DECLARATION

I, Dennis Mooya declare that the thesis, which I hereby submit for the degree of Master of Science in Integrated Soil Fertility Management at the University of Zambia, is my own work and has not been previously submitted by me for a degree at this or any other tertiary institution.

SIGNATURE: ……………………

DATE:.…………………………..…

APPROVAL FORM

This thesis of Dennis Mooya is approved as fulfilling the requirements or partial fulfilment of the requirements for the award of Master of Science in Integrated Soil Fertility Management by the University of Zambia.

Examiner	**Signature**	**Date**
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ABSTRACT

The problem of drought and erratic rainfall, coupled with crop genotypes (both local and improved varieties) with low water utilisation efficiencies, are major contributors to low productivity of most crops. The poor agricultural productivity among the farming community results in poverty and food insecurity at national level and in low household incomes.

Selection of drought adapted genotypes in breeding programmes and efficient use of water are among the most important approaches in combating climate change effects like droughts and erratic rainfall. This study was conducted to characterise drought tolerance of twelve maize genotypes. An experiment was set up at the National Irrigation Research Station in Mazabuka, to determine the response of these genotypes to three water regimes at 30 %, 60 % and 100 % of crop water requirement (ETc). The twelve maize genotypes were planted at each water regime in a split – plot design arranged in a randomized layout. To evaluate the water utilisation of each maize genotype, water use efficiency, crop water productivity, crop yield response factor and harvest index were determined from the grain yield, above ground biomass and data collected during the experiment.

Deficit irrigation (30 % and 60 % ETc) resulted in crop yield reduction and significant effects on most of the measured parameters. Anthesis – silking interval was shortened, plant girth and height equally decreased with increased water stress at 30 % of ETc. The results showed variations in maize yield and this was attributed to genotype and water regime. The genotypes and water regimes contributed to yield by 30 % and 50.2 %, respectively. The grain yield in genotypes L512, L353, L857 and L07 had a yield advantage of 36.8 %, 34.6 %, 27.6 % and 18.0 %, respectively above the overall mean. Water Use Efficiency (WUE) at 30 % water regime was high in maize genotypes L512, L60, L713 and L857 with 2.412, 1.818, 1.900 and 2.265 kg/mm/ha, respectively. The Crop Yield Response Factor of genotypes L353, L512, L07 and L857 at 60 % water regime were below 1.0 indicating an efficient water use by most genotypes at 60 % water regime which resulted in a seasonal accumulative value of 505.3 mm for the season under study.

Based on the results, genotypes L512, L857, L07 and L353, were selected as drought tolerant genotypes.

I dedicate this work to three most important women in my life my mother, my only sister Doreen and Cleo my wife.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CC	Canopy Cover
WP	Crop Water Productivity
ET	Evapotranspiration
FAO	Food and Agriculture Organisation of the United Nations
FC	Field Capacity
HI	Harvest Index
PAW	Plant Available Water
PWP	Permanent Wilting Point
USDA	United States Department of Agriculture
WUE	Water Use Efficiency
Ky	Crop Yield Response Factor
Y	Grain yield
BM	Above ground biomass
ASI	anthesis – silking interval
RTD	root density
PG	plant girth
PH	plant height
d.f	Degrees of Freedom

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CHAPTER 1

1.0 INTRODUCTION

Maize (*Zea Mays L.*) is the third most important cereal crop species, after wheat and rice, grown throughout a wide range of climates. Maize is desired for its multiple purposes as human food, animal feed and for pharmaceutical and industrial manufacturing (Huang *et al.*, 2006). Present world production is about 594 million tons grain from approximately 139 million hectares of land (FAO, 2012).

Maize has a high photosynthetic efficiency which is made possible by the specialised anatomical and biochemical features that enable C_4 photosynthesis. As a C_4 crop, maize also confers high water use efficiency (WUE); maize can produce one kg of dry weight using about 40 kg of water, compared to water use ratios of 60 kg or more in most C_3 crops (Nafziger, 2008). The crop is grown in climates ranging from temperate to tropical environment during the period when mean daily temperatures are above 15°C and are frost-free. Adaptability of varieties to different climates varies widely. Successful cultivation markedly depends on the right choice of varieties so that the length of growing period of the crop matches the length of the growing season and the purpose for which the crop is being grown.

In Zambia, maize is a staple crop and is grown in all the ten provinces of the country with exception of areas where it is impossible to grow such as the wet, extremely sandy and the infertile areas such as the barotse flood plains and Luangwa valley. At the same time, this staple crop has a readily available market from the Government through the Food Reserve Agency (FRA). This readily available market leads to an increased cultivated land of maize crop by the smallholder farmers (Lungu *et al.*, 2010), despite a generally poor productivity. The maize production trends in Zambia can be analysed using crop forecast surveys to show how maize production has varied according to farm sizes over the years. The crop forecast survey is a nationally representative survey conducted annually by the Government's Central Statistical Office involving small and medium scale households. From this survey, annual crop production estimates are produced each year by the Ministry of Agriculture and Livestock. For instance, maize production increased from an average of 1.38 ton/ha in the baseline period to 2.78 ton/ha in the 2010/11 cropping season (MACO/CSO, 2011). This low maize productivity of 1 – 2 ton/ha among the smallholder farmers in Zambia is still far below the potential of 8 – 12 ton/ha of most varieties. This low yield is mainly attributed to poor farmer agronomic practices, infertile soil and the erratic rainfall to some extent (Lungu *et al*, 2010). To increase and sustain the maize production up to varietal potential, the improvement of maize genotypes by developing genotypes that are drought tolerant is critical.

Maize grain yields in the temperate developed world average 8.2 ton/ha, compared to 3.5 t/ha in tropical less developed countries. Drought is the most important abiotic stress constraint affecting 26 % of the arable areas of the world (Blum, 1988) destabilising maize grain production. Drought therefore, is one of the several reasons for the differences between production levels of temperate and tropical regions. In both regions water deficits occur unpredictably throughout the season. Since farmers usually plant a single variety in any given field, this implies a need for a good level of drought tolerance in the majority of varieties grown under rainfed conditions. Production in drought-prone regions such as Southern and Eastern Africa or West Africa shows a strong dependence on seasonal rainfall (Wortmann *et al.*, 1998). Maize is a staple food for more than 300 million people in sub-Saharan Africa and a number of countries in these geographic regions often experience drought in the same season, creating regional food shortages that cannot easily be alleviated by cross-border trade. Production of maize, for instance, in Southern Africa fluctuated from 12.5 million tons in 1992 (which was a drought year) to 23.5 million tons in 1993 (Edmeades, 2008).

The National Adoption Plans of Actions (NAPA) for Zambia as described in the Framework Convention on Climate Change (UNDP 2007), has highlighted that areas suitable for staple crops, such as maize production in the prominent producing regions are likely to be reduced by more than 80% due to effects of climate change. Within these regions, since the 1980s, there has also been a tendency for the late on-set and early withdrawal of rains, as well as an increased occurrence of drought years. Such water deficits could result in severe yield decrease for specific crops such as maize. Based on a CO_2 doubling scenario in these regions, some estimates predict a yield reduction of approximately 66% under rainfed conditions but only about 16% under irrigated conditions.

Drought is a major threat to Zambia's food security. Although Zambia has land in abundance relative to her population, a significant part of the arable land is in a semi-arid region that is frequently hit by drought. Only 3 % of the country's arable land is under irrigation while the remainder depends critically on rain fed subsistence agriculture. Such rain fed agriculture coupled with thin public resource endowments puts Zambia in a precarious position to deal with drought impacts (Thamana, 2008). With changes in rainfall patterns, the average length of the growing season for maize is also likely to become shorter, with models predicting an approximate reduction in the length of the season by 20%. At the national level, yield changes and other impacts of climate change suggest frequent shortages of grain and agroecological Region I is extremely vulnerable followed by Region II in terms of arable cropping. Hence planning for climate change in these two regions is a necessity. Key crop varieties, particularly maize, would not mature due to the shortening of the growing season in Regions I and II, undermining food security in the two regions (World Bank, 2007).

The use of genetics to improve drought tolerance and provide yield stability is an important part of the solution to stabilising global maize production. This does not imply that agronomic interventions that aim at maximising water availability at key growth stages are not critical. Genetic solutions are unlikely to close more than 30% of the gap between potential and realised yield under water stress (Edmeades *et al*., 2004). However, improved genetics can be conveniently packaged in a seed and, therefore, more easily and completely adopted than improved agronomic practices that depend more heavily on input availability, infrastructure, access to markets, and skills in crop and soil management. Seed of improved cultivars has proved to be an effective means of delivering conventional and transgenic traits that contribute to improved yield and yield stability (Campos *et al.*, 2004).

Steduto *et al.*, (2007) have shown that traits of water use efficiency (WUE), crop water productivity (WP) and crop yield response factor (Ky), have shown a linear relationship with the biomass produced and the water consumed across a range of given species. Water use efficiency is a measurable trait of a cropping system's capacity to convert water into plant biomass or grain. In crops, WUE is the efficiency with which an individual crop converts absorbed water to grain, expressed in kg/mm/ha (GRDC, 2009). While the crop water productivity (WP) is the above ground dry matter (g or Kg) produced per unit land area (m^2 or ha) per unit of water transpired (mm) and Crop yield response factor (Ky) estimates the yield decrease due to deficiency in full water requirement (or when water stressed) in a crop (FAO, 1979).

The WUE, WP and Ky are derived traits of a crop based on the soil, water and climatic conditions. These are important plant traits that should be evaluated in plant breeding programmes that seek to determine the crop's ability to utilise water (Seghatoleslami *et al.*, 2008). The water use efficiency, crop water productivity and crop yield response factor are important as they are related to plant performance. Therefore, water use efficiency is vital in estimating the genetic variance, and examines its relationship with yield (Donovan and Ehleringer, 1994). Efficient water use confers drought tolerance to plants as it maintains the soil moisture longer due to less transpired water by the plant during development. In agriculture, efficient water use is desirable because it is perhaps, one of the most important of all yield components and as such water use efficiency, crop water productivity and crop yield response factor traits are based on water used by, rather than applied to, a plant for the measurement to be meaningful (Martin and Thorstenson, 1988).

Most studies done in Zambia on drought tolerance selection in maize breeding focussed mainly on hybrids and open pollinated varieties and not on inbred lines. This study was set up to evaluate drought tolerance characteristics of inbred lines at different stages of development. The information from this evaluation would then be used to select particular inbred lines that could be used in later stages of breeding for drought tolerant hybrid maize varieties. The development of high yielding maize varieties that can tolerate drought is one way of mitigating the effects of climate change and contributing to food security.

The specific objectives were:

1. To evaluate plant biomass production among the maize genotypes under deficit irrigation.
2. To evaluate the partitioning of evapotranspiration (ET) into evaporation and transpiration of maize genotypes under different levels of water application through irrigation.
3. To evaluate water use efficiency, crop water productivity and crop yield response factor of the maize genotypes.
4. To evaluate the morphology attributes of maize genotypes associated with water use efficiency, crop water productivity and crop yield response factor.

This study was carried out with the assumption that there is enough variation among the inbred lines in terms of water use efficiency, crop water productivity, crop yield response, total biomass and grain yield produced due to varying water application among inbred lines studied.

CHAPTER 2

2.0 LITERATURE REVIEW

2.0 ORIGIN AND GEOGRAPHICAL DISTRIBUTION OF MAIZE

The centre of origin of maize (*Zea mays.L*), is the Mesoamerican region, probably the highlands of Mexico from where it spread rapidly. The Archaeological records and phylogenetic analysis also suggest that the domestication began at least 6,000 years ago. The spread of maize to the rest of the world was observed after the Europeans discovered the Americas in the 15^{th} century and this spread was prominent particularly in the temperate zones (Office of the Gene Technology Regulator, 2008). The origin of maize may never be known with certainty. One reason is that the hypotheses purporting to explain its origin cannot be tested experimentally. Therefore, science would perhaps be better served if less attention were given to determining maize's origin and more to understanding the remarkable variability found within the species (Brown et al., 1985).

By the last decade of the twentieth century a tidal wave of maize had engulfed Africa, save its driest and wettest crannies, supplanting historical African food grains like sorghum, millet, and rice. Maize's recent spread has been alarmingly fast, with the historical and social implications of that change receiving scant consideration by social scientists. In southern Africa maize has become by far the most important staple food, accounting for over 50% of calories in local diets. In Zambia, maize has been domesticated since the 1939s when it was introduced by the Europeans into the then North Rhodesia mines. Zambia has one of the world's highest percentages of maize consumption in the national diet of 58% of total calories (McCann, 2001).

Geographically, maize can be grown in a number of environments from 58˚ North (e.g. Canada and the Russian Federation) to 40˚ South (e.g. Chile). Generally, tropical maize is grown between 30˚ North and 30˚ South, subtropical maize between 30˚ and 34˚ both north and south, and temperate maize beyond 34˚ latitudes. Maize can be grown in a range of altitudes from sea level up to 3,800 metres (Farnham *et al.,* 2003).

The major production areas in the world, in terms of cultivated area and yields, are the temperate regions of the western hemisphere, China, Brazil and several countries in Europe.

Overall, maize production in the world is dominated by relatively few countries, with the top five being USA, China, Brazil, Mexico and Argentina. These countries account for nearly 75 % of the total world production (Nafziger, 2008).

The production trends have also shown that the highest yields are obtained in industrialized countries where the production is highly mechanized and based on well developed crop cultivars, seed selection and adequate inputs along with favourable climates and soils. The global maize production trends are shown in Table 1.

Table 1: Global maize production trends (adopted from FAO, 2007)

Country	Area (million Ha)	Yield (ton/Ha)	Production (million tons)
USA	35.0	9.5	331.2
China	29.5	5.2	151.9
Brazil	13.8	3.8	52.1
Mexico	7.3	3.2	23.5
Argentina	2.8	7.7	21.8
India	7.8	2.4	19.0
France	1.5	9.5	14.5
Indonesia	3.6	3.7	13.3
Canada	1.4	8.5	11.6
Italy	1.1	9.1	9.9
Hungary	1.3	6.7	8.4
Ukraine	1.9	3.9	7.4
Rest of the world	51.0	2.5	127.2
Total	158	5.0	791.8

Source: http//faostat.fao.org (2012)

2.1 MAIZE CROP MORPHOLOGY, GROWTH AND DEVELOPMENT

Zea is a genus of the family *Graminae* (*Poaceae*), commonly known as the grass family. Maize (*Zea. mays* L.) is a tall (1 – 4 m), monoecious annual grass with overlapping sheaths and broad conspicuously distichous blades (Hitchcock and Chase, 1971). The maize forms a seasonal root system that bears a single erect stem made up of nodes and internodes, although some cultivars may develop elongated lateral branches. Many temperate cultivars are shorter than tropical and subtropical cultivars. The leaves are broad and a single leaf develops at each node in two opposite ranks. Each leaf consists of a sheath surrounding the stalk expanded blade connected to the sheath by the blade joint. The mature maize plant can have up to approximately 30 leaves with variations in number, size and orientation between maize cultivars. Maize is a monoecious plant; it has a female and male (tassel) inflorescence. The male inflorescence forms at the top of the stem while the female develop in the leaf axis of the plant.

In terms of crop performance, growth refers to biomass accumulation and is measured by parameters such as leaf area, shoot/root weights and plant height. Hanway (1963) proposed eleven stages of development of maize, with stage 0 being germination and emergence and stages 1 – 5 occurring after silking. In terms of crop management it is more usual to condense the number of stages to six, with stages 6 incorporating dry – down and grain harvesting.

2.2 THE PROPERTIES AND USES OF THE MAIZE CROP

The harvested part of maize is grain, which is used for human and livestock consumption. Lesser amounts are grown for harvest of the entire above-ground plants at physiological maturity to be made into silage for animal feed. In some areas, after the grain has been harvested, the remainder is cut and used for animal feed. Yellow dent maize is primarily used for livestock feed, white dent maize is used primarily for production of meal and cereals for human consumption. Other dent lines have been bred for special purposes: e.g. waxy maize for production of amylopectin starch, high lysine maize for use in pig feed and high oil maize for production of vegetable oil for human consumption. Flint maize is grown in Central and South America, Asia and Southern Europe. Sweet corn was developed to be harvested in an immature stage for human consumption. Popcorn is used primarily for human consumption as freshly popped or other snack food items (Hoeft, 1986). Generally, maize is desired for its multiple purposes as human food, animal feed and for pharmaceutical and industrial manufacturing (Huang *et al.*, 2006).

2.3.0 WATER, TEMPERATURE AND NUTRIENT REQUIREMENTS OF MAIZE

Maize is generally a crop of warm climates with adequate moisture. Maize requires warm day time temperatures of 25°C - 30°C and cool nights. Temperatures below 8°C or above approximately 40°C usually cause ceasation of plant development (Birch *et al*, 2003).

Maize grown for whatever reason at commercial or small scale level has high demand for nutrients, especially nitrogen, phosphorus and potassium. Depending on the soil type, the micronutrients Zinc and Molybdenum are also important. However, seedlings do not tolerate high levels of fertiliser and, therefore, basal fertilizers should be drilled at least 5 cm to the side of the plant during sowing (Hughes, 2006).

Rainfall is a limiting factor to dry land production of commercial maize crops and this affects the yields obtained. Maize is particularly susceptible to water stress at flowering stage when yield is set.

2.3.1 SALINITY HAZARD

Salinity is regarded more as a problem of irrigated rather than dry land crops. Salt increases the energy that must be expended by the plant to extract water from the soil; this disrupts the normal growth of the crop and its yield. Maize is a salt sensitive or moderately salt tolerant plant and an Electrical Conductivity (EC) of less than 2 mS/cm at 25°C will likely not reduce the crop yields (Lafitte, 2000).

2.4 DEVICES FOR MONITORING SOIL WATER CONTENT

The methods used to determine moisture content can be grouped into distractive and non – distractive methods. The gravimetric method (destructive) involves weighing soil samples, drying them in an oven, weighing them again, and using the difference in weight to calculate the amount of water in the soil. While too it is time consuming to be used for day-to-day management decision, this highly accurate and low cost method is often used to calibrate other tools (Morris, 2006).

The current non – distractive viable technology for measuring soil moisture at depths greater than a few meters is the neutron probe. The use of the neutron moisture probe for measuring *in situ* soil water content was established in the agricultural industry but has since been used in other fields such as environmental monitoring. The neutron moisture probe has gained wide acceptance because the method is non-destructive, relatively fast, and can be performed at any time. The major disadvantage of the neutron probe is that the measurement process cannot be automated. A typical measurement involves manually lowering the probe to a specified depth and taking five readings at each depth interval and in case of many access tubes this would take hours (Lane and MacKenzie, 2001)

The next set of field methods are dielectric techniques. They estimate soil water content by measuring the soil bulk permittivity (or dielectric constant), which determines the velocity of an electromagnetic wave or pulse through the soil. They include, time domain reflectometry, frequency domain, phase transmission and time domain transmission.

The Diviner (capacitance) probe of 2000 series manufactured by Sentek, is one such tool. It has an automated "Swipe and Go" technology that allows the probe to be lowered and raised rapidly through an access tube without stopping at the individual measurement depths. The logger automatically obtains measurements at 10 cm intervals and logs the entire profile. This process allows the entire access tube (1.6 m) to be measured in less than a minute. The limitation of the Diviner probe (2000 series) is that the probe is mounted on a rod and is designed for shallow irrigation applications of less than 2 m (Dobchuk *et al.,* 2006).

The other methods used in the field are tensiometric methods which use different forms of tensiometers (Munoz-Carpena *et al*., 2004).

2.5 IRRIGATION AND DEFICIT IRRIGATION

The chances of increasing crop production in Sub-Saharan Africa seem to lie much in irrigated agriculture, as unreliable rainfall, both in terms of distribution and amount, is a major limitation to agriculture in the region. However, this hope is strongly challenged by the rapidly dwindling water resources of the region and the growing increase in competition for water by non-agricultural sectors. This challenge is a major cause of concern to irrigation stakeholders. Irrigated agriculture is under pressure to cut down the amount of water use for crop production and at the same time to produce more crops with less water (Igbadun *et al*., 2005).

The need to minimise the amount of water used in irrigation is a common concession among stakeholders in water resource management. As a step towards achieving the objective of more crops per drop of water, there is need for irrigators to begin to adopt the use of techniques and practices that regulate water application to crops and minimise needless waste. One such practice is deficit irrigation, Deficit irrigation is a practice of irrigating in an amount below that of a crop's maximum water demand so as to assess the crop's photosynthetic assimilation with less water or when subjected to water stress (Dacosta and Huang, 2006).

The objective of deficit irrigation is to save water, labour, and in some cases energy, by withholding or skipping irrigation, or reducing the amount of water applied per irrigation. The practice leads to some degree of moisture stress on the crop and an effect on crop yield. The water stress results in less evapotranspiration in plants due to closure of the stomata reduced assimilation of carbon and decreased biomass production (Smith and Kivumbi *et al*., 2002). When the water stress is not severe, the reduction in biomass production will have little adverse effect on the ultimate yield and can lead to appreciable increase in the productivity of water. But when the water stress is severe or occurs at the critical growth stages of a crop, the reduction in yield may be so high that the benefit and returns for water will be reduced.

The subject of deficit irrigation and the effect of moisture stress on crop production are widely reported in literature (FAO, 2002*)*. The effect of deficit irrigation for the same crop may vary with location as it very much depends on climate, which dictates the evaporative demand, and soil type, which dictates the available water for plant uptake. There is, therefore, need for comprehensive assessment of a location before recommendation and advice on deficit irrigation can be made in an area (Igbadun *et al.,* 2005).

2.6 IRRIGATION SCHEDULING

Irrigation scheduling, as defined by Broner (2005), is the decision of when and how much water to apply to a field. The purpose of irrigation scheduling is to determine the exact amount of water to apply to afield and the exact timing for application. The amount of water applied is determined by using a criterion to determine irrigation needs and a strategy to prescribe how much water to apply in any situation. The importance of irrigation scheduling is that it enables the irrigator to apply the exact amount of water to achieve the goal of using water efficiently and in turn, this increases irrigation efficiency. Irrigation scheduling offers several advantages, it enables the farmer to schedule water rotation among the various fields to minimise crop water stress and maximise yields. It reduces the farmer's cost of water and labour through less irrigation, thereby making maximum use of soil moisture storage (Igbadun et al., 2005).

The purpose of irrigation is to replace soil water losses not replaced by rainfall, fog, groundwater, or other water sources. Applications are normally timed to replace water before yield-reducing water stress occurs. Since water losses occur mainly through crop evapotranspiration (ETc), accurate estimates of ETc are needed for efficient irrigation management, especially for low-volume (drip, micro sprinkler) and sprinkler irrigation systems. Potential ETm is calculated as:

$$ETm = ETo \times Kc$$

Potential (maximum) ETm depends on the weather and on plant and management factors. Reference evapotranspiration (ETo) allows for the effects of weather, increasing and decreasing according to evaporative demand. Daily ETo are calculated from weather data using the standardised Penman-Monteith method (ASCE-EWRI, 2005).

Crop coefficient (Kc) estimates allow for plant and management factors including crop age, height and roughness, and irrigation frequency during early crop growth (Snyder and Sheradin, 1993).

2.7 DROUGHT OCCURRENCES AND CLIMATE CHANGE EFFECTS

Drought can be defined as a sustained and regionally extensive occurrence of below average natural water availability. It can also be defined in terms of either the external water status at the boundaries of the plant (soil, air) or the internal plant water status within the tissue (Tardieu, 1996). However, drought occurrence can be defined as an extended period of anomalously low soil moisture. The amount of water in the soil provides a useful indicator of drought as it reflects the aggregate effect of all hydrologic processes from changes in short-term precipitation events and temperature swings to long-term changes in climate and can represent the status of agriculture and potential hydrologic recharge to rivers and reservoirs (Sheffield *et al*., 2004). Empirical probability distributions can be derived for the modelled soil moisture fields for each month from the pre-industrial control simulations and the current state of drought is characterised by the quantile of the current soil moisture value in relation to the control period distribution (Sheffield and Wood, 2007).

The climate varies naturally in response to external forces, such as solar radiation and atmospheric aerosols and because of internal interactions between components of the climate system. The extremes of these variations have consequences on the terrestrial water cycle that impact human activities in terms of changes to the availability or absence of water, e.g., flooding or drought. When coupled with potential climate change, which may impact regionally and exaggerate the influence of natural variability, the extremes of climate may become more pronounced (Sheffield and Wood, 2007).

In Zambia, most studies indicate that drought occurrence and rainfall variability continue to increase due to the accelerated global warming associated anthropogenic activities. In a study on drought, rainfall variability and its implication on Zambia, Sichingabula (1998) concluded that in Zambia drought is a chronic phenomenon which requires pre – planned measures to minimise its impact. The impact of droughts in agriculture is observed in reduced crop yields or crop failure in extreme cases, of most Zambian field crops. Moreover, the southern, east or west Africa has been described as the drought prone regions with a strong dependence on rainfall. In sub-Saharan Africa, where maize is a staple food for more than 300 million people, a number of countries in these geographic regions often experience drought in the same season, creating regional food shortages that cannot easily be alleviated by cross-border trade (Edmeades, 2008).

2.8 SELECTION OF DROUGHT TOLERANCE MAIZE CULTIVARS

Significant yield losses in maize from drought are expected to increase with global climate change as temperatures rise and rainfall distribution changes in key traditional production areas. The success of conventional crop improvement over the past 50 years for drought tolerance forms a baseline against which new genetic methods must be compared. Selection based on performance in multi-environment trials has increased grain yield under drought through increased yield potential and kernel set, rapid silk exertion, and reduced barrenness, though at a lower rate than under optimal conditions. Knowledge of the physiology of drought tolerance is, therefore, important in breeding for drought tolerant maize cultivars (Campos *et al.*, 2004).

Plant traits such as number of ears, ears per plant, grain yield, thousand kernel weight, harvest index, plant height, number and fertile tillers, days to flowering and maturity, biomass yield, evapotranspiration rate, stomatal conductance, photosynthetic rate, ear length, leaf area and length, leaf area duration and rolling, have been documented to be important traits in drought breeding programmes (Branziger *et al.*, 2000).

2.9.0 MAIZE GENOTYPE DERIVED TRAITS RELATED TO DROUGHT TOLERANCE

2.9.1 Water use efficiency (WUE)

The term water use efficiency (WUE) has been extensively used for many years and it has been given distinct meanings by different disciplines. However, plant physiologists and agronomists have defined WUE as the ratio of the weight of dry matter produced to the amount of water transpired (Eamus, 1991). Water use efficiency can also be described as the measurable trait of a cropping system's capacity to convert water into plant biomass or grain. In crops (like maize) WUE is the efficiency with which an individual crop converts water transpired (or used) to grain, expressed in kg/mm/ha (GRDC, 2009). Dry matter production can be measured at the level of total crop, above ground crop and single leaves. Water loss can be defined as transpiration, transpiration plus soil evaporation, and transpiration plus soil evaporation plus interception loss. Therefore, WUE is expressed as;

$$WUE = \frac{Y}{\sum ET}$$

where; WUE is Water use efficiency computed by dividing the biomass and grain yield (Y) by the evapotranspiration and transpiration ($\sum$ET) as described by Donovan and Ehleringer (1994).

2.9.2 Crop water productivity (WP)

The crop water productivity expresses the above ground dry matter (g or kg) produced per unit land area (m^2 or ha) per unit of water transpired (mm). Many experiments have shown that the relationship between biomass produced and water consumed by a given species is highly linear (Steduto *et al.,* 2007).When normalised for the atmospheric CO_2 concentration and for the climatic factors, water productivity (WP*) gives a distinction between C_4 crops (WP*= 30 - 35 g/m^2) and C_3 crops (WP* = 15 - 20 g/m^2). Water productivity (WP*) is expressed as;

$$WP = \frac{Y}{\sum\left(\frac{T}{ET}\right)}$$

where, Y is the total biomass or grain yield, WP is the water productivity, ET is the evapotranspiration and T is transpiration.

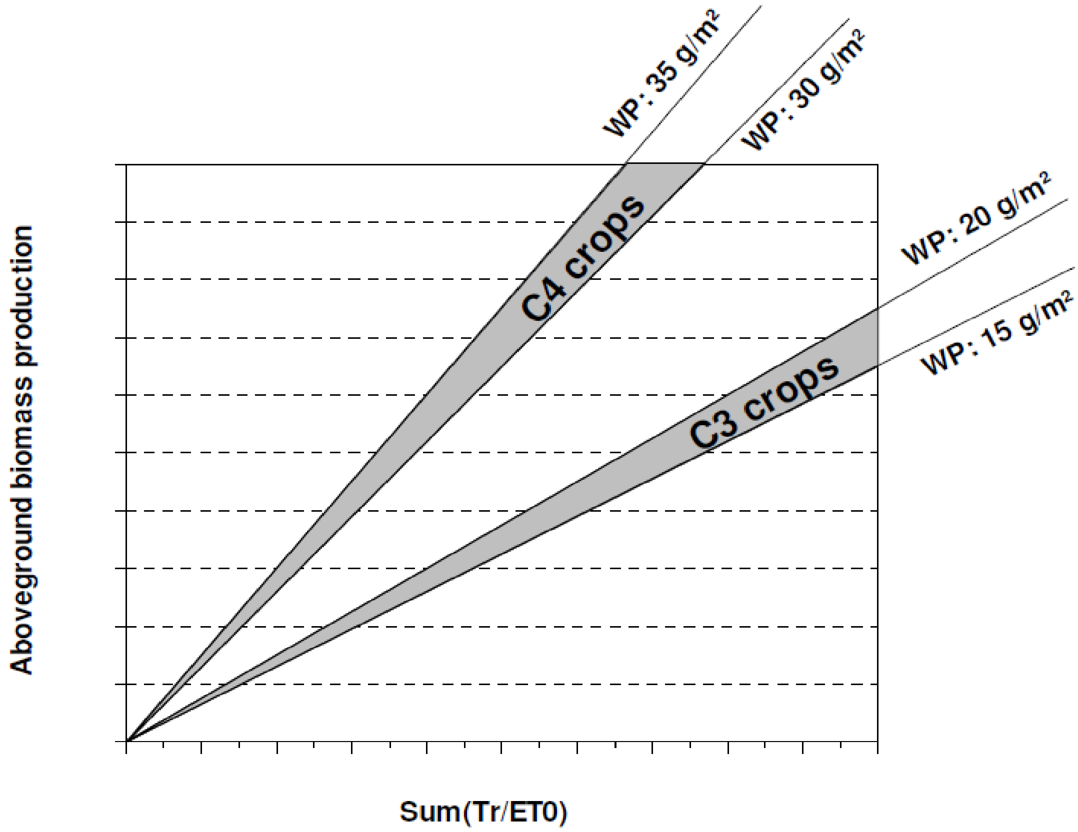


Figure 1: Crop water productivity after normalization for CO_2 ant ETo (Steduto *et al., 2007*)

2.9.3 Crop yield response factor (Ky)

A deficiency in the full water requirement (or water stress) leads to lower crop yields. The effect of this deficiency on yield is estimated by relating the relative yield decrease to the relative evapotranspiration deficit through a yield response factor (Ky) (FAO, 1979):

$$\left(1-\frac{Y_a}{Y_m}\right)=ky\left(1-\frac{ET_a}{ET_m}\right)$$

where, Y_a is actual yield, Y_m is maximum yield, ET_a is the actual crop evapotranspiration, ET_m is the maximum crop evapotranspiration and Ky is crop yield response factor.

The Ky values are crop specific and vary over the growing season according to growth stages

with: Ky>1: crop response is very sensitive to water deficit with proportional larger yield reduction when water use is reduced because of stress. Ky<1: crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reduction in yield with reduced water use. Ky=1: yield reduction is directly proportional to reduced water use.

Based on the analysis of an extensive amount of the available literature on crop-yield and water relationships and deficit irrigation, Ky values were derived for several crops. The analysis of deficit irrigation studies also allowed, for the majority of crops, the development of crop response functions when water deficits occur at different crop stages. As illustrated for maize in Figure 2, yield response will differ largely depending on the stage the water stress occurs. Typically flowering and yield formation stages are sensitive to stress, while stress occurring during the ripening phases has a limited impact, as in the vegetative phase, provided the crop is able to recover from stress in subsequent stages. The steeper the slope (i.e. the higher the Ky value), the greater the reduction of yield for a given reduction in ET because of water deficits in the specific period.

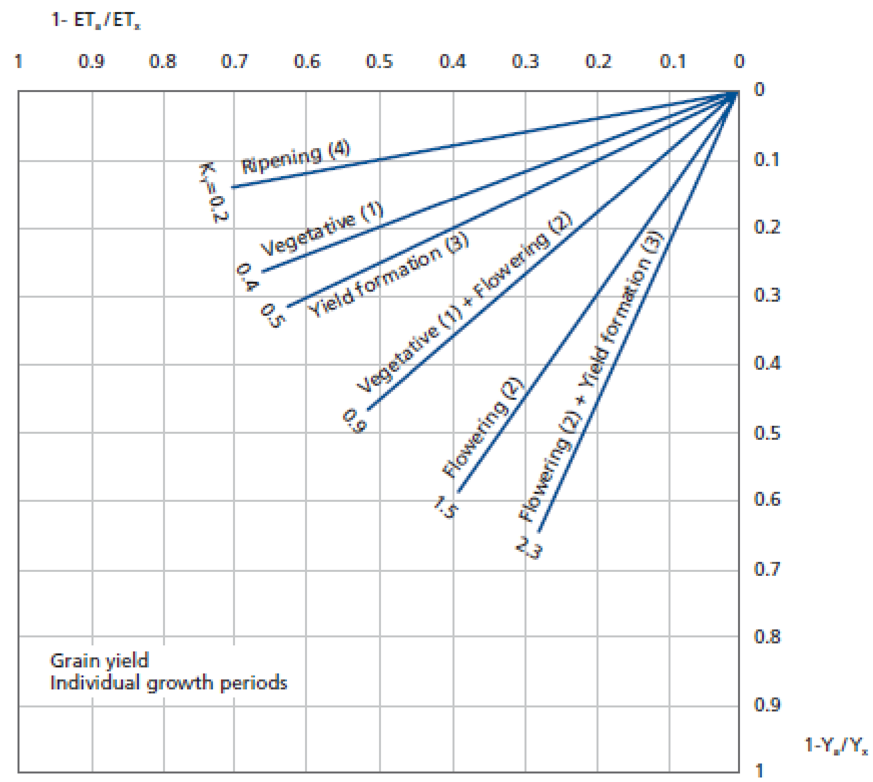


Figure 2: Linear water production functions for maize

2.9.4 Separation of evapotranspiration into soil evaporation and crop transpiration

The evapotranspiration (ETo) from a grass reference surface, not short of water, is an index for the evaporating power of the atmosphere. Crop transpiration (Tr) is calculated by multiplying ETo with the crop transpiration coefficient (Kcb) and by considering the effect of water stress.

Evapotranspiration (ETc) can be separated into soil evaporation (Es) and crop transpiration (Ta) through incorporation of a green canopy cover and soil moisture stress (Ks). The separation of ET into Ta and Es avoids the confounding effect of the non-productive consumptive use of water (Es), which is important especially during incomplete ground cover.

$$Tr = Ks \times (CC \times Kcb) \times ETo$$

where Ks is the soil water stress coefficient which becomes smaller than 1, and as such reduces crop transpiration, when insufficient water is available in the root zone to respond to the evaporative demand of the atmosphere. The crop transpiration coefficient Kcb is proportional with the green canopy cover (CC). The proportional factor is the maximum crop transpiration coefficient (Kcb) which integrates the effects of characteristics that distinguish the crop transpiration from the evapotranspiration from the grass reference surface.

The coefficient for transpiration (Kcb) is proportional to CC adjusted for aging, senescence and is crop-specific. Soil water stress is manifested through a stress coefficient Ks, a modifier which varies in value from one, when the effect is non-existent, to zero when the effect is maximum. The relation of Ks vs. root zone depletion between the upper and lower threshold is usually not linear due to plant acclimation and adaptation to the stress, and to the non-linearity of the matric potential vs. volumetric soil water content relationships. Convex and linear shapes can be considered.

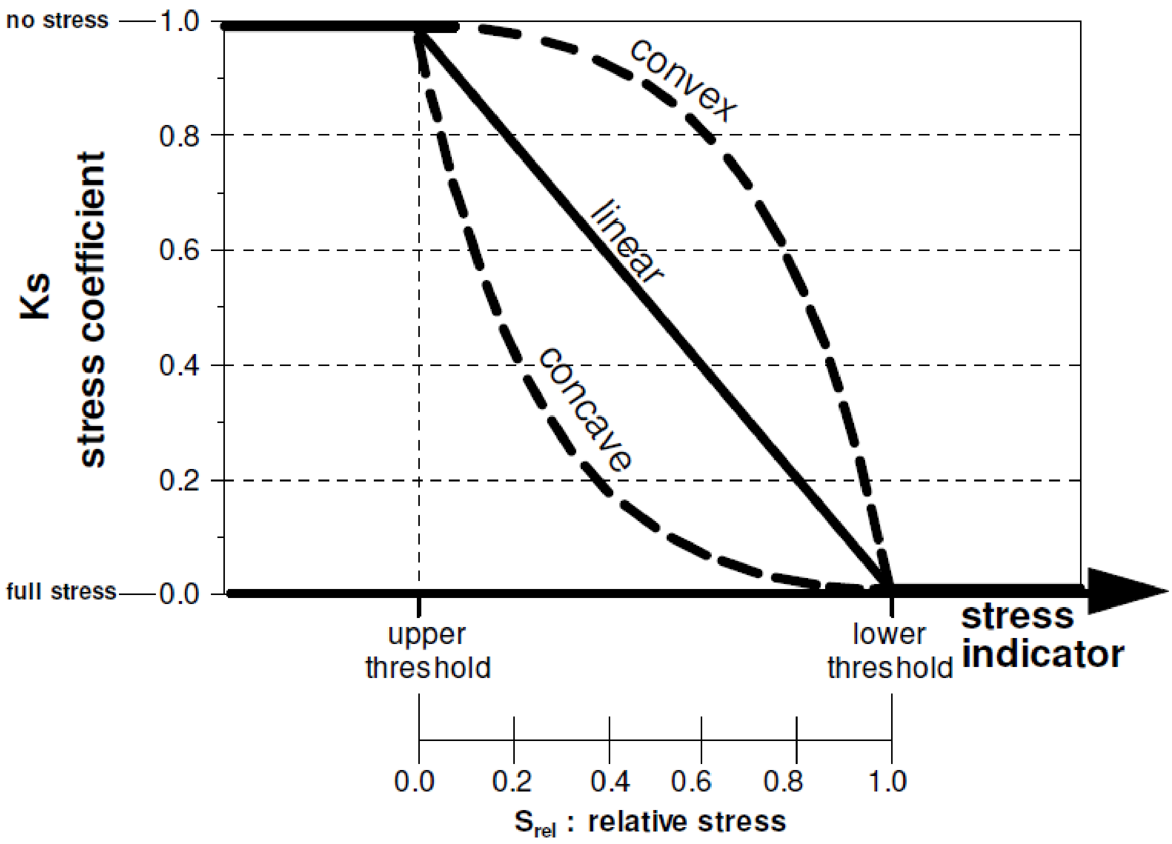


Figure 3:Stress coefficient (Ks) for various degrees of stress and for different shapes of the Ks curve (FAO, 2002)

2.9.5 Soil water balance

Producing optimal yield requires that the soil-water content be maintained between an upper limit at which leaching becomes excessive and a lower point at which crops are stressed. For most crops and especially those under irrigation management, the acceptable soil-water range is generally defined using the available soil-water concept which is the difference between the field capacity and the permanent wilting point. Field capacity is defined as the water content at which drainage becomes negligible on a free draining soil. The minimum soil-water content is defined when plants permanently wilt and is called the permanent wilting point. The soil water stored between field capacity and the permanent wilting point is called the total available water or available water capacity (AWC) and this is the water accessible in the root zone by the plant for normal water growth requirements (United States Department of Agriculture, 1993)

The root zone soil water balance aid in the computation of the actual crop evapotranspiration. It takes into account the water input and output and is represented as (Hartmann, 1998):

$$(P + C) - (R + D + ET) = S$$

where: P+C – gains, R+D+ET – losses, S is changes in storage, P is rainfall (mm) obtained from the rain gauge, C is capillarity, R is run off (mm), D is drainage component and ET_o is

Potential evapotranspiration computed from the climatic data. The unit on each of the terms of the water balance can either be volume per unit area or units of length or depth of water.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 THE STUDY AREA

The experiment was carried out at the National Irrigation Research Station, one of the stations that are under the Zambia Agriculture Research Institute in the Ministry of Agriculture and Livestock located in Mazabuka district. The station has an irrigation scheme with Kafue River as the source of irrigation water. Geographically, the station is at latitude 15˚45' south, and longitude 27˚56' east, at an altitude of 900 – 1000 m above the sea level. The exact experimental field was laid at latitude 15˚46'50'' south, and longitude 27˚55'31.4'' east, at an altitude of 984 m above the sea level.

3.2 CLIMATE

Mean annual rainfall in the study area is about 800 mm in wet years and less in dry years. The rains fall between the months of October to April. The mean daily maximum and minimum temperatures range from 24.7˚C to 33.6˚C and 7.4˚C to 18.2˚C, respectively, and the highest values are recorded in the months of October and November while the lowest values are recorded in June and July. The mean daily net solar radiation range from 5.7 MJ/m^2/day to 10.1 MJ/m^2/day. The total annual evaporation is about 1897 mm. The climate of the study area favours the cultivation of mostly cereals, legumes and vegetables. The production of most vegetables is under irrigation.

3.4 EXPERIMENTAL SITE CHARACTERISATION

The soils of the study area are typical of Alfisols (Sokotela *et al.,* 2010). The soil characteristics of the field where the experiment was laid are shown in Table 3.0 The characterisation is based on the selected soil chemical and physical properties. The soil textural class is predominately Sandy clay loam.

3.5 PLANT MATERIALS

The study involved twelve maize genotypes (inbred lines). The maize genotypes or inbreed lines used in this study were obtained from the Zambia Agriculture Research Institute (ZARI), from the Maize Research Programme.

3.6 TREATMENTS AND FIELD EXPERIMENTAL SETUP

In order to select the drought tolerant maize genotypes (inbreed lines), the 28 m x 2 m plots (blocks) were laid in a split plot experimental design with three treatments (in the main plot) in three replications. There were 108 treatment combinations which gave a total of nine blocks separated by a distance of more than 25 m apart. The treatment factors were water regimes as main factor, (levels of irrigation) at 30 %, 60 % and 100 % of maximum crop water requirement (ET_c) which led to cumulative amounts of 252.7 mm, 505.3 mm and 842.2 mm, respectively. The twelve (12) maize genotypes or inbred lines (subplot) were sub-factors. The ETc based irrigation schedule was developed to determine water amounts to irrigate daily (Appendix I). The irrigation schedule was developed from historical climatic data of the study area. The sprinkler method was used in this experiment to apply predetermined amounts of water to each block.

Table 2 Experimental layout

REP	**WR %**	**MAIZE GENOTYPES (INBREED LINES)**											
1	100	L857	L152	L07	L10	L60	L353	L428	L512	L640	L645	L713	L151
1	60	L10	L353	L512	L645	L640	L428	L60	L713	L857	L151	L152	L07
2	100	L60	L428	L640	L713	L151	L152	L07	L10	L353	L512	L645	L857
2	60	L640	L512	L428	L353	L152	L713	L10	L60	L857	L645	L07	L151
1	30	L60	L512	L428	L640	L353	L10	L645	L151	L152	L07	L857	L713
3	100	L151	L713	L640	L428	L60	L07	L152	L857	L645	L512	L353	L10
2	30	L353	L428	L512	L640	L713	L152	L07	L10	L60	L857	L151	L645
3	60	L151	L152	L07	L10	L60	L353	L428	L512	L640	L645	L713	L857
3	30	L152	L151	L857	L713	L645	L640	L512	L428	L353	L60	L10	L07

3.7 IRRIGATION AND IRRIGATION SCHEDULING

The irrigation was done weekly by summing up the daily ETc for the week. The irrigation pipe lines were set up per water regime such that three blocks of the same water regime would be irrigated at once. Irrigation was done in the mornings of the days set for irrigation and soil moisture content obtained. The irrigation system used in this experiment to apply water at 30 %, 60 % and 100 % of ETc was the sprinkler method. The sprinkler nozzle discharge was calculated by taking averages of the water discharge using the rain gauge over a series of irrigations before stressing began. The respective blocks were separated by a distance of more than 25 m apart. The maize irrigation schedule (attached at the appendices) was developed from the weather data of the environment were the experiment was carried out using the automated weather station.

3.8 AGRONOMIC OPERATIONS

The twelve maize genotypes (lines) were grown in a period of 130 days. The maize seed was planted at a spacing of 0.75 m x 0.25 m, three rows per maize genotype per block or replication. This translated into a total of 21 plants per subplot. The maize seed was planted with compound D (10 % N, 20 % P_2O_5, 10 % K plus 6 % S) basal dressing fertiliser at 20 kg P/ha, 10 kg N/ha and 10 kg K/ha. The chemical called Planet (Phorate active ingredient) was equally applied at 0.5 g/ planting station to prevent stalk borers. Other pesticides used to prevent crop damage from high infestation of stalk borers were, Furadan at 0.5 g per funnel of a plant 44 days after planting and Chloropyriphos at a dilution of 2 to 1 chemical to water 48 days after planting. All the blocks were irrigated at 100 ETc for 27 days after planting to give good plant establishment of all treatments before water stress (60 % and 30 %) was introduced. Ammonia top dressing fertiliser was applied to all plots at the same rate 80 N kg/ha 49 days after planting.

3.9.0 DATA COLLECTION

Morphological traits like plant height, plant diameter and canopy cover were collected weekly from each subplot representing the twelve maize genotypes in respective blocks. At harvest; data for yield and yield components were obtained.

The following parameters were measured:

3.9.1 Soil moisture use by maize genotypes

A total number of 108 access tubes were installed 3 weeks after germination to monitor the use of water by the maize genotypes. The access tubes were installed to the depths of 200 m using the augar. The diviner (capacitance) probe 2000 series was used to measure soil moisture on a weekly basis.

3.9.2 Crop growth parameters

The maize crop growth parameters selected in this study were plant height, plant girth (stem diameter), plant canopy cover and root growth. Plant height, plant girth and canopy cover measurements were done weekly starting at the 3 leaf stage, while root density was done at 77 days after planting and at harvest. The 300 cm metre rule was used to measure the 3 randomly selected plants for plant height and the same plants for plant girth using the verneir callipers. Canopy cover measurements were based on digital camera pictures captured on top of the crop focusing on 3 planting lines or a particular subplot with the maize genotype of interest. Root density was determined by firstly harvesting the above ground biomass and using the augar to dig up the roots at predetermined depths. The roots were then washed and dried to a constant weight at 60 °C. The known volume of the bucket augar was then used to determine root density. Plant height, plant girth and root density results were expressed in cm, cm and g/cm^3, respectively.

3.9.3 Days to 50 percent tasseling and 50 percent silking

The number of days to tasseling and silking (when approximately 50% of plants in plot completely tassel or silks) from planting were determined by daily counting the tasselled and silking plants per plot and dates of 50 % tasseling and silking was recorded.

3.9.4 Crop yield

The above plant biomass harvest was done twice at 77 days after planting and final harvest at 139 days after planting and the root density was determined at the same time. The preliminary distractive sampling of one plant per subplot was done 77 days after planting. The selected plants were washed and oven dried at a constant heat of 60˚C until a constant dry matter weight was obtained. The whole experimental field was harvested 139 days after planting. The total above ground biomass of all maize genotypes per plot was harvested. This was done by counting the total number of plants in each plot at the time of harvest and then cutting the whole plant and putting the biomass in the sacks for drying to a constant weight at 70˚C. The maize grains from the cobs were later weighed separately. The results of the harvest were expressed in ton/ha.

3.9.5 Harvest index (HI)

The HI was calculated from the ratio of grain yield to total above ground biomass in each experimental unit based on the same number of plants used for above ground biomass determination.

3.9.6 Crop water productivity

The crop water productivity was computed by dividing the above ground dry matter (g) produced per unit land area (m^2) per unit of water transpired (mm). The equation as presented by Steduto *et al*. (2007).

3.9.7 Crop yield response factor

The yield response factor was determined from the maximum and actual yields, then dividing by the maximum and actual evapotranspiration. The maximum values were based on prevailing environmental conditions under which the maize genotypes were grown (FAO, 1979)

3.9.8 Water use efficiency

Water use efficiency was computed by dividing the biomass and grain yield (Y) by the evapotranspiration and transpiration (∑ET) as described by Donovan and Ehleringer (1994)

3.9.9 Water balance and water distribution in the soil profiles

The water balance of soil profiles in respective with maize genotypes were obtained by taking moisture readings before and after irrigating. The diviner probe was used to determine the moisture in the soil profiles. This was done by taking into account the water input and output. The equation used was as presented by Hartmann (1998).

4.0 DATA ANALYSES

The collected data on different components were compiled and analysed statistically using the GENSTAT 14th Edition and excel. Data were subjected to analysis of variance (ANOVA) using General linear model procedure. Least Square Difference (LSD) was used to separate the means for the measured parameters ($P \leq 0.05$). Simple correlation was also done to determine the relationship between yield and other parameters.

5.0 LABORATORY ANALYSIS OF SOIL CHEMICAL AND PHYSICAL PARAMETERS

5.1 Soil Reaction (pH)

The soil reaction was determined in a 1:2.5 soil to solution of 0.01M Calcium chloride. Ten grams of soil was stirred with 25 ml of calcium chloride. The pH was then determined electrometrically.

5.2 Electrical conductivity (EC)

The EC of soil was measured using electric conductivity metre on 1:5 (soil: water) suspension, while that for irrigation water was measured directly at room temperature. The results were expressed in milisiemens per cent metre (mS/cm).

5.3 Exchangeable (Extractable) Bases (Ca, Mg, K, Na)

The bases were extracted by leaching 10 g soil with 50 ml of 1 M ammonium acetate buffered at pH 7.0. The ammonium ion displaces the cations. These are then collected in the filtrate and determined on the flame photometer for K and Na, directly from filtrate. Ca and Mg were further diluted with strontium chloride solution to a dilution factor of 10 and the amounts were determined on the atomic absorbance spectrophotometer (Chapman H.D, 1965). The results were expressed in cmol/kg of soil.

5.4 Total Nitrogen (Total N)

The kjeldahl digestion method was used to determine total soil nitrogen. In this method ammonium ion was steam distilled into boric acid and titrated with HCl (Bremner, 1960). The total nitrogen is expressed as a percentage.

5.5 Organic Carbon (C)

The Walkely – Black wet combustion method was employed to determine the organic carbon. The sample was treated with potassium dichromatic (a strong oxidizing agent) and then digested with a mixture of sulphuric and phosphoric acid. The excess dichromate is titrated with ferrous sulphate solution using diphenylamine indicator (Allibon 1965). A recovery factor is used in the calculation.

5.6 Available Phosphorus (P)

A modified Bray 1 method was employed. The extracting solution is a mixture of ammonium fluoride and hydrochloric acid. Ammonium molybdate and Antmony potassium tartrate are used for colour development. Ascobic acid is used as a reducing agent. The blue colour is read on the atomic absorbance spectrophotometer. Results read in mg/L but converted to mg/kg of soil.

5.7 Particle size analysis (clay, silt and total sand)

The hydrometer method was used in the soil particles analysis. In this method, the soil sample is oxidised with hydrogen peroxide and dispersed with sodium pyrophosphate. Clay and silt particles are analysed by sedimentation technique as they settle with time. The clay and silt concentration was determined at 40 seconds and clay alone after 8 hours using the hydrometer at 10 cm depth (Bonyoucos, 1962). The results of all sand, clay and silt particles were expressed in percentages and textural triangle was used to determine the soil texture.

5.8 Bulk density

The dry bulk density (Db) is the ratio between the mass of oven dry soil material and the volume of the undisturbed fresh sample. The bulk density was determined by the use of core rings, a method well described by Tan (2005). The core rings were inserted into the soil at different depths and weighed for their bulk weights after which they were oven dried at constant temperatures of 105˚C for 24 hrs. The oven dry weight was obtained and using the known volume core rings the bulk density was expressed in g/cm^3.

5.9 The soil field capacity and wilting point

The pressure plates were used to determine the soil water content at 0.33 bars and 15 bars. This was done by cutting a 1 cm high soil slice from the core rings; saturating them over night and putting them to pressure chamber for more than 48 hrs. The pressure at different pressure levels will extract the water out of the soil slices. The soil slices were then weighed and oven dried for 24 hrs, the wet weight and oven dry weight was used to determine the gravimetric water content at 0.33 bars and 15 bars. The water content at 0.33 bars was the field capacity, while the water content of slice soil at 15 bars was the wilting point. The difference between the water content at 15 bars and 0.33 bars was considered as the plant available water (Tan, 2005).

CHAPTER 4

4.0 RESULTS

4.1 General observations

The summary of selected soil chemical and physical properties at the soil of the selected site of study and where the experiment was laid are presented in Table 3.0 The soils indicated a fairly fertile soil state as most analysed chemical components were within the acceptable ranges to meet the requirements of a maize crop. The EC of both the soil and water used for irrigation indicated a non hazardous level of dissolved salts for the maize crop, with values of 1.12 mS/cm and 0.344 mS/cm, respectively. The soil textural class according to USDA classification was predominantly sandy clay loam with a soil density of 1.52 g/cm^3 in the root zone (Table 3).

Results of analysis of variance (appendices) show that there were highly significant differences among the twelve maize genotypes used in this study. The effect of water regime was significant in most measured parameters and highly significant in grain yield, above ground biomass, harvest index and plant height. The effect of maize genotype on all measured parameters was highly significant except for anthesis – silking interval (ASI). The water regime by maize interaction was equally highly significant on most measured parameters except for ASI and WUE in which it was significant.

4.2 Effect of maize genotype on grain yield, yield components, selected morphological traits, Ky and WUE

The results of mean separations (Tables 4) of 12 maize genotypes revealed a highly significant effect of genotypes on grain yield, yield components, selected morphological traits, and crop yield response factor and water use efficiency at $p \leq 0.05$.

Table 3: Selected soil chemical and physical parameters of the study area

Depth	pH	Ca	Mg	Na	K	N	Org C	P	Db	FC	WP	PAW	Clay	Silt	Sand
cm	**$CaCl_2$**	**cmol/kg**	**cmol/kg**	**cmol/kg**	**cmol/kg**	**%**	**%**	**mg/kg**	**g/cm^3**	**%**	**%**	**%**	**%**	**%**	**%**
0 - 15	6.34	9.98	6.65	0.01	1.18	0.08	0.85	14.46	1.48	11.3	4.8	6.5	33.6	5.6	60.8
15 - 40	6.32	4.92	6.67	0.01	0.92	0.01	0.49	2.52	1.52	15.9	8.5	7.4	26.1	12.1	61.8
40 - 75	6.51	4.49	7.15	0.01	0.68				1.53	20.2	12	8.2	38.1	10.7	51.2
75 –129	6.67	4.15	7.01	0.03	0.43				1.53	21.2	12.2	9	43.4	10.4	46.2
	6.9	8.76	7.04	0.03	0.62										
129-200									1.44	20.2	11.9	8.3	40.5	12.1	47.4
Critical Values	**4.5**	**0.1**	**0.1**		**0.22**	**0.1**	**2**	**0.25**							

4.2.1 Grain yield

There were highly significant differences in grain yield among the different genotypes (Table 4). The mean grain yield across all genotypes was 1.455 ton/ha. The yield range among the genotypes was from 0.93 ton/ha to 2 ton/ha. The highest yield was obtained in genotypes L512, L353, L857 and L07. This represented a yield advantage of 36.8 %, 34.6 %, 27.6 % and 18 %, respectively above the overall mean. The lowest yield was obtained in L640 with 0.93 ton/ha.

4.2.2 Yield components

The effect of genotypes on yield components was highly significant (Table 4) at $p \leq 0.05$. The overall mean of above ground biomass was 8.82 ton/ha and the highest biomass was obtained in genotype L151, L07 and L 10. The lowest biomass was 6.02 ton/ha in L857. However, results show high HI in genotypes L 857, L 353 and L 512 with HI value of 0.33, 0.25 and 0.23, respectively and overall mean of 0.17. The lowest HI was obtained in genotype L 640 with HI of 0.09.

4.2.3 Selected morphological traits

The selected morphological traits of anthesis – silking interval, root density, plant girth and plant height depended on genotype and are shown in Table 4 below. The ASI was shortest in genotypes L 713, L 07, L 353 and longest in genotype L60. Most genotypes had shorter ASI compared to the overall mean of 2.2 days. The root density overall mean was 10.3 mg/cm^3 and decreased in the order of L 428, L 07, L 152, L10 and L 645. The range of root density was 6.2 mg/cm^3 to 16.75 mg/cm^3, the lowest being genotype L 353. Plant girth or plant diameter was highest in the decreasing order of genotype L 07, L 10, L 428, L 60 and L645. The plant girth range among the genotypes was from 1.8 cm to 2.9cm with overall mean of 2.4 cm. Plant height results show an overall plant height mean of 107.45 cm. The tallest genotypes were in decreasing order of L 10, L 07, L 152, L 512, L 428 and L 60 was shortest with 76.67 cm.

Table 4: Effect of maize genotype on grain yield, yield components, selected morphological traits, Ky and WUE

Genotype	Y	BM	ASI	HI	WUE	RTD	Ky	PG	PH
	(ton/Ha)	(ton/Ha)	(days)		(kg/Ha/mm)	(mg/cm^3)		(cm)	(cm)
L07	1.730	11.78	0.56	0.14	3.23	14.64	1.062	2.871	134.89
L10	1.256	10.02	4.78	0.13	2.20	11.22	1.576	2.747	146.44
L151	1.262	12.78	2.78	0.01	2.50	8.16	1.311	2.316	90.93
L152	1.393	8.81	1.00	0.18	2.62	13.64	1.354	2.334	120.96
L353	1.959	6.33	0.89	0.25	3.58	6.20	0.868	2.168	97.26
L428	1.209	8.64	2.11	0.15	2.37	16.75	1.263	2.656	113.41
L512	1.991	8.52	1.89	0.23	3.95	10.05	0.831	2.154	118.81
L60	0.959	6.76	4.89	0.17	2.13	7.06	1.391	2.440	107.59
L640	0.934	9.35	2.00	0.09	1.60	9.45	1.428	2.346	76.67
L645	1.714	8.41	1.78	0.17	2.57	10.42	1.309	2.405	101.41
L713	1.192	8.37	0.00	0.14	2.58	7.30	1.188	2.214	91.22
L857	1.857	6.07	3.89	0.33	3.60	8.45	1.027	1.777	89.78
MEAN	1.455	8.82	2.158	0.17	2.744	10.30	1.217	2.369	107.45
LSD (5 %)	**0.342**	**1.19**	**3.4**	**2.1**	**0.979**	**2.6**	**0.31**	**0.05**	**1.03**
C.V %	**25**	**14.3**	**167.8**	**12.9**	**37.9**	**27.2**	**21.6**	**2.2**	**1**

KEY: Y: Grain yield, BM: above ground biomass, ASI: anthesis – silking interval, HI: harvest index, WUE: water use efficiency, RTD: root density, Ky: crop yield response factor, PG: plant girth, PH: plant height.

4.2.4 Crop yield response factor

The crop yield response factor results show that genotype had high significance on crop yield response factor. The Ky values ranged from 0.831 to 1.576. The highest was L 10 and lowest was in L 512. The overall mean was 1.217

4.2.5 Water Use Efficiency

There were highly significant differences in WUE among genotypes at $P \leq 0.05$ (Table 4). Results for WUE ranged from 1.6 kg/ha mm^{-1} (L640) to 3.95 kg/ha mm^{-1} (L512). Genotypes that recorded high WUE were observed to have had high grains yield also. The mean plot of genotypes at 30 % water stress (Figure 4) show high WUE in L512, L857, L713 and L60 with WUE value of 2.412 kg/ha mm^{-1}, 2.265 kg/ha mm^{-1}, 1.904 kg/ha mm^{-1} and 1.818 kg/ha mm^{-1}, respectively. The genotypes LI51 and L152 were known as drought tolerant (DT) materials while the other ten were being evaluated. Therefore, materials that had high water use efficient above L151 and L152 were selected as DT materials.

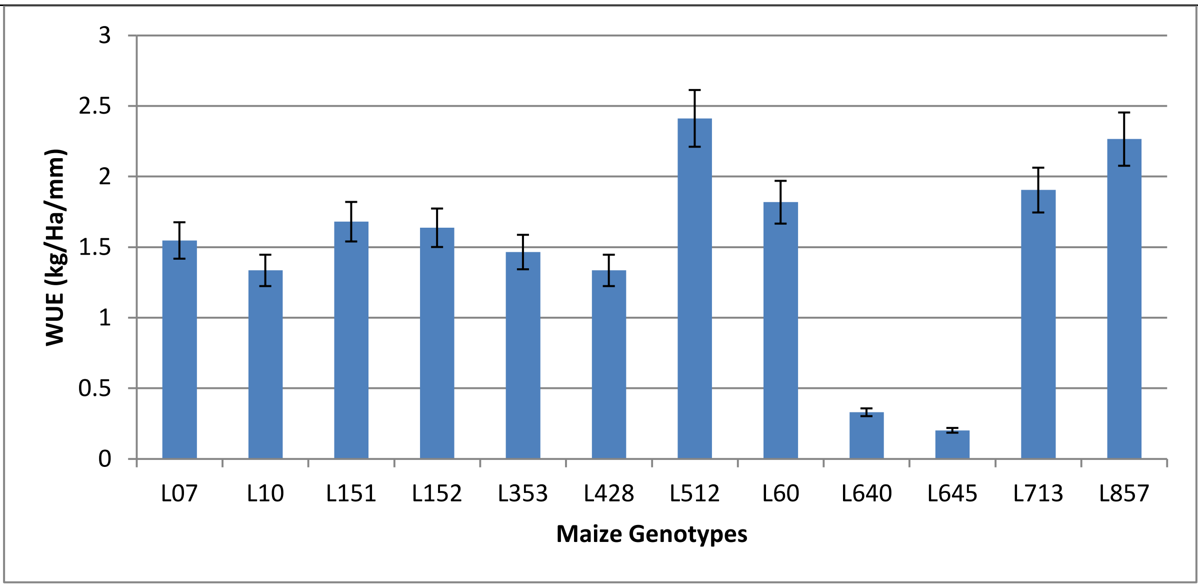


Figure 4: WUE at 30 % water stress

4.3 Effect of water regime on grain yield, yield components, selected morphological traits, Ky and WUE

Water regime had significant effect on all parameters measured; the 100 % water regime had high yield, yield components and other measured parameters. Water supply decrease resulted in reduced value of most measured parameters (Table 5).

4.3.1 Grain yield

Water regime had high effect on grain yield, a 100 % ETc water regime had high yield (2.048 ton/ha) of 69.87 % above the lower water regime of 30 % ETc.

4.3.2 Yield components

The results (Table 5) show that increased water supply increased the biomass accumulation in the order of 100 %, 60 % and 30 % ETc. The HI was high in optimum water regime but means were not significantly different from 60 % ETc.

Table 5: Effect of water regime on grain yield, yield components, selected morphological traits, Ky and WUE across genotypes

Water Regime	Y (ton/Ha)	BM (ton/Ha)	ASI (days)	HI	WUE (kg/Ha/mm)	RTD (g/cm^3)	Ky	PG (cm)	PH (cm)
30 % ETc	0.617	6.13	3.67	0.13	2.44	0.00893	1.179	2.3657	94.31
60 % ETc	1.699	8.97	1.19	0.20	3.36	0.0081	1.255	2.3389	108.55
100 % ETc	2.048	11.35	1.61	0.19	2.43	0.0138	1.00	2.4024	119.49
LSD (5 %)	**0.3106**	**0.528**	**1.109**	**0.501**	**0.925**	**0.0023**	**0.3644**	**0.036**	**0.99**

KEY: Y: Grain yield, BM: above ground biomass, ASI: anthesis – silking interval, HI: harvest index, WUE: water use efficiency, RTD: root density, Ky: crop yield response factor, PG: plant girth, PH: plant height

4.3.3 Selected morphological traits

Varying water supply had no significant effect on plant girth but significantly affected plant height, root density, and ASI. The ASI was increased by 56.1 % due to water stress of 30 %. 100 % water regime treatment increased both plant height and root density by 21 % and 35.2 %, respectively, compared to 30 % and 60 % water regimes.

4.3.4 Crop yield response factor

Water stress of both 30 % and 60 % water regimes had no effect on crop yield response factor (Ky). However, a 30 % water stress had a lower crop yield response factor of 1.179 in comparison to 60 % water regime. The Ky values separated at water stress of 60 % and 30 % show a differences in water use among the genotypes. The genotypes L353, L512, L07 and L857 had Ky values below 1 (less water users) at 60 % water stress, while at 30 % water stress only L512 and L857 were below Ky value of 1. The other genotypes were all above Ky value of 1(more water users) when stressed (Figure 5).

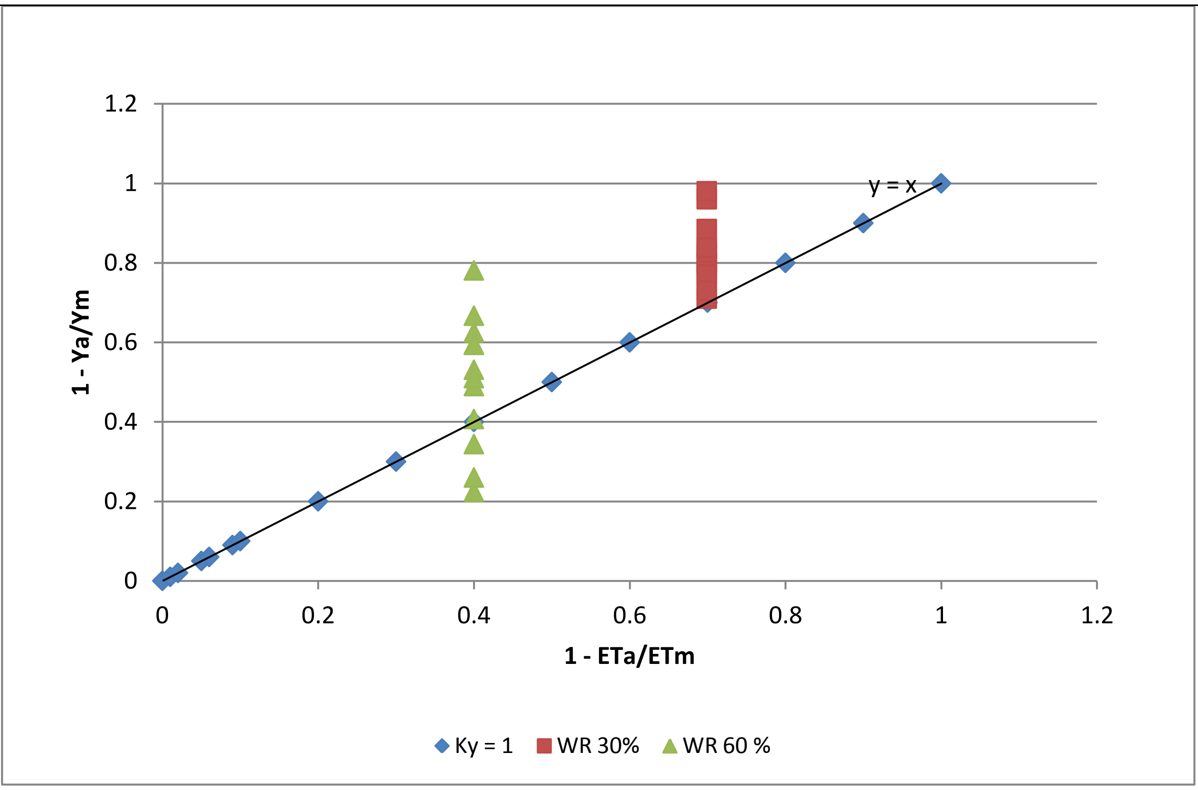


Figure 5: Ky values at 60 % and 30 % water stress

4.3.5 Water Use Efficiency

Different water regimes had different significant effects on WUE with 60 % water regime having a high WUE (3.36 kg/ha/mm) by 27.7 % above the optimum water supply. The WUE means were not significantly different between 30 % and 100% water regimes.

4.4 Relationship among grain yield, yield components, selected morphological traits, and WUE.

Simple correlation analyses were conducted among various components measured to determine the strength of association of these traits for grain yield, yield components, selected morphological traits, and WUE and also to estimate the inter component correlations among them. Results are presented in Table 6. There were both positive and negative correlations among the measured parameter. However, the strength of association was not very strong in most parameters except for HI association with grain yield (r = 0.7814) and WUE (r = 0.7617) also WUE showed a strong dependence on grain yield (r = 0.5935).

Table 6: Correlations among grain yield, yield components, selected morphological traits, and WUE.

Parameter	Y	WUE	RTD	PH	PG	HI	ASI	BM
Y	1	0.5935	0.3831	0.2975	-0.0774	0.7814	-0.1964	0.4427
WUE		1	0.0161	-0.0238	-0.2116	0.7617	-0.0553	-0.0319
RTD			1	0.4473	0.4155	0.1185	-0.1271	0.2703
PH				1	0.4718	0.0767	0.0273	0.2968
PG					1	-0.3925	0.0323	0.3467
HI						1	-0.0996	-0.1166
ASI							1	-0.0785
BM								1

Correlations at P ≤ 0.05

KEY: Y: Grain yield, BM: above ground biomass, ASI: anthesis – silking interval, HI: harvest index, WUE: water use efficiency, RTD: root density, PG: plant girth, PH: plant height.

The results showed that all the traits apart from plant girth (r = - 0.0774) and anthesis – silking interval (r = - 0.1964) were positively and significantly correlated to grain yield. This means that grain yield depended on above ground biomass, WUE, HI, plant height and root density in this study. The WUE factor recorded a negative correlation with above ground biomass (r = -0.0319), anthesis – silking interval (r = -0.0553), plant girth (r = -0.2116) and plant height (r = -0.0238), while root density (r = 0.0161) and harvest index (r = 0.7617) were positively correlated with WUE. The correlations of root density with other traits (Table 6) were all strongly positive except for anthesis – silking interval (r = -0.1271) which was negatively correlated with root density. Plant height was positively correlated with plant girth (r =0.4718), harvest index (r =0.0767), anthesis – silking interval (r =0.0273) and above ground biomass (r =0.2968). There was also association between plant height, root density, grain yield and WUE in this study. There was equally positive correlation of plant girth with above ground biomass (r =0.3467) and anthesis – silking interval (r =0.0323), while the association with harvest index was negative. The results also show negative correlation of harvest index with both anthesis –silking interval (r = -0.0996) and above ground biomass (r = -0.1166). The above ground biomass trait had positive correlation with all other traits except for harvest index, anthesis –silking interval and WUE which reviewed negative association to above ground biomass.

4.5 Monitoring of water use by genotypes in the soil profile as monitored by the diviner probe

The accumulative water monitored in each profile (of a genotype) to a depth of 160 cm was measured at weekly intervals to assess water depletion in respective soil profiles by the genotypes. At 40 DAP with optimum water supply or 100 % ETc (Figure 6); genotypes L353, L10, L857, L428, L 60 and L152 had more moisture accumulation spread up to the 100 cm soil profile. These genotypes used less of the applied water at this growth stage compared to genotypes, L512, L713, L07, L151, L645 and L640 which used most applied water and had less accumulated moisture measured. With a reduction to 60 % of optimum water requirement (Figure 7) at the same growth stage, only genotypes L713 and L645 used less water while the other genotypes had relatively less moisture measured of less than 20 mm. The genotype order of increased water used was, L07, L640, L10, L428, L151, L512 and

L857. At 30 % water stress, genotype L713 and L152 used less water in the soil profiles and recorded accumulated moisture of 80 mm up to the depth of 100 cm (Figure 8).

The soil moisture measured 72 DAP revealed that genotypes, L10, L353, L645, L428 and L152 used less water at optimum water crop water requirement (Figure 9) and measured accumulated soil moisture of 12 mm. Genotypes L640, L151, L713, L857, L512 and L07 showed more water depletion in their respective soil profiles. At water stress of 60 % (Figure 10), the soil moisture depletion in the soil profile of respective genotypes was in the order, L857, L512, L353, L07, L10, L151, L640, L713, L152, L645, L428 and L60 used moisture the least at this growth stage. However, at 30 % water stress all genotypes revealed high moisture use with not more than 5 mm accumulated moisture measured except for L07 which had higher accumulated soil moisture (Figure 11).

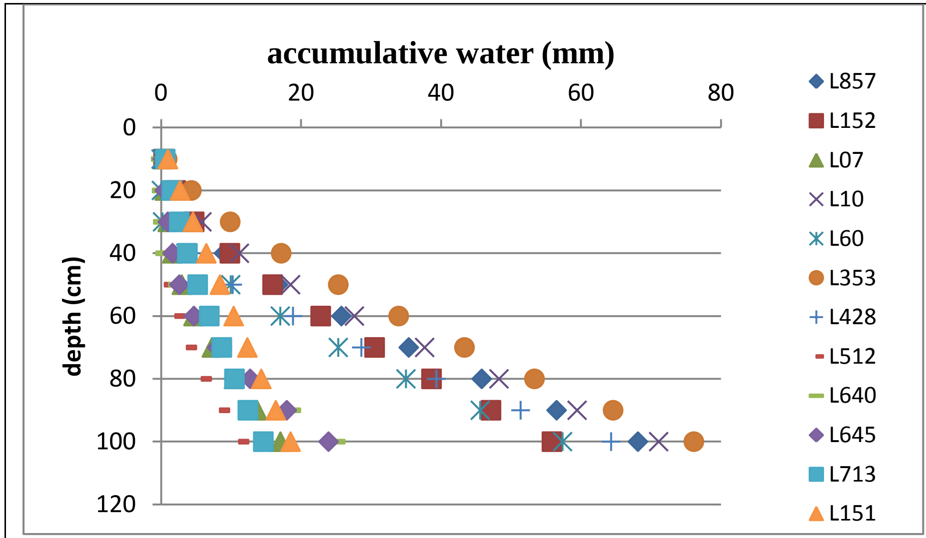


Figure 6: Soil profile moisture content at 40 DAP in 100 % WR

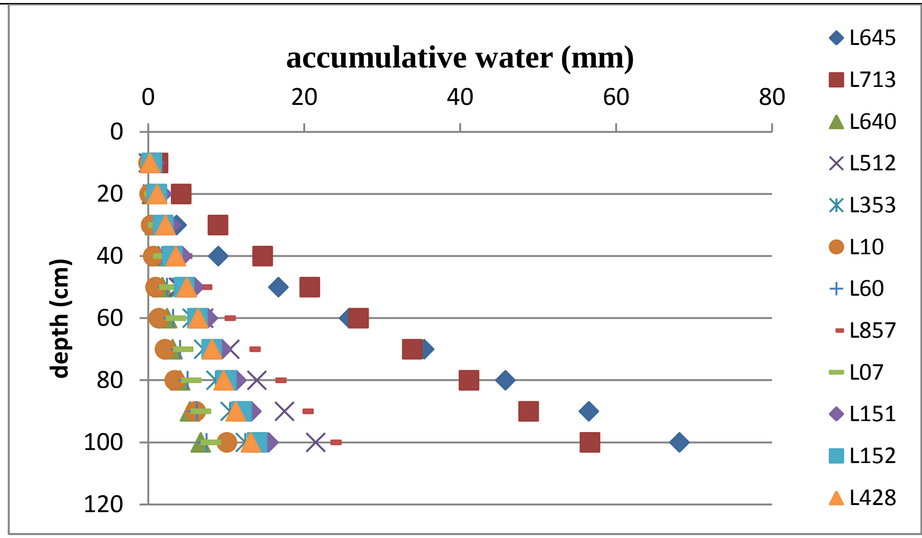


Figure 7: Soil profile moisture content at 40 DAP at 60 % WR

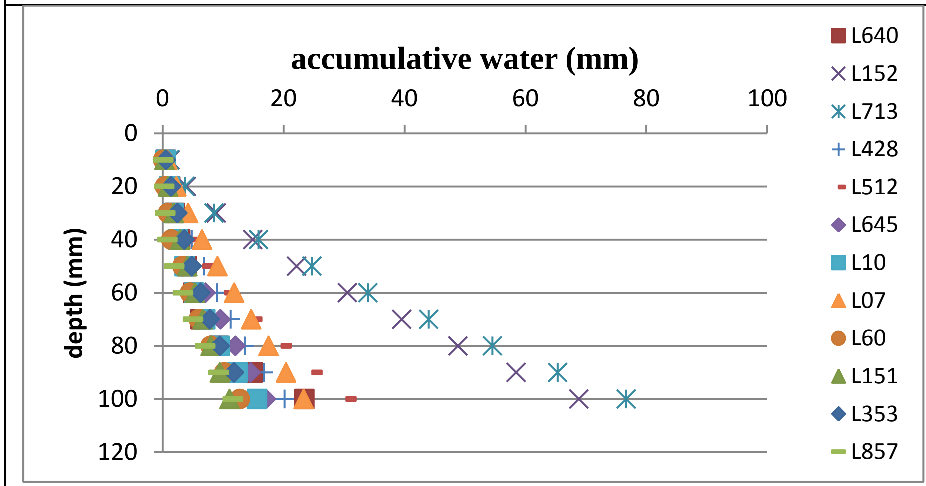


Figure 8: Soil profile moisture content at 40 DAP in 30 % WR

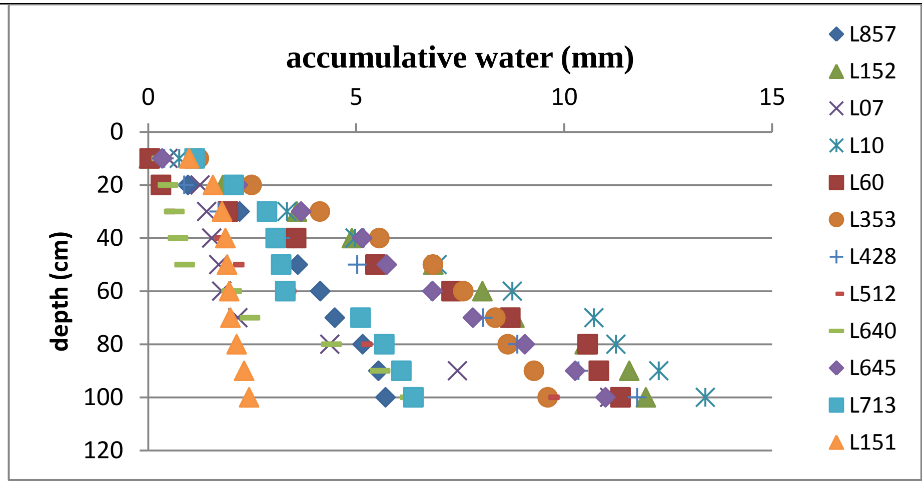
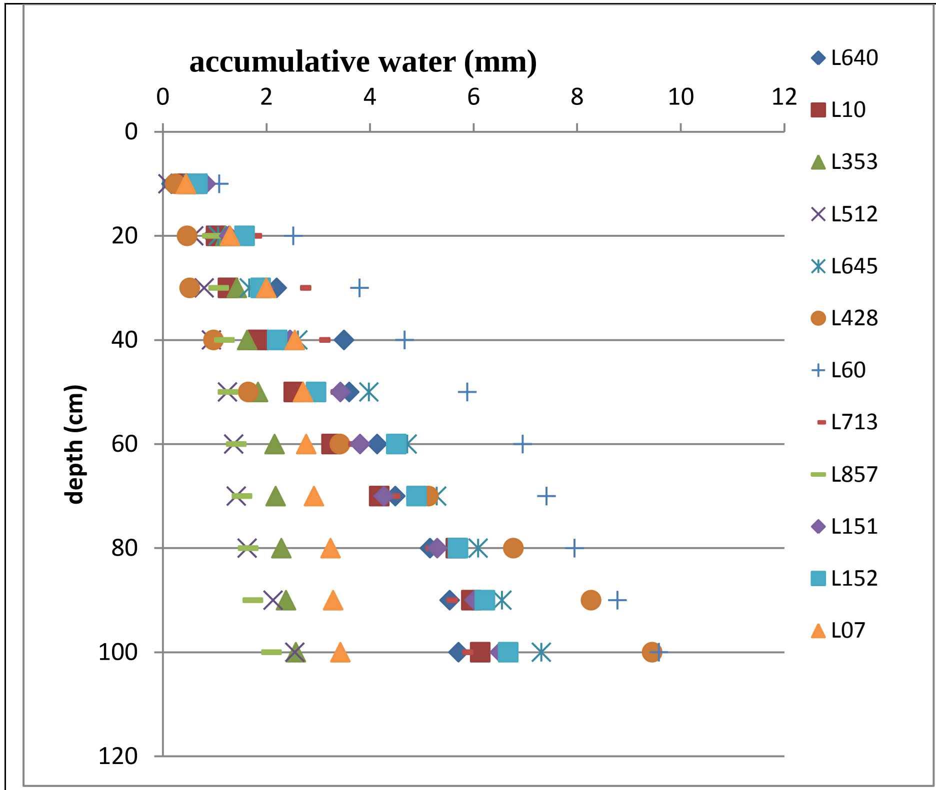


Figure 9: Soil profile moisture content at 72 DAP in 100 % WR



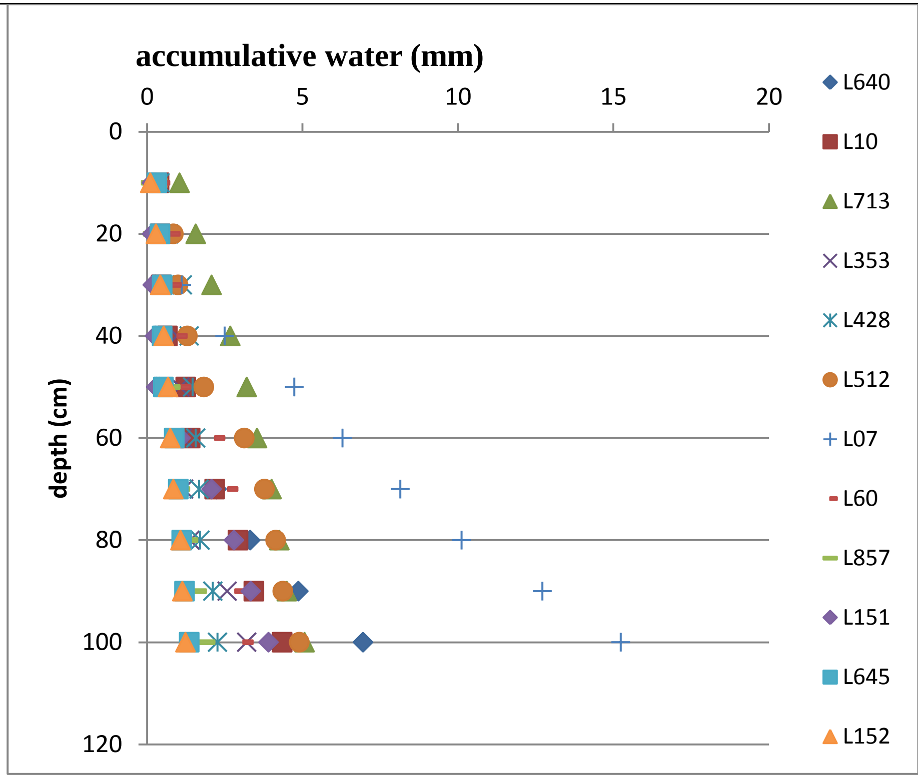


Figure 10: Soil profile moisture content at 72 DAP in 60 % WR	Figure 11: Soil profile moisture content at 72 DAP in 30 % WR

4.6 Separation of evapotranspiration into soil evaporation and crop transpiration

Table 7 shows the results of the separation of evapotranspiration (ETc) into soil surface evaporation (Es) and water transpired by the crop (Tc). The results show more transpiration as water supply increased from optimum water supply to deficit levels of 60 % and 30 % for all maize genotypes in the growing season. The transpired water across all water regimes and genotypes ranged from 25.78 mm to 145.64 mm. The difference in water transpired by genotypes between 100 % and 60 % water regimes was less than 50 mm in all genotypes except in genotypes L428 and L713 which had a difference of 56.81 mm and 61.89 mm, respectively. More water was lost through soil surface evaporation than was transpiration in all water regimes and genotypes by 19.3 % above the overall mean.

4.7 Crop Water Productivity

The crop water productivity (WP) was determined based on grain yield and water used in biomass production (Figure 12) ranged from 22.63 g/m^2 to 6.89 g/m^2 in the genotypes under study (Table 7). The crop water productivity overall mean of genotypes was 12.195 g/m^2 and WP advantage above the overall mean in genotype L645, L857, L512, L353 and L07 was 85.5 %, 32.5 %, 8.4 %, 6.6 % and 3.3 %, respectively.

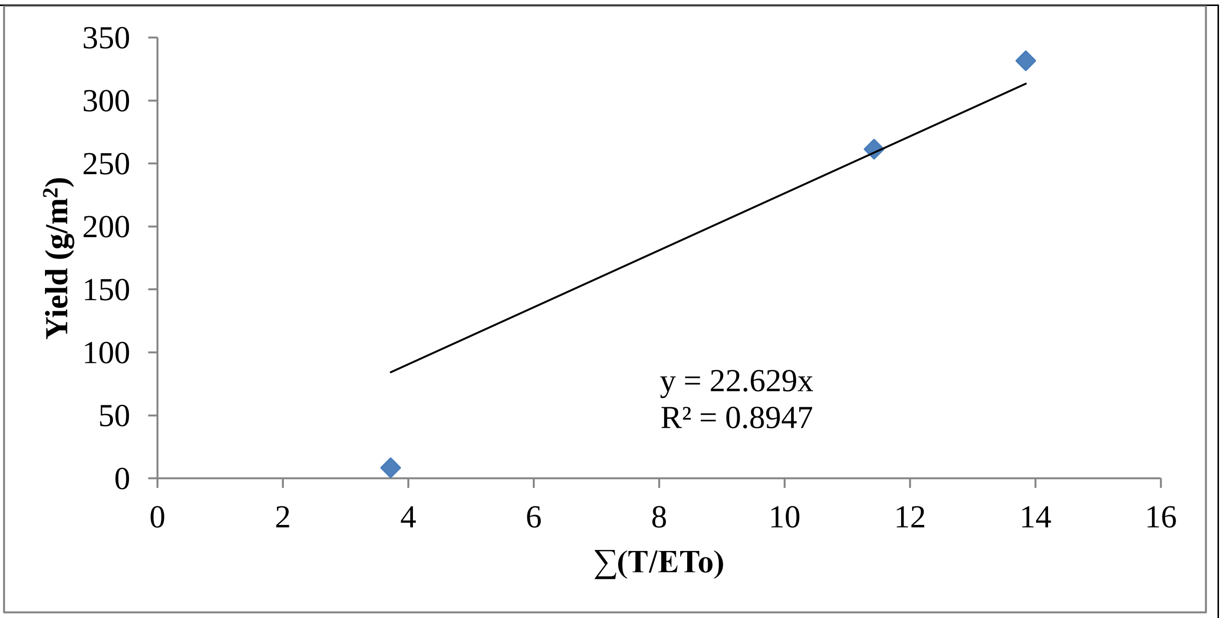


Figure 12. Determination of crop water productivity of genotype L645

Table 7: Separation of evapotranspiration into evaporation and transpiration and the genotype water productivity

Genotype	WR %	ETc (mm)	Es (mm)	Tc (mm)	WP* (g/m^2)
L07	100	842.2	722.66	119.54	12.6
	60	505.3	391.66	113.64	
	30	252.7	195.5	57.20	
L10	100	842.2	714.16	128.04	9.17
	60	505.3	388.39	116.91	
	30	252.7	199.77	52.93	
L151	100	842.2	725.91	116.29	10.96
	60	505.3	418.9	86.40	
	30	252.7	216.09	36.61	
L152	100	842.2	734.74	107.46	13.45
	60	505.3	419.81	85.49	
	30	252.7	217.21	35.49	
L353	100	842.2	711.95	130.25	13
	60	505.3	410.89	94.41	
	30	252.7	202.42	50.28	
L428	100	842.2	696.56	145.64	8.86
	60	505.3	416.47	88.83	
	30	252.7	207.94	44.76	
L512	100	842.2	697.55	144.65	13.22
	60	505.3	385.70	119.60	
	30	252.7	214.11	38.59	
L60	100	842.2	704.84	137.36	6.89
	60	505.3	404.51	100.79	
	30	252.7	192.23	60.47	
L640	100	842.2	741.70	100.50	9.76
	60	505.3	431.99	73.31	
	30	252.7	213.52	39.18	
L645	100	842.2	745.71	96.49	22.63
	60	505.3	422.61	82.69	
	30	252.7	226.92	25.78	
L713	100	842.2	713.27	128.93	9.19
	60	505.3	438.26	67.04	
	30	252.7	216.27	36.43	
L857	100	842.2	724.41	117.79	16.61
	60	505.3	430.91	74.39	
	30	252.7	195.08	57.62	
MEAN			**446.96**	**86.44**	**12.195**

KEY: ETc: Evapotranspiration, Es: soil evaporation, Tc: Crop transpiration and WP: Crop water productivity

CHAPTER 5

5.0 DISCUSSION

In view of the non improving production trend of maize (*Zea mays*) in the country (MACO/CSO, 2011) and how it is affected by climatic change like drought and erratic rainfall, the study evaluated the performance of selected maize genotypes grown under varying water regimes. The overall objective of the study was to determine the response of maize genotypes to water stress and identify or select the genotypes that can be used in breeding for (low water use) drought tolerance (DT). The genotypes showed significant differences in grain yield, yield components, selected morphological traits, Ky, WP and WUE. The general biomass production in the experiment was proportional to the availability of water. As the stress intensity increased at 30 % water regime, biomass production decreased (Table 5). This trend was in agreement with the experimental results reported in other studies which attributed poor production of dry matter to water stress (Pandey *et al*., 1983 and El – Bagoury *et al*., 1977). In this study, the genotypes LI51 and L152 were known drought tolerant (DT) materials and were therefore, used as references for the other ten genotypes. The comparison was done consistently across all measured parameters.

The results of the study showed genotypic variations among all genotypes for grain yield, yield components and other determined factors or traits. The grain yield variation was highly influenced by genotype and water regime. The projections from the ANOVA showed a variation contribution from genotypes of 30 % and variation contribution of 50.2 % from the water regime factor. The water regime factor was one of the limiting factors to yield as it is related to water stress caused by drought (Lawlor and Comic, 2002). Maize is fairly sensitive to water stress and excessive moisture stress is the most limiting factor in maize production (Pandey et al., 2000 and Cakir, 2004) and, hence, its importance in this study. Crop yield is a complex trait which is affected by genotype, environment and their interaction and in this study, the four genotypes L512, L353, L857 and L07 had high yield at 30 % water stress and based on yield, the four genotypes were considered as efficiently utilising water as they could still yield relatively high yield compared to other genotypes at the same water stress level. The other yield components actually revealed the factors associated with high yield in the four high grain yielding genotypes. Genotype L07 had high above ground biomass and high root density in the root zone (Shah *et al.*, 2011), thus, it was efficiently using growth requirements (water) efficiently for both above ground biomass and grain production. The genotypes L353, L512 and L857 on the other hand used most growth requirements on grain and had less above ground biomass. This in turn, resulted into the high HI for the three genotypes as HI is the ratio of economic yield (typically grain) to total above ground biomass yield, measuring a crop's success in partitioning total photosynthate to harvestable product and genotypes with higher values were preferred (Lorenz *et al.*, 2009).

Other than grain yield, ASI is another important parameter considered when breeding for drought tolerant maize and the shorter the ASI the better. Mostly an ASI of 4 – 5 days is normally recommended (Banzinger *et al.*, 2000). All genotypes had less than 4 days ASI with L353 having the shortest.

The other important factor which relates to the water use of genotypes is crop yield response factor (Ky). The yield response factor captures the essence of the complex linkages between production and water use by a crop, where many biological, physical and chemical processes are involved. The relationship shows a remarkable validity and allows for a workable procedure to quantify the effects of water deficits (water stress) on yield. The Ky values are crop specific and vary over the growing season according to growth stages with: Ky >1 meaning that crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced because of stress. Ky <1 meaning that the crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use. Ky =1 indicates a yield reduction that is directly proportional to reduced water use (Smith and Steduto, 2012). In this study, a statistical mean analysis revealed that L353 and L512 had Ky< 1 (Table 4) and a plot for Ky indicated that the genotypes L353, L512, L07 and L857 had Ky < 1 for 60 % water stress (Figure 5). These were more tolerant to water stress, a trait that is preferred in breeding for drought tolerance. Based on the analysis of an extensive amount of the available literature on crop-yield and water relationships and deficit irrigation, the seasonal Ky for maize is taken as 1.25 (FAO, 2002).

Water use efficiency (WUE) is often equated with drought resistance and the improvement of crop yield under stress, which is not necessarily the case. Drought resistance is sometimes considered as a penalty towards yield potential, which is not necessarily the case (Blum, 2005). In this experiment, the WUE was used to separate and show water utilisation among the genotypes. WUE was selected factor (trait) because when breeding for drought tolerance, biomass productivity and water use efficiency are considered important agronomic characteristics (Boyer, 1996). There is also increasing interest in improving WUE of crop cultivars so that plants can grow and yield well under water deficient conditions. In this study, results show efficient water use across all genotypes at 60 % water stress. However, at the highest water stress level of 30 % ETc, WUE in L512, L857, L713 and L60 was high with value of 2.412 kg/ha mm^{-1}, 2.265 kg/ha mm^{-1}, 1.904 kg/ha mm^{-1} and 1.818 kg/ha mm^{-1}, respectively.

The results of soil available water use as monitored by the probe indicated variations of water use among the genotypes at different growth stages. At the vegetative (40 DAP) the genotypes L353 and L857 depleted less water in the profiles, while L512 and L07 used more water at both full crop water requirement and at 60 % water stress. However, at flowering to grain filling stages (72 DAP) all genotypes used more water at all water regimes in the order, L857, L512, L353, L07, L10, L151, L640, L713, L152, L645, L428 and L60.

The findings of this research are similar to research work such as the one discussed by Huang *et al* (2006) supported this trend of water use by these genotypes, L353 and L857 were assessed to be relatively shorter plants and smaller leaf size compared to other genotypes. The root density of the two genotypes was equally lower. This allowed the two genotypes to both transpire and absorb less water at vegetative stage and used more water at flowering to grain filling stage as observed by relatively a higher grain yield even at 30 % water stress. The genotypes L512 and L07 had high root density and relatively taller compared to other genotypes in the study. Genotype L07 had high root density of 42.1 % and height of 25.5 % above the overall means, respectively. This trait allowed the genotype to use more water at grain filling stage. The genotype L512 was assessed to have narrow leafs or leaves that appear to be rolled. This too allowed less transpiration and water was used more to grain filling at this growth stage (Yenesew and Tilahun, 2009) as monitored by the water use at 72 DAP using the probe (Figures 9 – 11).

The separation of ETc into Es and Tc allowed the assessment of the exact use of water by genotypes based on the transpired amounts. The separation also indicated minimal differences of less than 50 mm water transpired by genotypes between 100 % and 60 % water regimes. As determined under WUE, there is no significant difference between 100 % and 60 % water regimes and water transpired by most genotypes in this study. Crop Water

Productivity is based on yield and water use in the specific environment, a high value is preferred. In this study genotype L645, L857, L512, L353 and L07 had a WP advantage above the overall mean of 85.5 %, 32.5 %, 8.4 %, 6.6 % and 3.3 %, respectively. These genotypes had relatively high WP and WP can be high in case of water stress to a limit that would not affect the yield of the crop only to acceptable levels (Hsiano *et al*, 2009).

CHAPTER 6

6.0 CONCLUSION

The study was set out to evaluate and select maize genotypes that had traits of drought tolerance. Ten parameters were measured in the study and the results revealed that all genotypes were different in their grain yield, yield components, selected morphological traits and water utilisation efficiency as observed from the respective crop yield response factor, crop water productivity and water use efficiency. These differences showed presence of genetic variation for these traits, a key factor in plant breeding and selection for drought tolerance in maize.

The genotypes L512, L353, L857 and L07 had high yield at all water regimes and this is a desired trait. The other important trait is ASI which was shortest in L353; the genotypes L512, L353, L857 and L07 all had Ky values below 1 at 60 % water regime. The WUE was high in L512 and L857. The crop water productivity was equally high in genotypes L512, L353, L857 and L07.

These genotypes (L512, L353, L857 and L07) could be considered for selection as parental material that could be used in breeding programmes with the objective to developing appropriate varieties for efficient water utilisation and drought tolerance. The consistency in superiority of most measured parameters by these genotypes at both 60 % and 30 % water regimes imply that these genotypes can be suitable for most regions of Zambia and varieties developed from these materials can benefit a wide range of farmers. There was positive correlation among some of the measured parameter giving a high probability of genetic factor contributing to the differences in genotype water utilisation traits in this study.

It can also be concluded that the study demonstrated the presence of adequate genotypic traits among maize genotypes in their water utilisation efficiency. This suggests that deliberate selection using superior genotypes identified in this study could lead to development of appropriate varieties which could give higher grain yields in reduced water environments. Such varieties could contribute to higher maize production if adopted by more farmers.

The other genotypes such as L 428 and L 713 that had traits suitable for other uses could be suitable for silage production as the biomass production was high at 60 % water regime and had superior vigour at vegetative stage but low tonnage in grain yield. It is recommended that, F1 crosses be developed from these parental lines and identification of markers linked to drought tolerance be done for further development of drought tolerant maize varieties.

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APPENDICES

Appendix 1: Irrigation Schedule for maize

Planting Date: 12-Sep-12 Place: Nanga

Harvest Date: 10-Jan-13 Interval: 7 days

Days	Date	ETo (mm)	kc	ETc (mm)	30% (mm)	60% (mm)	100% (mm)
	12-Sep-12	8.81	0.74	6.56	2.0	3.9	6.6
1	13-Sep-12	8.86	0.74	6.60	2.0	4.0	6.6
2	14-Sep-12	8.92	0.74	6.64	2.0	4.0	6.6
3	15-Sep-12	8.97	0.74	6.68	2.0	4.0	6.7
4	16-Sep-12	9.03	0.74	6.72	2.0	4.0	6.7
5	17-Sep-12	9.08	0.74	6.76	2.0	4.1	6.8
6	18-Sep-12	9.13	0.74	6.80	2.0	4.1	6.8
7	19-Sep-12	9.18	0.74	6.84	2.1	4.1	6.8
8	20-Sep-12	9.23	0.74	6.87	2.1	4.1	6.9
9	21-Sep-12	9.28	0.74	6.91	2.1	4.1	6.9
10	22-Sep-12	9.33	0.74	6.95	2.1	4.2	6.9
11	23-Sep-12	9.37	0.74	6.98	2.1	4.2	7.0
12	24-Sep-12	9.42	0.74	7.01	2.1	4.2	7.0
13	25-Sep-12	9.46	0.74	7.04	2.1	4.2	7.0
14	26-Sep-12	9.50	0.74	7.08	2.1	4.2	7.1
15	27-Sep-12	9.54	0.74	7.10	2.1	4.3	7.1
16	28-Sep-12	9.58	0.74	7.13	2.1	4.3	7.1
17	29-Sep-12	9.61	0.74	7.16	2.1	4.3	7.2
18	30-Sep-12	9.65	0.74	7.18	2.2	4.3	7.2
19	1-Oct-12	9.68	0.74	7.20	2.2	4.3	7.2
20	2-Oct-12	9.70	0.74	7.22	2.2	4.3	7.2
21	3-Oct-12	9.73	0.74	7.24	2.2	4.3	7.2
22	4-Oct-12	9.75	0.74	7.26	2.2	4.4	7.3
23	5-Oct-12	9.77	0.74	7.27	2.2	4.4	7.3
24	6-Oct-12	9.78	0.74	7.28	2.2	4.4	7.3
25	7-Oct-12	9.80	0.75	7.39	2.2	4.4	7.4
26	8-Oct-12	9.80	0.76	7.50	2.2	4.5	7.5
27	9-Oct-12	9.81	0.77	7.60	2.3	4.6	7.6
28	10-Oct-12	9.81	0.78	7.70	2.3	4.6	7.7
29	11-Oct-12	9.81	0.80	7.80	2.3	4.7	7.8
30	12-Oct-12	9.80	0.81	7.89	2.4	4.7	7.9
31	13-Oct-12	9.79	0.82	7.98	2.4	4.8	8.0
32	14-Oct-12	9.78	0.83	8.07	2.4	4.8	8.1
33	15-Oct-12	9.76	0.84	8.15	2.4	4.9	8.2
34	16-Oct-12	9.74	0.85	8.23	2.5	4.9	8.2
35	17-Oct-12	9.71	0.86	8.31	2.5	5.0	8.3

36	18-Oct-12	9.68	0.87	8.38	2.5	5.0	8.4
37	19-Oct-12	9.64	0.88	8.44	2.5	5.1	8.4
38	20-Oct-12	9.60	0.89	8.50	2.6	5.1	8.5
39	21-Oct-12	9.55	0.90	8.56	2.6	5.1	8.6
40	22-Oct-12	9.51	0.91	8.61	2.6	5.2	8.6
41	23-Oct-12	9.45	0.92	8.66	2.6	5.2	8.7
42	24-Oct-12	9.40	0.93	8.71	2.6	5.2	8.7
43	25-Oct-12	9.34	0.94	8.75	2.6	5.2	8.7
44	26-Oct-12	9.28	0.95	8.78	2.6	5.3	8.8
45	27-Oct-12	9.22	0.96	8.82	2.6	5.3	8.8
46	28-Oct-12	9.15	0.97	8.84	2.7	5.3	8.8
47	29-Oct-12	9.08	0.98	8.87	2.7	5.3	8.9
48	30-Oct-12	9.01	0.99	8.89	2.7	5.3	8.9
49	31-Oct-12	8.94	1.00	8.91	2.7	5.3	8.9
50	1-Nov-12	8.86	1.01	8.92	2.7	5.4	8.9
51	2-Nov-12	8.79	1.02	8.94	2.7	5.4	8.9
52	3-Nov-12	8.71	1.03	8.94	2.7	5.4	8.9
53	4-Nov-12	8.63	1.04	8.95	2.7	5.4	9.0
54	5-Nov-12	8.55	1.05	8.95	2.7	5.4	9.0
55	6-Nov-12	8.47	1.05	8.87	2.7	5.3	8.9
56	7-Nov-12	8.38	1.05	8.78	2.6	5.3	8.8
57	8-Nov-12	8.30	1.05	8.70	2.6	5.2	8.7
58	9-Nov-12	8.22	1.05	8.61	2.6	5.2	8.6
59	10-Nov-12	8.14	1.05	8.52	2.6	5.1	8.5
60	11-Nov-12	8.05	1.05	8.43	2.5	5.1	8.4
61	12-Nov-12	7.97	1.05	8.35	2.5	5.0	8.3
62	13-Nov-12	7.89	1.05	8.26	2.5	5.0	8.3
63	14-Nov-12	7.81	1.05	8.18	2.5	4.9	8.2
64	15-Nov-12	7.72	1.05	8.09	2.4	4.9	8.1
65	16-Nov-12	7.64	1.05	8.01	2.4	4.8	8.0
66	17-Nov-12	7.56	1.05	7.92	2.4	4.8	7.9
67	18-Nov-12	7.49	1.05	7.84	2.4	4.7	7.8
68	19-Nov-12	7.41	1.05	7.76	2.3	4.7	7.8
69	20-Nov-12	7.33	1.05	7.68	2.3	4.6	7.7
70	21-Nov-12	7.26	1.05	7.60	2.3	4.6	7.6
71	22-Nov-12	7.18	1.05	7.52	2.3	4.5	7.5
72	23-Nov-12	7.11	1.05	7.45	2.2	4.5	7.4
73	24-Nov-12	7.04	1.05	7.37	2.2	4.4	7.4
74	25-Nov-12	6.97	1.05	7.30	2.2	4.4	7.3
75	26-Nov-12	6.90	1.05	7.23	2.2	4.3	7.2
76	27-Nov-12	6.83	1.05	7.16	2.1	4.3	7.2
77	28-Nov-12	6.76	1.05	7.08	2.1	4.3	7.1
78	29-Nov-12	6.70	1.05	7.02	2.1	4.2	7.0
79	30-Nov-12	6.63	1.05	6.95	2.1	4.2	6.9

80	1-Dec-12	6.57	1.05	6.88	2.1	4.1	6.9
81	2-Dec-12	6.51	1.05	6.82	2.0	4.1	6.8
82	3-Dec-12	6.45	1.05	6.75	2.0	4.1	6.8
83	4-Dec-12	6.39	1.05	6.69	2.0	4.0	6.7
84	5-Dec-12	6.33	1.05	6.63	2.0	4.0	6.6
85	6-Dec-12	6.28	1.05	6.57	2.0	3.9	6.6
86	7-Dec-12	6.22	1.05	6.52	2.0	3.9	6.5
87	8-Dec-12	6.17	1.05	6.46	1.9	3.9	6.5
88	9-Dec-12	6.12	1.05	6.41	1.9	3.8	6.4
89	10-Dec-12	6.07	1.05	6.35	1.9	3.8	6.4
90	11-Dec-12	6.02	1.05	6.30	1.9	3.8	6.3
91	12-Dec-12	5.97	1.03	6.16	1.8	3.7	6.2
92	13-Dec-12	5.93	1.02	6.02	1.8	3.6	6.0
93	14-Dec-12	5.88	1.00	5.89	1.8	3.5	5.9
94	15-Dec-12	5.84	0.99	5.76	1.7	3.5	5.8
95	16-Dec-12	5.80	0.97	5.63	1.7	3.4	5.6
96	17-Dec-12	5.76	0.96	5.50	1.7	3.3	5.5
97	18-Dec-12	5.72	0.94	5.38	1.6	3.2	5.4
98	19-Dec-12	5.69	0.92	5.26	1.6	3.2	5.3
99	20-Dec-12	5.66	0.91	5.14	1.5	3.1	5.1
100	21-Dec-12	5.62	0.89	5.03	1.5	3.0	5.0
101	22-Dec-12	5.59	0.88	4.91	1.5	2.9	4.9
102	23-Dec-12	5.56	0.86	4.80	1.4	2.9	4.8
103	24-Dec-12	5.54	0.85	4.69	1.4	2.8	4.7
104	25-Dec-12	5.50	0.83	4.58	1.4	2.7	4.6
105	26-Dec-12	5.46	0.82	4.46	1.3	2.7	4.5
106	27-Dec-12	5.43	0.82	4.43	1.3	2.7	4.4
107	28-Dec-12	5.39	0.82	4.43	1.3	2.7	4.4
108	29-Dec-12	5.35	0.83	4.44	1.3	2.7	4.4
109	30-Dec-12	5.35	0.83	4.44	1.3	2.7	4.4
110	31-Dec-12	5.35	0.83	4.44	1.3	2.7	4.4
111	1-Jan-13	5.35	0.83	4.44	1.3	2.7	4.4
112	2-Jan-13	5.33	0.83	4.44	1.3	2.7	4.4
113	3-Jan-13	5.32	0.84	4.44	1.3	2.7	4.4
114	4-Jan-13	5.30	0.84	4.44	1.3	2.7	4.4
115	5-Jan-13	5.28	0.84	4.44	1.3	2.7	4.4
116	6-Jan-13	5.26	0.84	4.44	1.3	2.7	4.4
117	7-Jan-13	5.25	0.84	4.41	1.3	2.6	4.4
117	7-Jan-13	5.25	0.84	4.39	1.3	2.6	4.4
117	7-Jan-13	5.24	0.83	4.37	1.3	2.6	4.4
117	7-Jan-13	5.24	0.83	4.35	1.3	2.6	4.3
	Total				252.7	505.3	842.2

Appendix 2: Analysis of variance for above ground biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.843	0.421	0.65	
Water Regime	2	491.095	245.548	376.93	<.001
Error a	4	2.606	0.651	0.41	
Maize Genotype	11	401.448	36.495	22.81	<.001
Water Regime x Maize genotype	22	377.757	17.171	10.73	<.001
Error b	66	105.607	1.6		
Total	107	1379.356			

Appendix 3: Analysis of variance for grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.1711	0.0855	0.38	
Water Regime	2	40.1173	20.0587	89.01	<.001
Error a	4	0.9014	0.2253	1.7	
Maize Genotype	11	14.1472	1.2861	9.7	<.001
Water Regime x Maize genotype	22	16.2223	0.7374	5.56	<.001
Error b	66	8.6156	0.1325		
Total	107	79.6629			

Appendix 4: Analysis of variance for WUE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1.444	0.722	0.36	
Water Regime	2	20.594	10.297	5.15	0.078
Error a	4	7.993	1.998	1.85	
Maize Genotype (M.G)	11	48.465	4.406	4.07	<.001
Water Regime x M.G	22	56.579	2.572	2.38	0.004
Error b	65	70.316	1.082		
Total	106	205.353			

Appendix 5: Analysis of variance for root density

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1.04E-05	5.21E-06	0.43	
Water Regime	2	6.84E-04	3.42E-04	27.92	0.004
Error a	4	4.90E-05	1.22E-05	1.57	
Maize Genotype (M.G)	11	1.06E-03	9.62E-05	12.33	<.001
Water Regime x M.G	22	1.27E-03	5.77E-05	7.4	<.001
Error b	66	5.15E-04	7.80E-06		
Total	107	3.59E-03			

Appendix 6: Analysis of variance for crop yield response factor

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.12433	0.06217	0.48	
Water Regime	1	0.10476	0.10476	0.81	0.463
Error a	2	0.25825	0.12913	1.86	
Maize Genotype (M.G)	11	3.43705	0.31246	4.51	<.001
Water Regime x M.G	11	2.79277	0.25389	3.66	<.001
Error b	44	3.05165	0.06936		
Total	71	9.76881			

Appendix 7: Analysis of variance for anthesis - silking interval

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	19.8	9.9	3.45	
Water Regime	2	126.13	63.06	21.97	0.007
Error a	4	11.48	2.87	0.22	
Maize Genotype (M.G)	11	282.99	25.73	1.96	0.047
Water Regime x M.G	22	446.54	20.3	1.55	0.089
Error b	66	865.39	13.11		
Total	107	1752.32			

Appendix 8: Analysis of variance for plant girth (diameter)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.004527	0.002263	0.74	
Water Regime	2	0.073148	0.036574	11.91	0.021
Error a	4	0.012283	0.003071	1.17	
Maize Genotype (M.G)	11	8.539931	0.776357	296.57	<.001
Water Regime x M.G	22	1.860505	0.084568	32.31	<.001
Error b	66	0.172773	0.002618		
Total	107	10.663168			

Appendix 9: Analysis of variance for plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	6.923	3.462	1.51	
Water Regime	2	11482.397	5741.199	2510.57	<.001
Error a	4	9.147	2.287	1.9	
Maize Genotype (M.G)	11	41016.421	3728.766	3099.07	<.001
Water Regime x M.G	22	16636.542	756.206	628.5	<.001
Error b	66	79.411	1.203		
Total	107	69230.841			