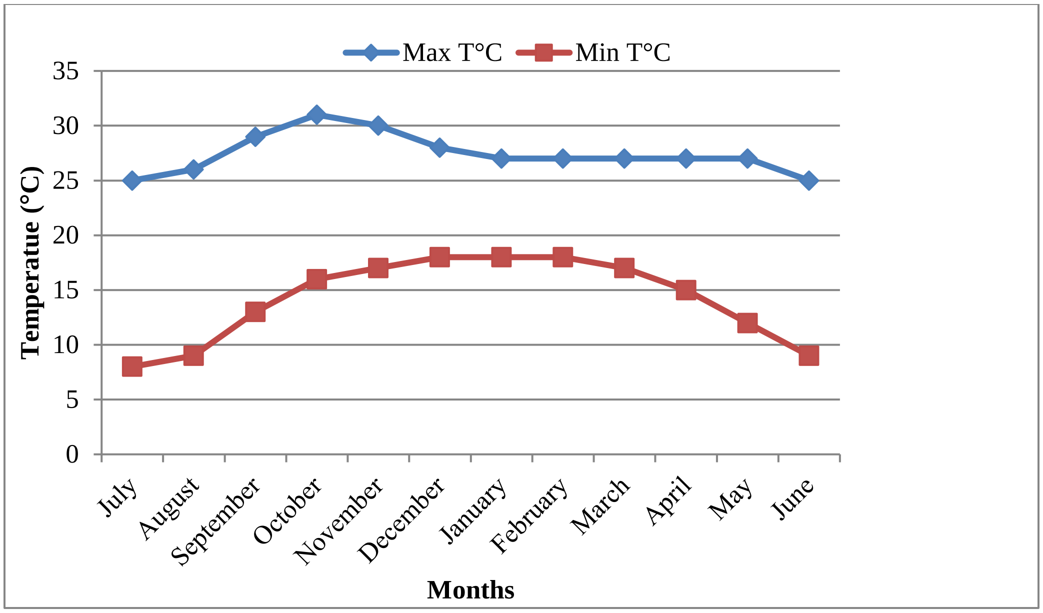

Figure 5: Maximum and minimum temperatures (long term averages). Source: New Local Climate.

4.4MaizeGrowth

Results on maize growth and associated development stages are presented in Figure 6 and 7.Figure 8 shows maize growing in the flat without mulch treatment at 68 days after planting.

The number of days to 50% tasseling ranged from 56 to 59 with a mean of 58 days. Maize in the FPM was the first to reach this mark at 56 days and the last to raech the mark was maize in the RP treatments. There were no significant differences in the number of days they took to reach 50% tasseling.

The number of days to 50% silking varied from 64 to 66 with a mean of 65 days. The first to reach 50% silking was maize from the RP and RPM treatments at 64 and the last was maize from the FP and FPM treatments at 66 days.There were no significant differences amongtreatments in the number of days taken to reach 50% silking.

The time taken for 100% of the maize to tassel varied from 65 to 69 with a mean of 67 day. The first to reach the 100% mark was maize from RPM and FPM at 65 days and the last was from the FP treatments at 69 days. There were no significant differences among the treatments in the number of days taken to reach 100% tasseling.

The number of days to reach 100%silkingvaried from 72 to 75 with a mean of 75 days. The first to reach the 100% mark was maize from FP and RP treatments at 72 days and the last was the FPM treatments at 75. There were no significant differences among the treatments. Maize in the FPM treatments reached the 50% and 100% early because the roots were stressed by presence of excess moisture in the root zone.

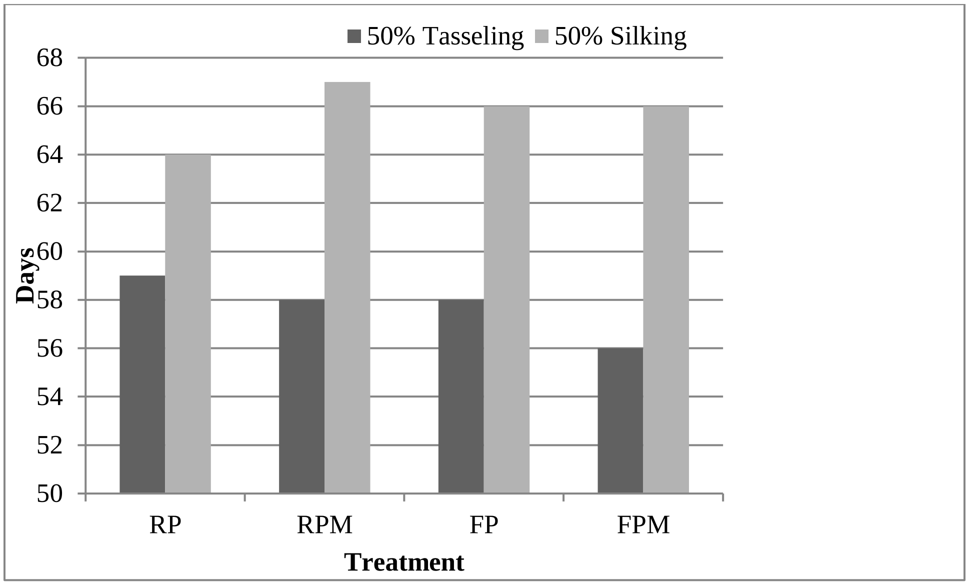

Figure 6 : Days to 50% Tasseling and 50%Silking

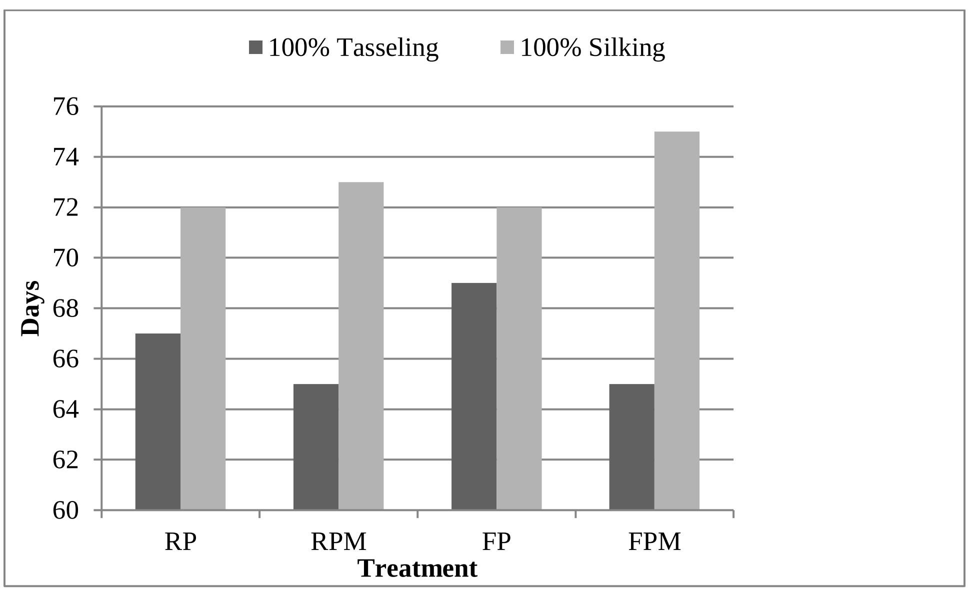

Figure 7: Days to 100% Tasselling and Silking

At 47 days of growth in the field plants had six to ten leaves per plant.

Figure 8: Maize growing in a flat with no mulch treatment at plot 47 days after planting

4.5 Effect of Ridging and Mulchingon Leaf Area Index (LAI)

Effects of the ridging and mulching treatments on leaf area index during plant growing season are shown in Figure 9. There was a sharp increase in leaf area index during the early growth stages up to sixty-six days after planting. After that, there was a sharp decline in LAI indicating leaf senescence. Significant differences were observed in the third recording (sixty-five days after planting) at ($p < 0.05$). LAI was consistently higher in flat without mulch treatment. There was more increase in LAI in a flat without mulch treatments than the others. It was followed by ridge without mulch treatment, and after reaching the peak, the FP and RPM had the same LAI during the decline period. The flat without mulch treatments (FP) were able to lose more water by evaporation from the bare surface or runoff hence there was less accumulation of water in the plants root zone.

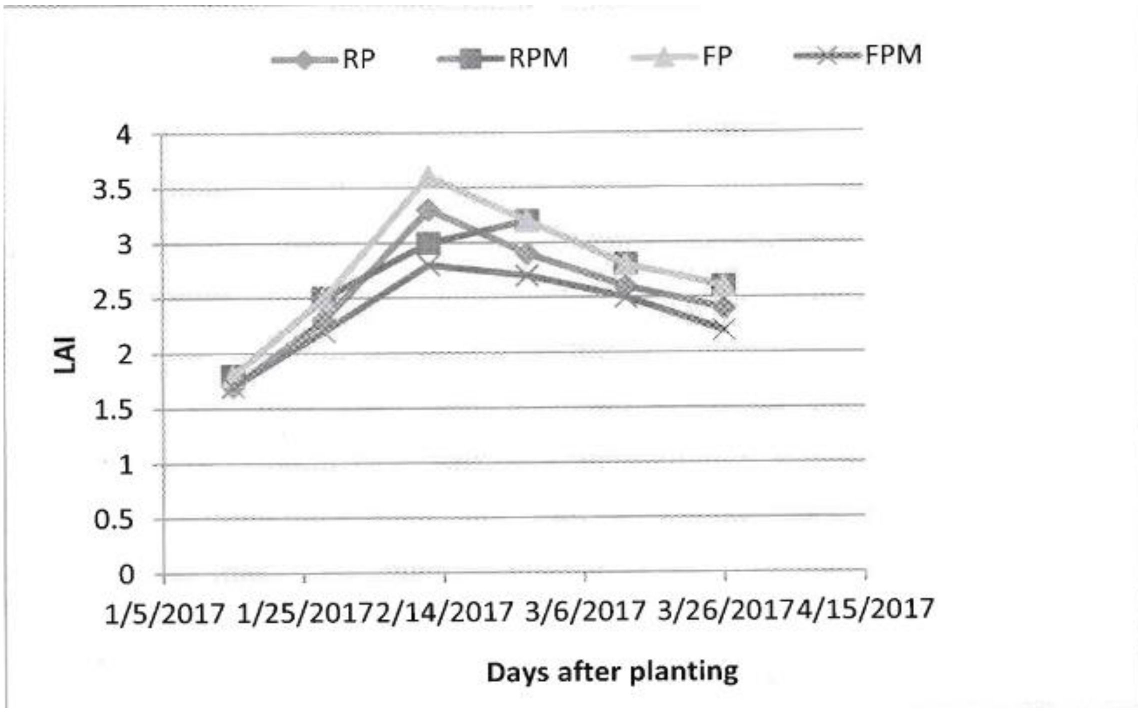

Figure 9: Effect of the ridging and mulching on LAI during the growing season.

4.6 Effect of Treatments on Maize Biomass Production during Plant Growth

Results on aboveground biomass accumulation of the maize during the plant growth are presented in Figure 10 and the effects of ridging and mulching on biomass, stover, grain yield are shown in Figure 10. The overall biomass production ranged from 9.47to 12.27tons/ha with a mean of 11.1tons/ha. The highest was observed from the RPM treatment and lowest was from the FPM treatment. There were no significant differences among the treatments.

Stover biomass varied from 5.92 to 7.84ton/ha with a mean of 6.75tons/ha. The highest was observed from RPM treatments and lowest from FPM treatments.There weresignificant differences among the treatments ($p < 0.05$).

The grain yield varied from3.54 to 4.78tons/ha with a mean of 4.35tons/ha. The highest was from RP treatments and lowest from FPM treatments. There were significant differences among the treatments ($P < 0.05$).

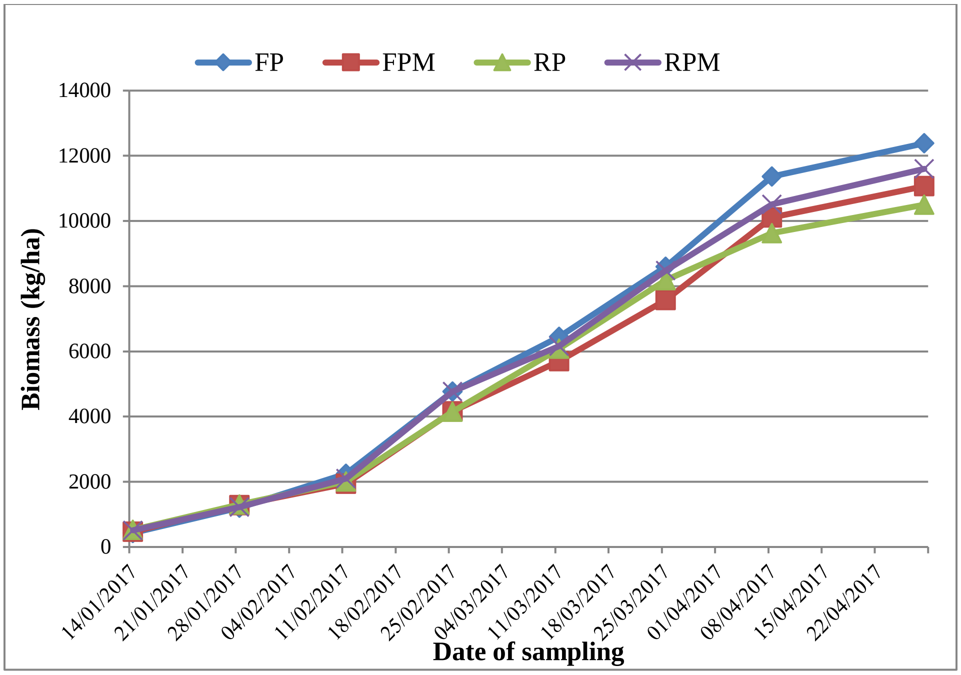

Figure 10: Effect of treatment on maize biomass accumulation during the growing season

Harvest index varied from 36.2 to 44..09% with a mean of 39.27%. The highest was from the RP treatments and lowest from the RPM treatments and was significantly different among the treatments ($p < 0.05$).There were no significant differences in shoot biomass during the growth stage. Presence of more water in the ridge with mulch treatment favoured the growth of un-economically harvestable parts of the plant. The FPM produced the lowest biomass and grain yield because of excess water in the root zone which affected the growth and functions of the roots due to poor aeration and low temperatures. The FPM treatments had shown higher root zone moisture content and the ridged without mulch treatments a lower root zone moisture content. The ridged treatments were able to shed excess water hence growth was not retarded and improved yield in the treatments than the others. Variation in HI can be attributed to crop management as said by Yanget al., 2000; Guo et al., 2004; Kermanian et al., 2007.,D'Andreas et al., 2008.

The good drainage in the treatments encouraged the good growth of economically harvestable parts of the plant. There was enough air for optimum root growth.

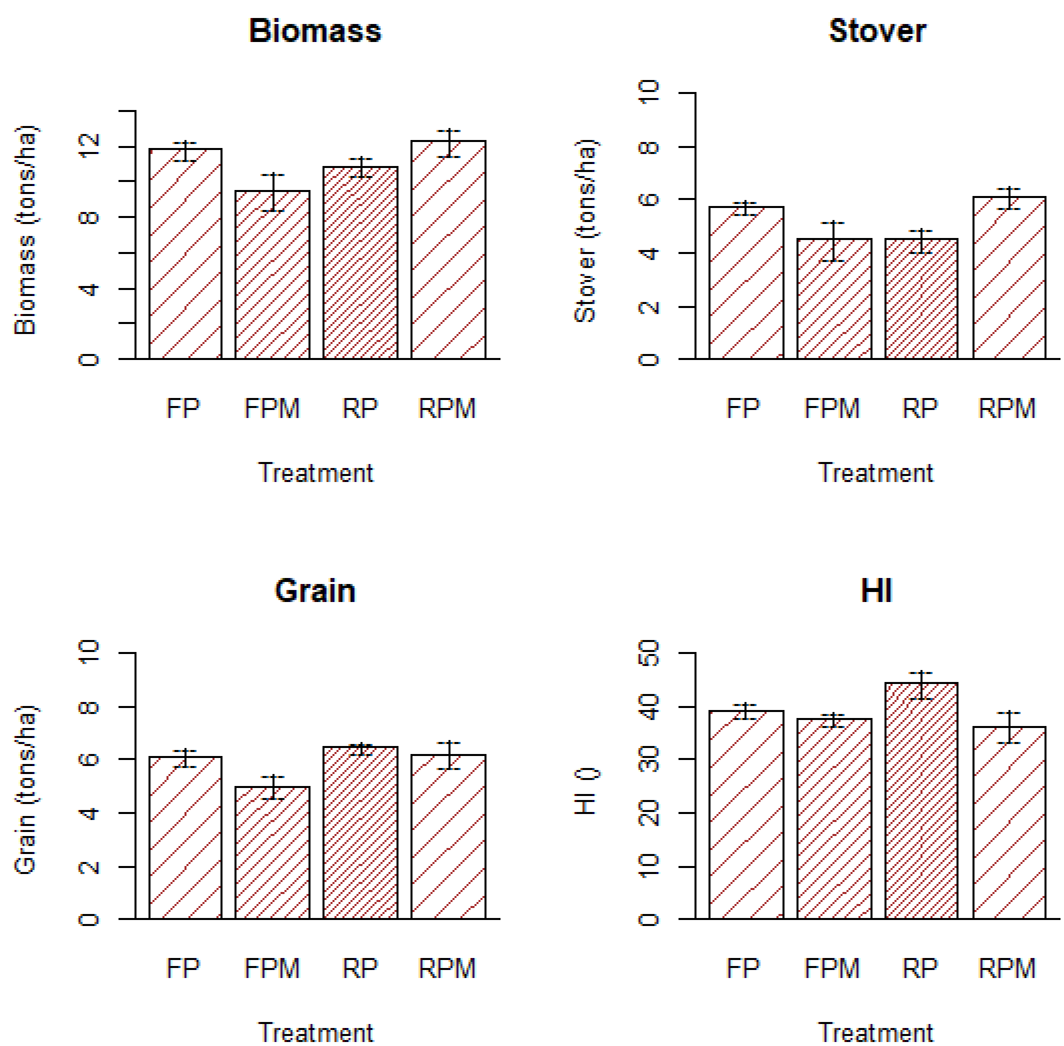

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Figure 11: Effects of Ridging and Mulching on Biomass, Stover, Grain, and Harvest Index (HI).

4.7EffectofRidging and Mulching on Rainwater Use Efficiency

Results on RWUE are presented in Figure 12. The biomass RWUE varied from 11.88 to 15.37kg DM/ha/ mm with an average of 13.92kgDM/ha/mm. There were no significant differences among the treatments.

Similarly, the stover RWUE varied from7.44 to 9.83 with an average of8.42 kg DM/ha/ mm. There were no significant differences among the treatments.

The RWUE based on grain yield varied from 4.45 to 5.99 kg DM/ha/mm with an average of 5.44 kg DM/ha/mm. The highest was observed from RP treatment and lowest from FPM treatments. There were significant differences observed among treatments ($p < 0.05$).The ridged with no mulch treatments had shown efficient rain water use than the other treatments

Efficient water use in the production of dry matter depends on many factors. Dry matter production is largely determined by crop and soil characteristics that maximize use of radiation. High dry matter production means high rain water use efficiency and more extraction of water by roots of plants. Water was not limiting during the growing season and hence there were no significant differences in biomass and stover rain water use efficiency among the treatments. Plant growth rate and yield are related to water supply. The ridged without mulch treatments had good drainage. There was good conversion of rain water into economically crop yield components of the plant.

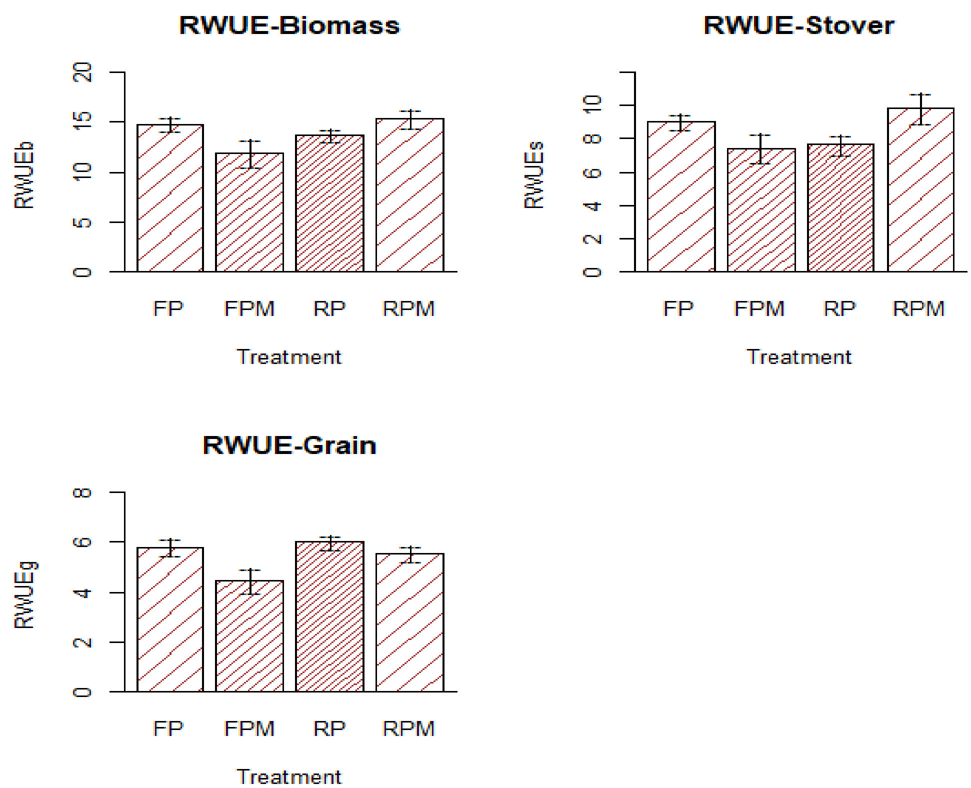

Figure 12: Treatment effect of ridging and mulching on RWUE

4.8 Effect of Treatment son Root Zone Soil Moisture Storage

Results on root zone soil moisture storage are presented in Figure 13,14,15 and 16. Soil moisture storage in the root zone varied from 129.1mm to 236mm with a mean of 181mm and was not significantly different among the treatments. Soil moisture storage was consistently higher in the FPM treatments (with an average of 178.4mm) and consistently lower in the RP treatments (with an average of 163.6mm).The general trend was that soil moisture storage was decreasing from 10-30cm and increasing from 40-80cm. Most of the roots of the maize plant are found between 20-30cm and the decrease could have been as a result of extraction by the roots of plants. A study by Qin et al., (2006) showed that up to 80% of maize roots can be concentrated in the 0-30cm layer.

Soil moisture storage of the root zone measured in the field was within the upper limit of field capacity and lower limit of wilting point and going beyond field capacity around March. The higher moisture content in the mulched treatments more especially in the flat with mulch treatments could have resulted in poor aeration and low temperatures. More water in the root zone can lead to less root activity. And lower HI as pointed out by Li, (2005) and Zhang and Yang, (2004).

Since the mulched treatments had more water storage, mulching can be beneficial in seasons of soil moisture stress. Studies have shown that mulching commonly increases yield of a wide range of agricultural crops compared with conventional practices in semi-arid regions of China (Huang et al., 2005). .Zhou et al., (2009) compliments that mulch exhibit great potential with limited rainfall.

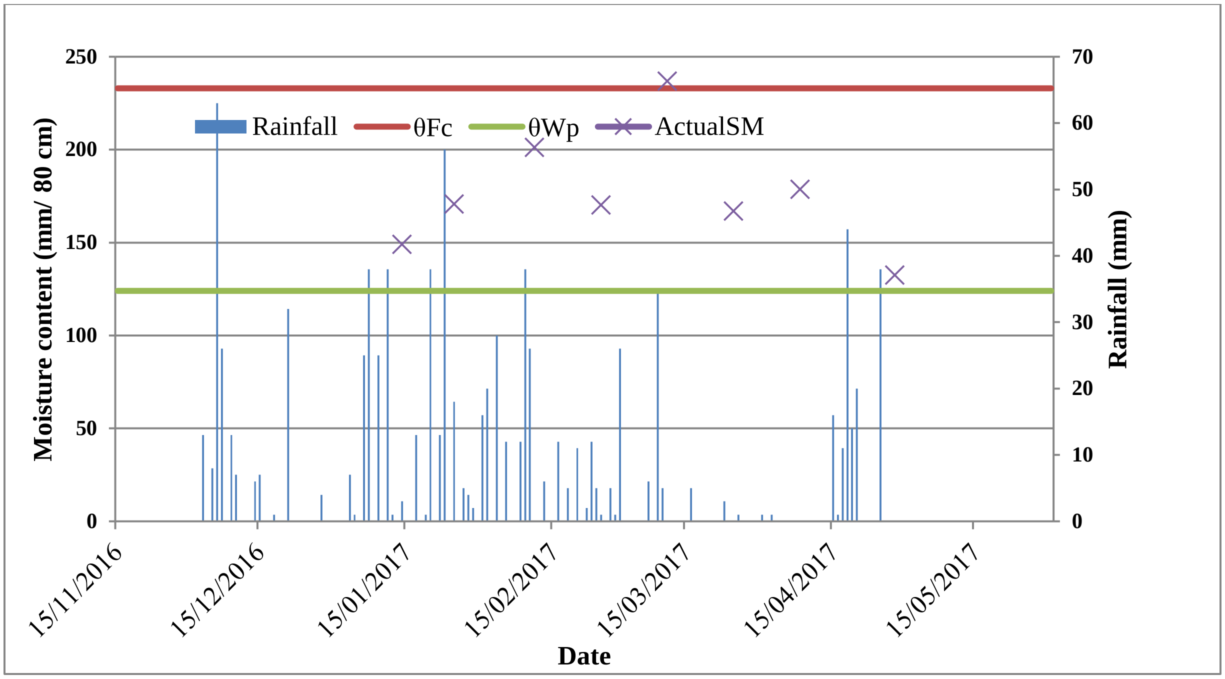

Figure 13: Evolution of cumulative root-zone soil moisture storageunderFPpractice

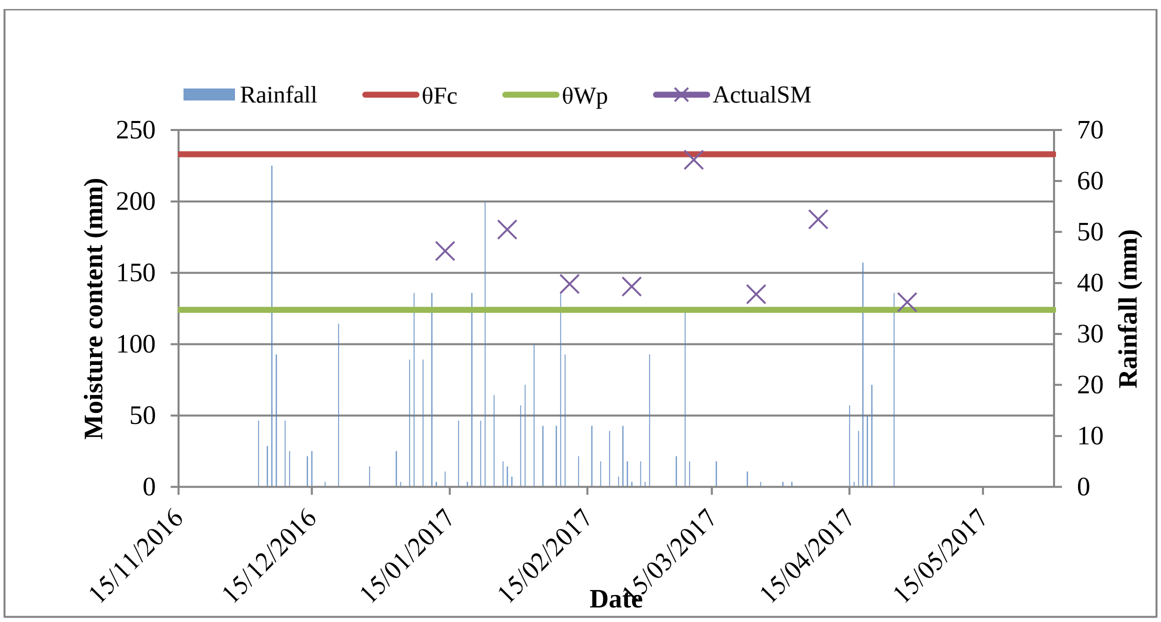

Figure 14: Evolution of cumulative root-zone soil moisture storage under RP practice

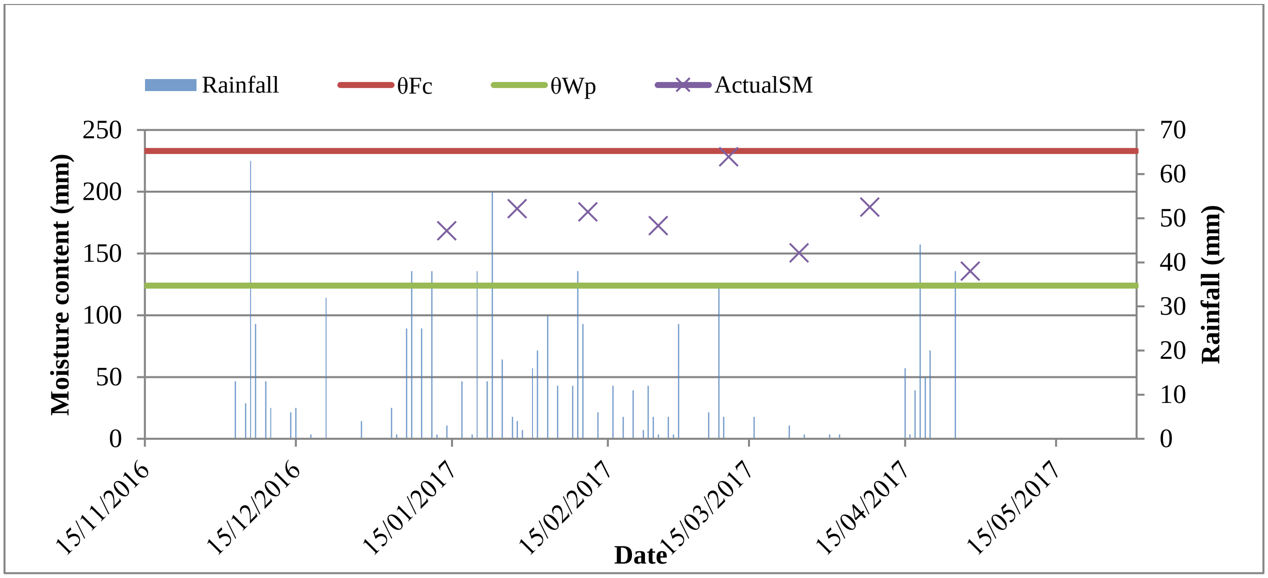

Figure 15: Evolution of cumulative root-zone soil moisture storage under RPM practice

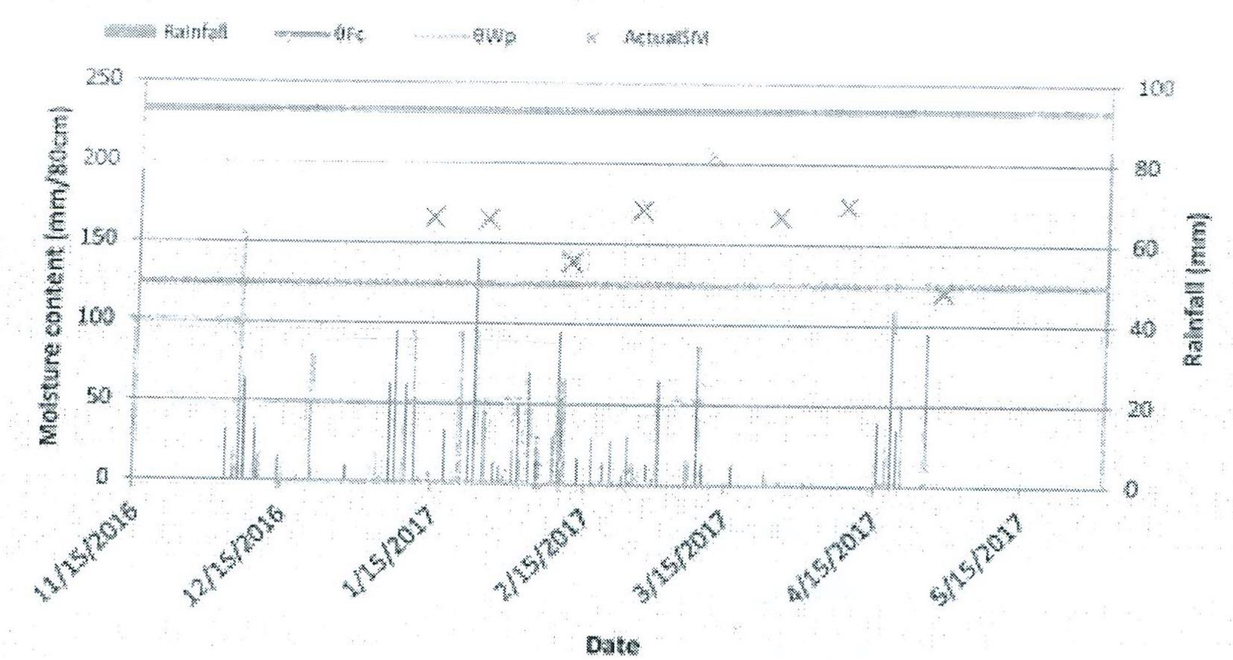

Figure 16: Evolution of cumulative root-zone soil moisture storage under FPM practice

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

The study evaluated maize yield, water use efficiency and moisture storage of the root zone of the maize crop under mulching and ridging and without mulching and ridging. The results showed that maize yield was significantly different in the treatments. The ridge without mulch treatments gave the highest yield and was lowest in the flat with mulch treatments. Days to 50% and 100% tasselling and silking were not statistically different among the treatments. Above ground shoot biomass during plant growth was not statistically different among the treatments.

The RWUE for biomass and stover was not statistically different among the treatments but the RWUE for grain was statistically different among the treatments. More efficient use of water was observed in the RP treatments and less in the FPM treatments.

Soil moisture storage in the root zone was not significantly different among the treatments but soil moisture storage was consistently higher in the RPM treatments and consistently lower in the RP treatments.

In the study mulched treatment did not give the highest yield. This could have been probably due to the normal rainfall during the experimental season. Results of experiments from other researchers have shown that mulching can play a significant role in conserving soil moisture and mulching can thereforebe most suitable in seasons of soil moisture stress. Other conditions such as soil temperature have to be suitable as well. On the other hand, ridging improves drainage in the soil root zone. Ridging promotes growth and high consumption of soil moisture by the plant. This in turn led to enhanced maize development and high grain yield in ridged without mulch treatments.

In the face of growing water scarcity and uncertainties of climate change, mulching would be necessary for improving the efficiency of crop water use, while simultaneously reducing adverse environmental impacts. It is of utmost importance to respond to increasing food demand of the population. To this effect,rain-fed agriculture must adopt more knowledge-intensive management solutions and systems. More-over, competing demand for water from other economic sectors such as industrial use will continue to grow. Agriculture is by far the largest consumer of water. Efficient use of this water would make significant gains in saving this moisture by dressing the soil surface with some amendments that would act as a barrier to loss of water by evaporation. Putting a soil cover in the growing of maize would, therefore, play a crucial role in maintaining soil water status along with other benefits like weed control, low soil bulk density and nutrient availability and retention. As small-scale farmers are being encouraged to practice conservation farming, they should also be encouraged to adopt such water conservation measures such as mulching for increased food production.

More research required to determine the suitability of mulching under Zambian conditions. Commercial and small scale farmers should start to adopt mulching and grow crops like maize in the rainy season in drought prone areas.

Ridging helped plants shed off excess water in the root zone and should be encouraged in areas that receive higher rainfall like Luapula and Northern Provinces of Zambia.

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APPENDICES

Appendix 1: Anova Table for Grain Yield

Source of Variation	dfssms		F valuePr (>F)		
Replication	1	0.0435	0.0435	0.169	0.6931
Treatments	3	2.700	0.900	3.501	0.0781* s
Residuals	7	1.800	0.2571		

Appendix 2: Anova Table for Biomass

Source of Variation	dfssms		F valuePr (> F)		
Replications	1	1.32	1.32	0.828	0.393
Treatments	3	13.5	4.5	2.822	0.47 * s
Residuals	7	11.6	1.595		

Appendix 3:Anova Table for H.I.

Source of Variation	dfssms		F valuePr (>F)		
Replication	1	31.21	31.21	3.482	0.1042
Treatments	3	106.39	35.46	3.942	0.0615 * s
Residuals	7	62.98	9.0		

Appendix 4:Anova Table for Stover

Source of Variation	df	ss	ms	F value	Pr (>F)
Replications	1	1.834	1.83	2.1	0.190
Treatments	3	7.421	2.475	2.84	0.115 ns
Residuals	7	6.099	0.87		

Appendix 5: Anova Table for RWUEg

Source of Variation	df	ss	ms	F value	Pr (>F)
Replications	1	0.068	0.0685	0.169	0.6929
Treatments	3	4.243	1.414	3.501	0.078 * s
Residuals	7	2.828	0.4040		

Appendix 6: Anova Table for RWUEb

Source of Variation	df	ss	ms	F value	Pr (>F)
Replication	1	2.081	2.081	0.827	0.393
Treatments	3	21.21	70.70	2.811	0.117 ns
Residuals	7	17.61	2.515		

Appendix 7: Anova Table for RWUEs

Source of Variation	dfssms		F valuePr (.F)		
Replication	1	2.880	2.880	2.088	0.192
Treatments	3	11.663	2.888	2.819	0.117ns
Residuals	7	9.654	1.379		

Appendix 8: Anova Table for LAI 1 (36 days after planting)

Source of Variation	dfssms		F value	Pr (>)	
Replication	1	0.0312	0.0313	0.330	0.583
Treatments	3	0.0167	0.0056	0.059	0.080 ns
Residuals	7	0.6621	0.0946		

Appendix 9: Anova Table for LAI 2 (51 days after planting)

Source of Variation	dfssmsF value		Pr (>F)		
Treatments	3	0.01670.0056		0.059	0.980 ns
Replication	1	0.032	0.03125	0.3125	0.583
Residuals	7	0.6621	0.9458		

Appendix 10: Anova Table for LAI 3 (66 days after planting)

Source of Variation	df	ss	ms	F value	Pr (>F)
Replication	1	0.0612	0.0612	0.511	0.4978
Treatments	3	1.2467	0.4156	3.468	0.0795* s
Residuals	7	0.8388	0.1198		

Appendix 11: Anova Table for LAI 4 (81 days after planting)

Source of Variation	df	ss	ms	F value	Pr (>)
Replication	1	0.0613	0.0613	0.317	0.591
Treatments	3	0.6067	0.2022	1.047	0.429 ns
Residuals	7	0.1932	0.1932		

Appendix 12: Anova Table for LAI 5(96 days after planting)

Source of Variation	df	ss	ms	F value	Pr (>F)
Replication	1	0.0000	0.0000	0.0000	1.0000
Treatments	3	0.1625	0.0504	0.508	0.689 ns
Residuals	7	0.7467	0.1067		

Appendix 13:Anova Table for LAI 6 (111 days after planting)

Source of Variation	dfssms			F value	Pr (>F)
Replication	1	0.000	0.000	0.000	1.000
Treatments	3	0.3025	0.1008	0.945	0.469
Residuals	7	0.7467	0.1067		

Appendix 14: Anova Table for Cumulative Root Zone Soil Moisture (35 days after planting)

Source of Variation	dfssms			F value	Pr (>)
Replication	1	539.6	1.196	0.31	
Treatments	3	1092.0	364.0	0.0807	0.529 ns
Residuals	7	3158.2	451.2		

Appendix 15: Anova Table for Cumulative Root Zone Soil Moisture (52 days after planting)

Source of Variation	dfssmsF value			Pr (>)	
Replication	1	1588	1588.7	1.226	0.305
Treatments	3	376.0	125.2	0.097	0.959 ns
Residuals	7	9066	1295.1		

Appendix 16: Anova Table for Cumulative Root Zone Soil Moisture (65 days after planting)

Source of Variation	dfssms		F value	Pr (>)	
Replication	5217	5217	3.786	0.0928* s	
Treatments	3	6920	2307	1.647	0.258 ns
Residuals	7	9647	1378		

Appendix 17: Anova Table for Cumulative Root Zone Soil Moisture (80 days after planting)

Source of Variation	dfssms		F value	Pr (>)	
Replication	1	169	169.3	0.168	0.694
Treatments	3	3517	1172	1.163	0.389
Residuals	7	7054	1007.7		

Appendix 18: Anova Table for Cumulative Root Zone Soil Moisture (95 days after planting)

Source of variation	dfssms		F value	Pr (>)	
Replication	1	83.9	83.9	83.85	0.511
Treatments	3	147.6	49.21	49.21	0.837 ns
Residuals	7	1224.2	174.89		

Appendix 19: Anova Table for Cumulative Root Zone Soil moisture (110 days after planting)

Source of variation	dfssms	F value	Pr (>)		
Replication	1	566	566.2	0.367	0.564
Treatments	3	3679	1226.4	0.795	0.534 ns
Residuals	7	10795	1542.2		

Appendix 20: Anova Table for Cumulative Root Zone Soil Moisture (122 days after planting)

Source of variation	dfssms	F value	Pr (>)		
Replications	1	2976.1	2976.1	14.309	0.0069**s
Treatments	3	763.7	89.7	0.423	0.727 ns
Residuals	7	1455.9	208.0		

Appendix 21: Anova Table for Cumulative Root Zone Soil Moisture (146 days after planting)

Source of variation	dfssmsF value	Pr (>)			
Replication	1	89.8	89.78	01.064	0.337
Treatments	3	69.2	23.08	0.273	0.843 ns
Residuals	7	590.9	84.41		