BREEDING MAIZE FOR EARLY MATURITY AND DROUGHT TOLERANCE IN KENYA USING ANTHESIS TO SILKING INTERVAL

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE AWARD OF A MASTER OF SCIENCE DEGREE IN PLANT BREEDING AND
BIOTECHNOLOGY

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A56/65361/2010

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DEDICATION

I dedicate this work to my parents who facilitated me financially to pursue this course and to the mighty God for His divine powers, mercies, health, protection and love that followed me through and through.

ACKNOWLEDGEMENT

This thesis would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study.

First and foremost, my utmost gratitude to Dr. E. C. K. Ngugi, my first supervisor whose sincerity, patience, steadfast encouragement and criticism I will never forget. You let me experience maize field research and practical issues beyond textbooks. Dr. Ngugi has been my inspiration as I faced all the obstacles in the completion this research work.

I also extend my gratitude to my second supervisor, Dr. J. M. Kinama, senior lecturer, University of Nairobi who had kind concern, time and consideration regarding my academic requirements. I will forever be indebted to your unfailing and unselfish support throughout my research work.

My sincere thanks to Dr. G. Chemining'wa, the chairman, Plant Science and Crop Protection department; University of Nairobi, for his moral support; Prof. S. Shibairo, Dean-Faculty of Agriculture, for the insights he shared; Prof. P. M. Kimani and Dr. Kiarie for their inputs especially in the curriculum part of this study. You helped me with valuable insights relevant to Plant Breeding and Biotechnology course.

My humbled thanks to Titus Kosgey, and Mary Wambugu for the guidance and assistance you gave on how to use SAS program; Tutus I will never forget your PROC CORR guidance, you helped me big time with correlations. Olivya for the relevant SAS codes you gave me, the critique you made on my thesis - am humbled.

To all the library staff-University of Nairobi, thanks for the literature such as journals and articles that you made available online.

My humbled appreciation to Cheserek Jane for kindly providing the already developed F2 generation genotypes. My sincere thanks to KARI Kiboko for the facilities you provided.

I can’t forget my field assistant, Mr. Nzalu who was my special eye whenever I wasn’t around. Everything went on well in the field because of you sir, God bless you very much.

To the staff in the Plant Science and Crop Protection; Land and Resource Management Departments for allowing me to use your facilities, I am grateful.

To my fellow Masters’ students who in one way or another were of assistance especially when I felt that the journey is too tough, your word of encouragement carried me on.

My unending thanks to my family who were always there for me through all times and seasons. Thanks for believing in me.

Last but not least and the one above all of us, the omnipresent God, for answering my prayers for giving me the strength to plod on despite my structure wanting to give up and throw in the towel, thank you so much Dear Lord

ACRONYMS

ETc - Actual evapotranspiration

ETo - Potential evapotranspiration

ASI - Anthesis-silking interval

ASALs - Arid and semi-arid lands

BIBD - Balanced incomplete block designs

CIMMYT - International Centre for Maize and Wheat Improvement

DM - Dry matter

DTMA - Drought Tolerant Maize for Africa

EPP - Ears per plant

EUW - Effective use of water

FAO - Food and Agricultural Organization

GY - Grain yield

HI - Harvest index

IFPRI - International Food Policy Research Institute

KARI - Kenya Agricultural Research Institute

WU - Water use

WUE - Water Use Efficiency

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ABSTRACT

Maize is the most important staple crop grown in all the agro-ecological zones of Kenya including the Arid and semi-arid lands (ASALs) that cover 80% of the total land mass. Due to climate change prevalent globally, an increase in rainfall variance will lead most of the times to frequent droughts in Kenya's dry-lands. In this study, one hundred and thirty five F2;F3 progenies developed from crosses between long ASI, Katumani composites and short ASI, elite CIMMYT genotypes were evaluated alongside five checks (Duma 43 Hybrid, Local Katumani composite, CML440/CML445, CML312/CML442 and P100C6/CML78) under drought stressed and well-watered environments, at the Kiboko sub-station of KARI during 2011 and 2012 seasons in an alpha lattice design with three replications.

The results showed that the genotypic, environmental, and genotype x environment (G x E) interaction variances were all significant under drought stress. The G x E variance for ASI was greater than the genotypic variance under water stress whereas for grain yield the G x E variance was almost similar to the genotypic variance. Under drought stress, the ASI mean increased significantly up to 7.667 days from an average of 1.6 days under well watered environment. Days to maturity, under drought stress decreased to an average of 53 days compared to an average of 57days under well watered conditions for all the genotypes.

The mean grain yield (GY) decreased significantly by an average of 78.02% under drought stress. The G x E interactions contributed largely to the variations in performance across the two contrasting environments. The high yielding early- maturing genotypes (KDV2/CML444-14, and KDV2/CML440-224) under drought stress were alsohigh yielding under well watered environments.

Anthesis to silking interval (ASI) was significantly negatively correlated with GY (-0.446***) under stress but not under well watered conditions. The ASI was positively significantly correlated with stress susceptible index (SSI)(0.304***), leaf rolling (LR)- (0.219**), senescence (SEN) (0.153*) but ASI was negatively significantly correlated with stress tolerance index (STI) (-0.378***), geometric mean productivity (GMP) (-0.448***), mean productivity (MP) (-0.419***), yield stress index (YSI) (-0.303***) and water use efficiency (WUE) (-0.365***). These relationships confirmed that ASI is important for use in selection under drought stressed environments. Genotypes with a high WUE index under drought stress had a higher chance of having a shorter ASI. Similarly, such genotypes with a high WUE index under drought stress had a higher chance of being high yielding. F3; F4 genotypes KDV2/CML444-14, and KDV2/CML440-224 were early maturing, had a short ASI, a high WUE index and were high yielding under drought stressed environments.

On the other hand, grain yield under drought stress was positively, significantly correlated with MP (0.819 ***), GMP (0.961***), STI (0.890***), WUE (0.581***) and YSI (0.739***) under drought stressed environment.

It is therefore concluded that in breeding maize for drought tolerance, consideration should be given to establishing carefully managed drought stress environments. Under such environments, ASI, earliness, WUE and computed drought indices are important secondary selection parameters. In this study it was proven that it is possible to combine both drought escaping mechanisms such as earliness and drought tolerance mechanisms such as ASI in developing high yielding, early maturing drought tolerant maize for ASALs in Kenya.

CHAPTER ONE

INTRODUCTION

Sustainable agriculture is a pre-requisite for sustainable food production. Contributions to sustainable food production in sub-Saharan Africa in the 21st century through crop improvement require envisioning the nature of future agricultural systems, as well as new technologies that are likely to enhance the efficiency of crop improvement programs in the region.

Plant breeders have from the past focused on breeding for drought stress in various major food crops (Magorokosho *et al*., 2003). In Kenya, this has been brought about by the increase in population, migration of people into the Arid and Semi-arid Lands (ASALs) and most importantly because of climate change (Kinama *et al*., 2007). In the ASALs of Kenya, rainfall variability across and within seasons has resulted in moisture constrains. Climate change enhances soil evaporation and reduces water available to crops due to expected temperature increases. Indeed, soil evaporation takes up to 50% of total rainfall in the soil water balance in semi arid areas (Kinama *et al*., 2005).

Globally, the demand of maize is expected to surpass that of both wheat and rice by the year 2020. This shift is expected from a 50% increase in global maize demand from 558 million in 1995 tons to 837 million tons by 2020. Maize requirements in the developing world alone have increased from 282 million tons in 1995 and are expected to reach over 504 million tons in 2020 (IFPRI 2000, Conway *et al*, 1999). This will be due to rising incomes in most of the developing world and the consequent growth in meat and poultry consumption. This would translate to an increase in the demand for maize as livestock feed (especially for poultry and pigs). Table 1 presents the trend particularly evident in East and South-East Asia, where demand for maize is projected to increase the most (IFPRI 2000, Aldrich *et al*. 1975).

Table 1: Maize demand projections, 1995-2020

Region	1995 Demand (tons)	2020 Demand (tons)	% Change
Global	558	558	50
Developing world	282	504	79
East and S.E Asia	150	280	46
South Asia	12	23	92
Sub-Saharan Africa	27	52	93
Latin America	76	123	62
WANA	16	26	63

* WANA = West Asia/North Africa Source: IFPRI (2000).

Thus the challenge of meeting this unprecedented demand of maize is daunting especially for the developing world and its resource poor and subsistence farmers.

Cereal grains constitute a large part of dietary energy and energy sources world wide. Cereal grains: wheat, maize, rice, barley, sorghum, oats, rye, and millet provide 56% of the food energy and 50% of the protein consumed (FAO, 2009). In Africa maize supplies at least one fifth of the total daily calories consumed and accounts for 17 to 60% of people’s total daily protein supply, as estimated by FAO food balance sheets (Diallo, 2001). Maize alone accounts for over 50% of the total daily calories of people in rural and urban poor of the Eastern and Central Africa developing countries.

Wheat, maize and rice, together comprise at least 75% of the world's grain production (Figure 1). Maize being the third most important cereal crop in the world after wheat and rice contributes substantially to the total cereal grain production in the world economy as a trade, food, feed, and industrial grain crop (Pingali, 2001; FAO, 2009). However, maize is the world's most widely grown cereal both for fodder and grain production and ranks top in cereal grain yield per unit area of land, making it the most productive species of food plants (Aldrich *et al*. 1975).

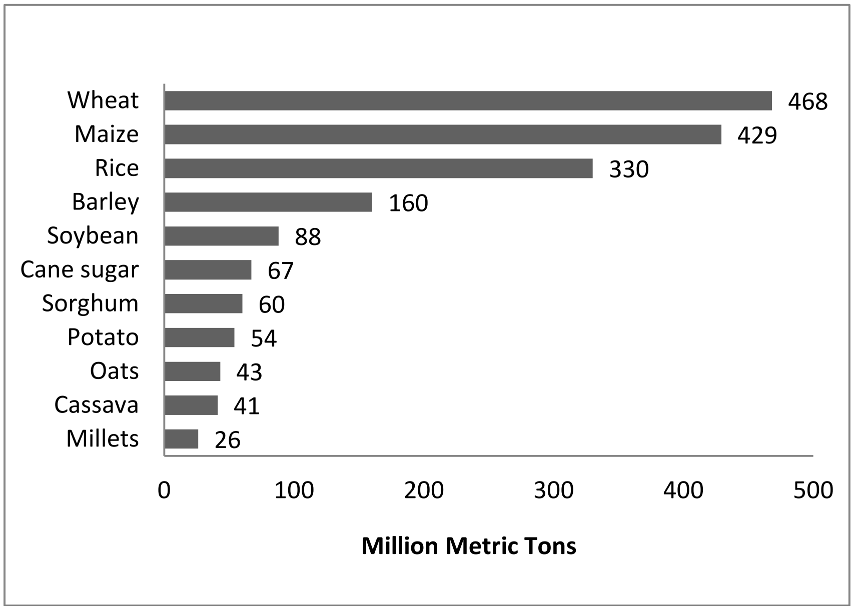


Figure 1: Important crops in world food production, 2008

Source: FAO, 2009

Kenya depends largely on agriculture with maize, wheat, sorghum, rice and barley being the most grown cereals in the country (FAO, 2011). Maize is a staple food in the country and among the widely grown cereals across the country (USAID, 2010). It is widely produced, dominates all national food security considerations and contributes highly to agricultural employment (Jayne *et al.,* 2005 and Nyoro, 2003). Maize has a per capita consumption of 98 kilograms translating to between 30 and 34 million bags (2.7 to 3.1 million metric tons) of annual consumption

(Kang’ethe 2011). National maize production levels have been declining since 2006 from an all time high of over 34 million bags in 2006 to about 25 million bags on 1.6 million hectares land in 2008 (Wambui, 2008). The area under maize cultivation has stabilized at around 1.5 million hectares, producing about 26 million bags of maize per annum. This falls short of the annual domestic maize consumption estimated at 34 million bags (Kamau, 2002 and FAO, 2003).

Current statistics show that Kenya is struggling to achieve self sufficiency in maize production. This has been due to challenges such as lack of productivity enhancing technologies, high incidence of pests and diseases, lack of credit, climatic factors and continued loss of soil fertility (Nyoro *et al*., 2007). The on-farm yields have gone to as low as 1.5–2.6 tons per hectare compared to on-station yields of about 5–8 tons per hectare (FAOSTAT, 2010). In the last one decade, the country has over relied on imports and emergency humanitarian assistance as seen in 2009, when Kenya imported 16.8 million bags of maize (GoK, 2010).

Chronology of droughts 1997–2009

January 1997: the Kenyan Government declared a state of national disaster after a severe drought threatened the livelihoods of 2 million people.

December 2000: 4 million people were in need of food aid after Kenya was hit by its worst drought in 37 years.

March-June 2004: the long rains failed and the subsequent crop failure left more than 2.3 million people in need of assistance.

December 2005: President Kibaki declared a ‘national catastrophe’ in reference to the famine that affected 2.5 million people in northern Kenya.

January 2009: President Kibaki declared drought and famine in the country a national disaster and announced that 10 million people are food insecure and in need of emergency support.

Source: UNEP, 2010.

In the foregoing box of chronology of drought events in Kenya, it means then that more research need to be devoted on constraining factors such as drought, and low soil fertility to boost maize production in the country especially in the ASALs. More resources should therefore be devoted to research to enable further expansion of area under maize cultivation in ASALs due to diminishing availability of arable land for maize farming. This further implies that future growth in maize production would have to depend mainly on use of improved yield productivity enhancing technologies. Such technologies will include among others, the use of improved germ-plasm with enhanced resistance to the common biotic and abiotic traits. Maize in Kenya is mainly produced in the highlands and mid altitude regions. About 70 per cent of Kenya's maize is produced mainly by farmers in the North Rift Valley region, traditionally Kenya's 'grain basket' (WEMA, 2010). In the marginal environments, population pressure has driven communities to grow the adapted landraces in place of improved germ-plasm.

In high potential environments, where there is increased soil acidification and nutrient depletion, maize, which is a heavy dependant on nitrogen and phosphorus, is threatened. These add on to the increasing lists of biotic and abiotic stresses that must be addressed. Thus understanding the plant's physiological requirements in relation to abiotic and biotic stresses is essential to a breeder for progress (Sangoi, 2000).

PROBLEM STATEMENT AND JUSTIFICATION

There is evidence from Food and Agricultural Organization (FAO) that 850 million people in the world are affected by food insecurity, of which 820 million live in the developing countries. Kenya alone has 10 million people faced with starvation out of its total population of 39 million people (Ngaira, 2009; Kenya census, 2009)**.**

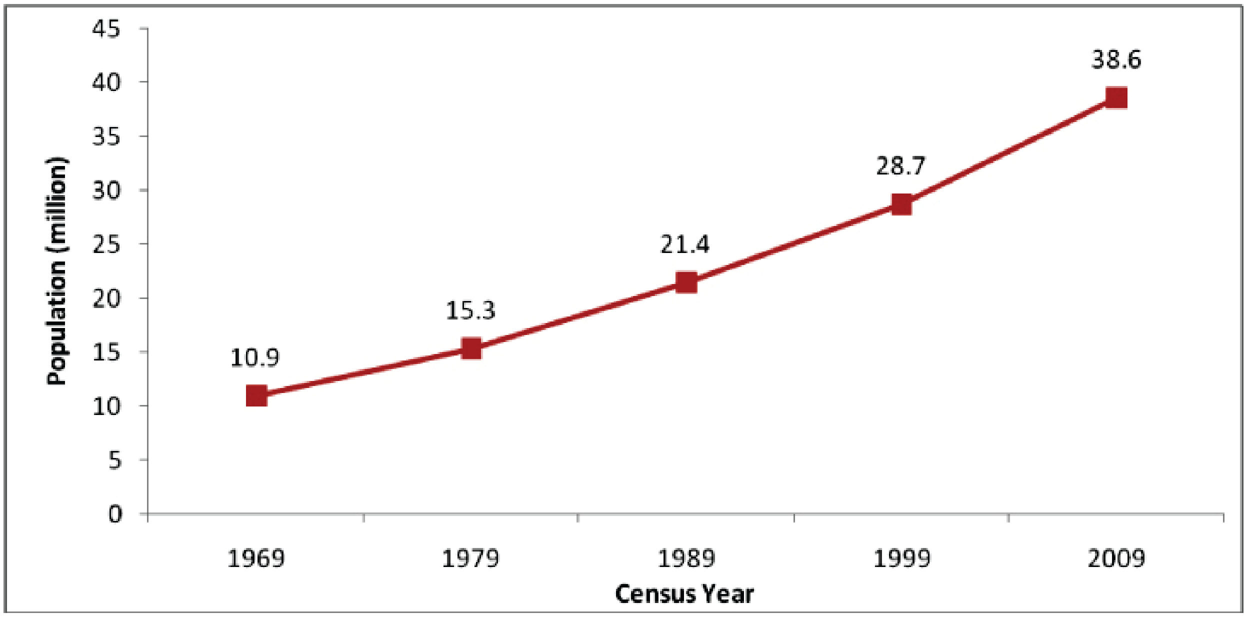


Figure 2: Kenya population 1969-2009

Source: Kenya Census, 2009

Over dependence on rain -fed maize production, by small holder farmers in the highlands and mid altitude regions in western, central, eastern and parts of rift valley regions in Kenya has led to inadequate production and a short supply of the grain by 24% (Nyoro, 2007). This is due to the fact that most farmers use poor farming methods. In addition, these arable regions that entirely depend on rain fed agriculture constitute only 18% while the ASALs constitute 82% of the total Kenyan land and supports about 20% of the population (Munyiri *et al.*, 2010). Most of the arable land is also devoted to other crops such as sugarcane in western Kenya, coffee and tea in central and south rift, wheat in the north rift and rice in eastern and western regions of the country. Dairy farming in such areas too has confined maize production to a small percentage of arable land. Production to meet both human and livestock needs, in such areas must therefore be supplemented.

In addition, the increasing cost of fossil fuels together with the environmental concerns related to applying large amounts of chemical fertilizers and the emergence of maize as a major bio-fuel plant has complicated the food security situation globally (World Bank, 2007). Moreover, climatic change, which potentially leads to increased temperatures and evapotranspiration losses and eventually decreased rainfall, is expected to have a particularly negative effect on the agricultural production of many developing regions of Africa and Asia (Bates *et al.*, 2008; Rijsberman, 2006; Lobell *et al.*, 2008). The rises in temperatures imply more frequent warm spells and heat waves (Pachauri and Reisinger, 2007). Such global warming is also increasingly associated with erratic weather, particularly an increase in rainfall variance (Mude *et al.*, 2007; World Bank, 2010) leading to frequent droughts (Pachauri and Reisinger, 2007). Climate change is thus expected to have substantial and predominantly negative impacts on Sub Saharan Africa’s agricultural systems (Cooper *et al.*, 2008; Thornton *et al*., 2009), and affect vulnerable regions such as the ASALs in Kenya (Thornton *et* al., 2008). These regions will definitely witness a negative impact on the production of several major crops crucial to food security.

Heisey and Edmeades (1999) estimated that one quarter of the global maize area is affected by drought in any given year. Maize yields remain low and highly variable between years across sub Saharan Africa at 1.6 tons/ha due to drought (Bänziger and Diallo, 2001; FAOSTAT, 2010).

Kenya is a drought-prone country, primarily because of its peculiar eco-climatic conditions. Although dissected by the equator in its southern half, Kenya contains only a few pockets of high and regular rainfall of over 2000mm. In general, maize needs at least 500-700mm of well distributed rainfall during the growing season. This amount of rainfall may not be enough however if the moisture cannot be stored in the soil due to heavy run off, shallow soils and high rates of evapotranspiration (Lafitte *at al.*, 2004). Arid and semi-arid lands (ASALs) cover over 80% of the territory. Kenya records maize yield loss of up to 17-20% due to drought stress (Lafitte, 1994; Diallo *et al.*, 2001). In these areas, where annual rainfall amounts are very low (varies from 200 to 500 mm) and occur in a bi-modal pattern, periodical droughts are part of the climate system (Gichuki, 2000; Kandji, 2006).

This has called for the need to breed for germ-plasm that is either drought tolerant or drought escaping such as early maturing composites such as Katumani and Makueni that utilize the little rains available and matures early. Drought stress at flowering may stimulate young kernel abortion immediately after fertilization (Sangoi, 2000). Selection for earliness matches the phenology of the crop to the pattern of water availability. Since the time from sowing to flowering or physiological maturity is a highly heritable trait, selection for earliness can easily be accomplished (Bänziger *et al.*, 2000).

Drought is a polygenic stress and considered as one of the most important factors limiting crop yields around the world. As climate change leads to increasingly hotter and drier periods, the importance of drought constraints on yield and yield components has increased. This together with low grain yield heritability under drought (Bänziger *et al*, 2000) further complicates breeding for drought tolerance among maize genotypes because of several gene interactions and climate change.

The delay in silking during drought stress results in decreased male to female flowering synchrony or increased anthesis to silking interval (ASI). However, it is possible to select genotypes with short ASI under drought stress. The ASI (secondary trait) is highly correlated with yield under drought stress (Bolanõs and Edmeades, 1996; Edmeades *et al.,* 1998). Grain yield on its own has shown little success in the selection of drought tolerant varieties because under drought stress its heritability usually decreases (Bänziger *et al.,* 2000).

Anthesis to silking interval trait unlike yield has medium to high heritability under drought stress (Bänziger *et al,* 2000; Bolanõs and Edmeades, 1996). Edmeades *et al.,* (1998), Magorokosho *et al.,* (2003) and Magorokosho *et al.,* (1997a) established that ASI is an ideal selection criterion under drought stress because it is genetically associated with grain yield under stress, is highly heritable, cheap and fast to measure. ASI is also stable within the stress period. Other secondary traits used in conjunction with ASI in the measurement of drought stress are; leaf rolling, tassel size, ears per plant (prolificacy), rate of senescence, grains per ear and kernel size (Magorokosho *et al.,* 1997a).

There has been tremendous success in setting up in Africa, projects on breeding maize for drought tolerance such as drought tolerant maize for Africa (DTMA). In this respect CIMMYT in conjunction with IITA have developed medium to late maturing genotypes. Continuous selection has shown to improve maize drought tolerance in drought prone areas (Chapman and Edmeades, 1999).

The major focus in breeding for drought stress has been at flowering and post-flowering stages of the crop. This is the stage when the crop is hardest hit by the stress (Bänziger *et al.*, 2000).

From Table 2 below, the focus in developing maize tolerant to drought stress should be to incorporate drought tolerant genes when the plant is at the flowering stage (Bänziger *et al.*, 2000).

Table 2: Influence of drought on maize at different growth phases

	Germination	**Pre-flowering**	**Flowering**	**Post-flowering**
Plant number	***			
Leaf area		***	*	
Leaf senescence		*	**	***
Anthesis-silking interval		*	***	
Ear number			***	
Grains per ear			***	
Kernel size				***
Yield	***	*	***	**
Breeding Progress	*	**	***	***

* least severe ** medium severity *** most severe

KARI Katumani has successfully exploited earliness in the development of drought escaping varieties such as Katumani and Makueni composites.

Open pollinated varieties (KDV2 and KDV 4) developed by KARI that are drought escaping have been used as parental genotypes for the development of early maturing drought tolerant maize (Cheserek, 2010). These OPVs were early maturing (<53 days) but had a long ASI (>6days) hence could not withstand drought stress incidences. These OPVs when crossed to the late maturing (>60 days) short ASI (<4days) CIMMYT lines (CML440, CML 445, CML 444 and CML 442) generated a pool of maize germ-plasm with variable days to maturity and ASI (Cheserek, 2010).

Combining both early maturing (drought escape) and drought tolerant genes (short ASI) may lead to the development of varieties that are both drought tolerant and drought escaping and such varieties will help to alleviate maize failure in the ASALs. In addition, such development and dissemination of drought tolerant, high-yielding, locally-adapted maize varieties will help to reduce famine among 30–40 million people in sub-Saharan Africa (Muhammad *et al,* 2009).

HYPOTHESIS

- It is possible to select for earliness and short anthesis-silking interval traits in developing drought tolerant maize genotypes.

BROAD OBJECTIVE

- To develop early maturing and drought tolerant maize varieties with high yielding potential for the Kenyan arid and semi arid lands (ASALs).

SPECIFIC OBJECTIVE

- To select for high yielding genotypes that have both earliness (drought escape) and short ASI genes in already developed F2 maize genotypes.

- To measure the water use efficiency of drought tolerant maize genotypes

CHAPTER TWO

LITERATURE REVIEW

3.2 Drought with respect to Plant Growth and Yield

Maize production is affected by both abiotic and biotic constraints. The biotic constraints are insect pests, parasitic weeds and leaf and ear diseases. The abiotic constraints are low soil fertility, drought, soil toxicity, high temperatures, flooding and soil salinity. Drought is a widespread phenomenon across large areas of Sub Saharan Africa, with an estimated 22% of mid altitude/subtropical and 25% of lowland tropical maize growing regions affected annually due to inadequate water supply during the growing season (Heisey and Edmeades, 1999). In as much as drought occurring at vegetative stage mainly causes delay in silking than a subsequent reduction in grain yield, drought stress at flowering and post flowering can cause up to 17-37% yield loss (Diallo *et al*., 2001; Olaoye *et al.*, 2009).

Drought stress particularly affects the ability of the maize plant to produce grain at three critical stages of plant growth namely; early in the growing season (when plant stands are established), at flowering, and during mid to late grain filling leading to the following effects:

i). By damaging plant stands at the beginning of a season, drought can strongly curtail yield. This is relatively common because the probability of drought is high at this time. A farmer confronted with this situation has several management options, all requiring replanting later in the season. They include replanting the field(s) with the same cultivar, planting a shorter maturity cultivar, or planting a different species that matures more rapidly.

ii). Mid-season drought is less likely to occur than drought at the beginning or end of the season, but it can be devastating because maize is particularly susceptible to drought stress during this period when the plant flowers. Short of irrigation, the farmer has no management alternatives since it is too late in the season to replant.

iii). Grain yield reductions from mid to late grain filling are not nearly as severe as those produced by a similar stress during flowering. Again though, farmers are left with no management options for responding to the stress.

This shows that the most critical stage that can lead to severe food shortage is the mid-season drought (ii) where the only alternative is irrigation or using drought tolerant germ-plasm (Guelloub *et al.*, 2003). Using irrigation to supplement the deficit, may have three major effects: (1) yield improvement, (2) stabilization of production from year to year (increasing reliability), and (3) providing the conditions suitable for economic use of higher technology inputs, such as high yielding varieties, fertilizers, and herbicides, irrespective of seasonal rainfall. This is however a major set back in the dry lands due to lack of fresh water to be allocated for crop irrigation. The only source of water for such practice could be the non-conventional one (saline water, brackish water) which could affect not only the final yield if compared to the use of fresh water, but also leads to soil salinity build up (Guelloubi *et al.*, 2003).

In addition, most Kenyan farmers are resource poor and cannot afford irrigation facilities adding to the fact that Kenya is 82% dry thus getting even the salty/brackish water for irrigation then liming the soils after some time by itself is challenging.

Drought leads to reduced leaf surface area, delayed silk emergence, reduced stem internodes, fewer roots and slow grain expansion in that order. Leaf senescence is accelerated starting with older leaves at the bottom of the plant but at severe drought levels, the top leaves are also affected reducing radiation interceptions and water use efficiency (Bänziger, 2000; Efeoglu *et al.*, 2009). In fact the yield of maize is directy related to rainfall amount (Mungai *et al.*, 2001)

The leaves which are the cooking pots for the maize plant are heavily affected by water deficits, and this leads to a decline in photosynthesis per plant. This can be either due to reduced light interception as leaf expansion is reduced or as leaves senesce. Leaf expansion is reduced because of leaf rolling. Another reason could be due to reductions in carbon fixation per unit leaf area as stomates close or as increased photo-oxidation damages the photosynthetic mechanism. Photosynthesis and respiration decline because of stomatal closure and photo-oxidation and enzyme damage due to increased abscisic acid deposition in the guard cells (Bänziger *et al.*, 2000). This further reduces the photosynthates leading to reduced kernel size. The accumulation of abscisic acid (ABA) may enhance survival but reduces productivity (Mugo *et al*., 1998)

Stem reserves are remobilized especially when stress coincides with the phase of linear grain growth. In extreme cases this can result in premature lodging (Bänziger *at al.*, 2000).

Pre-anthesis drought leads to limited vegetative growth, leaf rolling thus, carbon gain will be reduced throughout the growing season (Munyiri *et al.*, 2010; Zinselmeier *et al.*, 1995). Prolonged drought stress during the vegetative stages affects the length of the internodes by influencing the cell size development and thus, the capacity for storing assimilates. These effects lead to reduced leaf surface area limiting photosynthesis during grain filling and in turn lead to the remobilization of stem reserves for ear development (Blum, 1998).

Post-anthesis drought leads to abortion of ovules, kernels, and ears which occurs from one week before silking to two weeks after silking without water. This is because of impairment of assimilates at low water potential (Zinselmeier *at al.*, 1995).

It is generally accepted that, when drought begins to affect the plant during reproduction, the plant decreases the reproductive demand for carbon by reducing the number or size of the sinks. Consequently, tillers may degenerate, flowers drop, pollen die, and ovules abort (Blum, 1998).

Ovule abortion can occur when ovules fail to extrude silks because of slow growth rates, whereas kernels abort following pollination due to lack of photosynthates (Borra´s *et al.,* 2007). Barrenness can lead to a complete loss of grain yield. Female reproductive structures are more seriously damaged than tassels, though tassel blasting can occur if temperatures exceed 38°C (Bänziger *et al.*, 2000)

In general, water deficit at vegetative stage reduces plant height, leaf area by 15%, shoot dry matter by 17%, and root dry matter of the upper 25 cm depth, kernel number per cob is reduced by 18% and grain yield per plant is reduced by 19-20% as compared to well watered plants (Sah and Zamora, 2005).

However, water deficit at reproductive stage reduces more leaf area, kernel number and grain yield per plant than water deficit at vegetative stage. At reproductive stage, water deficit reduces shoot dry matter by 15%, leaf area by 33%, kernel size and kernel number per cob is reduced by up to 14% and 40% respectively and harvest index is also reduced. Grain yield is reduced by 48-50% and this is due to increased barrenness, suggesting that the ability of a cultivar to produce an ear under stress is the most important characteristic associated with drought tolerance (Bolanõs and Edmeades, 1996; Sah and Zamora, 2005).

A well developed root system as a constitutive trait is favourable in many environments. It enables the plant to make better use of water and minerals and is an important component of drought tolerance at different growth stages (Blum, 2002). The potential quantity of accumulated water depends on the extent of root proliferation in the soil volume. Patterns of resource allocation change when water is limited, for instance, root tissues tend to grow more than the leaf tissues. When drought stress occurs during early growth stages the root/shoot ratio changes considerably and usually increases (Bänziger *et al.,* 2000). The most rapid root development occurs during the first 8 weeks after planting when the plant is in active vegetative stage. When rainfall is adequate, the root system of maize formed during the first 60 days can sustain the plant until harvest. On the other hand, when soil moisture is limited, root growth may last throughout the growing season, even when nitrogen fertilization is inadequate (Mungai *et al.*, 2001).

In contrast, in the dry lands vigorous root growth occurs at the expense of grain production, despite the advantage of improved water acquisition in dry soils (Blum, 1998). Increases in grain yield under drought, resulting from selection for drought tolerance, are associated with a smaller root biomass in the upper 50 cm of the root profile in a tropical maize population (Bolanõs *et al.*, 1993b, Bruce *et al*., 2002). However, due to the difficulties associated with the study of root architecture, for most breeding programs, the role of this architecture and function in drought adaptation has not yet been accurately accounted for (Osmont *et al*., 2007).

2.2 Water Use (WU) and Water Use Efficiency (WUE)

Since plant production is a function of WU, the issue for the breeder is how to reduce WU under stress while minimizing the associated reduction in production. This is the dehydration tolerance (the relative capacity to sustain or conserve plant functions in a dehydrated state) mechanism which can allow for better yields in times of water stress (Blum, 2005). Water use efficiency (WUE) on the other hand, is the total above-ground dry matter (DM) produced by plants per unit of water used (Efeoglu *et al.,* 2009).

The WUE of a crop does differ among species, climates, and from year to year; and furthermore, it may depend on the availability of different mineral nutrients, hence caution must while using it to measure drought resistant cultivars (Boyer, 1996, Lorens *et al*., 1987).

Bouman, (2007), stated that water use efficiency relies on:

- The soil's ability to capture and store water;
- The crop's ability to access water stored in the soil and rainfall during the season;
- The crop's ability to convert water into biomass; and
- The crop's ability to convert biomass into grain (harvest index).

Water use efficiency can be used to calculate the potential yield of a crop given the available moisture. Growers can use this information to assess the costs and benefits of different management decisions, in order to improve their profitability and manage risk (GRDC, 2009).

Maize is a C4 plant, which confers potentially more efficient use of carbon dioxide, solar radiation, water and nitrogen in photosynthesis than C3 crops. Naturally, maize makes efficient use of water. However, it is considered more susceptible to water stress than other crops because of its unusual floral structure with separate male and female floral organs and the near-synchronous development of florets on a (usually) single ear borne on each stem (Huang *et al.*, 2006).

Drought has a negative effect on yield for water plays a major role on the physiological activities of the maize crop as summarized by the equation below.

$GY = WU * WUE * HI;$

$WUE = Biomass/ETc$

Where:

- WU = water transpired/used by the crop
- WUE = water use efficiency i.e. biomass/unit water transpired.
- HI = harvest index
- ETc = Actual evapotranspiration

Utilizing stem reserves for grain filling under stress namely, soluble carbohydrate reserves in the stem at the time of anthesis may contribute to superior performance under drought stress (Blum, 1988; Reynolds *et al*., 2005). Moreover (and even when it is conceptually difficult to support) there are reports indicating that this trait may also increase yield potential (Shearman *et al*., 2005). Improved WUE on the basis of reduced water use is expressed in improved yield under water-limited conditions. Under most dry land situations in Kenya, most crops depend on unpredictable seasonal rainfall, and hence the maximization of soil moisture use is a crucial component of drought resistance and/or avoidance. Research has shown that the effect of a single 'drought adaptive' gene on crop performance in water-limited environments can be assessed only when the whole system is considered in terms of grain yield, dry matter content, and WUE (Blum, 2005)

When effective and successful selection for yield under stress is exercised it most likely involves a genetic shift towards a dehydration-avoidant plant type. Dehydration avoidance is defined as the plant capacity to sustain high plant water status or cellular hydration under the effect of drought. Hence, by this mechanism the plant avoids being stressed because plant functions are relatively unexposed to tissue dehydration. Such a dehydration-avoidant phenotype is characterized by the maintenance of high plant water status under stress. This is achieved through early flowering, smaller plant, small leaf area (leaf rolling), or limited tillering in cereals (Blum, 2005). All these are in contrast to high yield potential and therefore, a crossover interaction for yield is to be expected over a range of environments. This crossover interaction can theoretically be avoided and drought resistance can be recombined with high yield potential if selection is designed to recombine a high yield potential genotype with relevant dehydration-avoidance factors that are not associated with lower yield potential (Blum, 2005; Blum, 1988).

Blum, (2005) reported that dehydration tolerance as an effective drought-resistance mechanism in crop plants is rare. It exists in the seed embryo, but once germinated the plant loses its tolerance. The only major exception that constitutes a form of an effective dehydration tolerance mechanism in crop plants is stem reserve utilization for grain filling under drought stress (Blum, 1998). This is a harmonized whole-plant process that allows effective grain filling when whole-plant photosynthesis is inhibited by stress during grain filling. It is a tolerance mechanism that allows grain filling in dehydrated or over-heated cereal plants, which can account for up to 90% of total grain weight under stress.

If low WU is the breeder’s target it is highly probable that selection for low water use can be achieved by directly selecting for simple plant physiological traits such as stay green (non-senescence), small tassel size, short anthesis-silking interval (ASI) in maize, high harvest index and stem rot disease resistant stems, without measuring WUE (Huang *et al.*, 2006; Bänziger *et al.*, 2000; Blum, 2005).

It is however important to note that that drought tolerance and WUE are not always synonymous. Genotypes with a higher WUE use the most water and may, therefore, be less productive when there are prolonged periods of dry weather. Thus, the selection of drought-tolerant crops for a higher WUE alone might not lead in the development of drought tolerant maize germplasm (Blum, 2009).

Currently, since high WUE has not been an ideal way of selecting for dehydration tolerance as it leads to reduced yield and reduced drought resistance in water stress regions, breeders are shifting towards effective use of water (EUW) in selecting for dehydration tolerance in cereals (Blum, 2009). Effective use of water (EUW) implies maximal soil moisture capture for transpiration which also involves reduced non-stomata transpiration and minimal water loss by soil evaporation. It is therefore assumed that EUW by way of improving plant water status helps sustain assimilate partitions and reproductive success. EUW therefore, is a major target for yield improvement in water-limited environments. It is not a coincidence that EUW is an inverse acronym of WUE because very often high WUE is achieved at the expense of reduced EUW (Blum, 2009).

2.3 Soil moisture and Evapotranspiration:

The maximum influence on the growth and yield of a crop depends on the availability of soil water since it is required in larger quantity than any other substance contributing to the growth and yield. In dry regions water becomes a key factor in evapotranspiration and to act as a plant coolant. Water serves the following functions in relation to plant life: a) Essential part of plant food constituting more than 90 per cent of plant tissues. b) Solvent and carrier of plant nutrients. c) Maintains cell turgidity and regulates soil temperature. Under soil moisture the following terms should be well known:

Field capacity is the condition of a soil when gravitational water has been removed meaning, the moisture content of the soil when downward movement of water has virtually ceased. The concept of field capacity is useful for determination of the amount of water available in a soil for plant growth.

Permanent wilting point refers to the moisture in a soil when the plant is permanently wilted meaning,. the moisture content of the soil when the plants loose their ability to recover from water deficits. It is the lower end of the soil moisture available range.

Available moisture is the water available between field capacity and permanent wilting point. Plants use this moisture.

Readily available moisture is the available moisture that can be used by plant. Plant roots cannot extract the water available near permanent wilting point. Therefore, the water used by plant is considered as readily available moisture.

2.4 Evapotranspiration (ET)

Evapotranspiration (ET) originates fro two terms; evaporation and plant transpiration. Evaporation is a term used to describe the sum of loss of water in form of water vapour from sources such as soil, canopy interception and water bodies Plant transpiration on the other hand accounts for the movement of water within a plant and the subsequent loss of water as vapor through leaf stomata. Evapotranspiration therefore is the total sum of water lost in form water vapour from sources such as soil, canopy interception and water bodies and through plant transpiration from the Earth's land surface to the atmosphere (Jensen *et al*, 1990; Owonubi *et al.*, 1991). **Potential evapotranspiration (ETo)** is a representation of the environmental demand for evapotranspiration and represents the evapotranspiration rate of an extended disease free short green crop/grass (alfalfa), completely shading the ground, of uniform height (8-15cm), well fertilized, actively growing and with adequate water status in the soil profile (Kassam, and Smith,2001). It is a reflection of the amount of energy in form of heat available to evaporate water, and available wind to transport the water vapour from the ground up into the atmosphere (Doorenbos & Pruitt, 1977, Kassam, and Smith*;* 2001). ETo has also been initially estimated by the use of the Penman- Monteith method. The FAO-56 Penman-Monteith method refers to the use of an equation for computing water evaporation from vegetated surfaces by use of lysimeters. It was proposed and developed by John Monteith in his seminal paper (Kowal, 1972; Monteith, 1965) in which he illustrated its thermodynamic basis with a psychometric chart.

$ETo = \{0.408\Delta(R_s - G) + \gamma(900/T_{mean} + 273)u_2(e_s - e_a)\}/\ \{\Delta + \gamma(1 + 0.34u_2)\}$....FAO-56 Penman-Monteith method

$ETo = 0.0023(T_{max} - T_{min})^{0.05}(T_{mean} + 17.8)R_a$……………………………………1985 Hargreaves−Samani method

Where;

R_s = solar radiation (MJ m^{-2} d^{-1})

G = the soil heat flux (MJ m^{-2} d^{-1})

e_s = daily mean saturation vapor pressure (kPa)

e_a = actual vapor pressure (kPa)

γ = the psychrometric constant (kPa/°C)

T_{min} = daily minimum air temperature (°C)

T_{ma}x = daily maximum air temperature (°C)

u_2 = mean daily wind speed at 2−m height (m/s)

Δ = the slope of the vapor pressure curve (kPa/°C)

T_{mean}= mean daily air temperature, computed as (Tmax + Tmin)/2, (°C)

Despite the advantages of the more physically based Penman methods, empirical ETo equations have remained in popular use because of simplicity and the smaller number of input parameters (weather data and other constants) needed for computation. The 1985 Hargreaves−Samani equation is among the empirical methods in common use. Hargreaves (2003) presented a good review of some background and abbreviated history of the development of the 1985 Hargreaves−Samani method and contrasts this method with other commonly used approaches. The method is popular in cases where the availability of data is limited, as it requires only measurements of maximum and minimum temperature, with extraterrestrial radiation calculated as a function of latitude and day of the year. The1985 Hargreaves−Samani method is often used to provide ETo estimations for weekly or longer periods and has been shown to provide ETo estimates that compare favorably to those of the FAO−56 Penman−Monteith equation at some arid and semi arid locations (Hargreaves, 2003).

Currently we have computerized devices that help you compute ETo of a place depending on the time set.

Actual evapotranspiration (ETc) is said to equal potential evapotranspiration when there is ample water (Teshome, 2004). ETc occurs when soil moisture is insufficient i.e. below the field capacity. Evapotranspiration in general is dependent on climatic factors such as temperature, humidity, wind speed and radiation.

Actual evapotranspiration (ETc) from a crop depends on the weather and the stomatal resistance. As soil water content is reduced so the stomata close and resistance is increased. Under constant weather conditions therefore ETc depends on the soil water content. It would be higher immediately after irrigation (when water is freely available to the plant and the soil surface is wet) and would decline over time as the soil dries.

A crop coefficient (Kc) relates to crop water use at a particular development stage to the amount of evapotranspiration (ETo) calculated from weather data. Table 3 shows average Kc values for the various crops and growth stages. Kc is also dependent on the climate and, in particular, on the relative humidity and the wind speed. The values indicated in Table 3 should be reduced by 0.05 if the relative humidity is high (RH > 80%) and the wind speed is low (u < 2 m/sec), e.g. Kc = 1.15 becomes Kc = 1.10. The values should be increased by 0.05 if the relative humidity is low (RH < 50%) and the wind speed is high (u > 5 m/sec), e.g. Kc = 1.05 becomes Kc = 1.10 (Doorenbos and Kassam, 1979)

Crop evapotranspiration (ETc) is calculated using the equation:

ETc = Kc x ETo

Where: ETc = Crop Evapotranspiration

Kc = Crop Coefficient

ETo = Reference Evapotranspiration (Kassam and Smith, 2001)

Table 2: The crop coefficient (Kc) for selected crops at various stages of growth

Crop	Initial stage	Crop dev. stage	Mid-season stage	Late season stage
Barley/Oats/Wheat	0.35	0.75	1.15	0.45
Bean, green	0.35	0.70	1.10	0.90
Bean, dry	0.35	0.70	1.10	0.30
Lentil/Pulses	0.45	0.75	1.10	0.50
Maize, sweet	0.40	0.80	1.15	1.00
Maize, grain	**0.40**	**0.80**	**1.15**	**0.70**
Melon	0.45	0.75	1.00	0.75
Millet	0.35	0.70	1.10	0.65
Peanut/Groundnut	0.45	0.75	1.05	0.70
Potato	0.45	0.75	1.15	0.85
Sorghum	0.35	0.75	1.10	0.65
Soybean	0.35	0.75	1.10	0.60
Sunflower	0.35	0.75	1.15	0.55

Source: Doorenbos and Kassam (1979).

Table 3 Factors affecting evapotranspiration

Evapotranspiration (ET)	**influence**	**Factor**
ETo	Weather	Sunshine Temperature Wind Humidity
ETc	Nature of soil Soil water content	Availability of water Stomatal resistance Soil evaporation

Source: Owonubi *et al.*, (1991)

2.5 Harvest index

High harvest index (HI) expresses successful plant reproduction and yield in terms of reproductive functions and assimilate partitioning towards reproduction. In most rain-fed environments crop water deficit develops during the reproductive growth stage thus reducing HI (Blum, 2009).

Whereas there is no significant difference in the harvest index between well watered plants and water stressed plants at vegetative stage of maize plant growth, water deficit at reproductive stage reduces the harvest index significantly. This lower harvest index due to drought at reproductive stage is an indicator of less partitioning of DM towards the grain (Sah and Zamora, 2005). Sinclair *et al.*, (1990) reported that under moderate water stress, HI was stable but decreased under severe water stress, where accumulated biomass was less than about 1100 gm^{-2}.

There has been a general increase in the yields of modern crops, with little change in the total above-ground biomass. This improvement is, therefore, attributed to an increase in the harvest index (HI). Sinclair *et al*., (1990) reported that a decrease in grain yield under moderate drought stress is proportional to the decrease in the accumulated biomass; the HI remained the same. The HI decreased, however, under severe water deficit, when the accumulated biomass was less than about 1100 g m-2.

Experiments with sorghum (*Sorghum bicolor* L. Moench), grown on stored soil water, showed an overall better grain yield of the hybrids compared to the open-pollinated varieties (OPV). This was attributed mainly to the fact that the HI of the hybrids was more than twice as high as that of the OPVs. In terms of the plant water status and mean daily biomass production, however, the OPVs were more drought-tolerant than the hybrids (Blum, 1988). Blum therefore suggested breeding for a higher potential HI of the OPVs since they were already drought tolerant.

2.6 Secondary Traits

During abiotic stress conditions, secondary traits other than grain yield (GY) have been successfully used to enhance the rate of genetic improvement for maize (Zea mays L.) population. This is because yield as a primary trait (a quantitatively inherited trait controlled by many genes i.e. it is polygenic trait) has shown little success if any in the selection of drought tolerant lines and hybrids. And even though yield as a primary trait is characterized by low heritability under stress, low genetic variance and a high genotype-by-environment (G X E) interaction, heritability of secondary traits whose genetic variance increases under stress, have remained stable across drought (stress) environments or may even increase and have helped in progress in breeding against drought stress (Jackson *et al*., 1996, Bolanõs & Edmeades, 1996). The exploitation of these highly heritable components (secondary traits) that are highly correlated to grain yield is therefore a more effective option than direct selection of yield *per se* (Kashiani and Saleh, 2010). The genetic correlations amongst these secondary traits and yield can be used to help improve primary traits (in this context yield) that have low heritability or are difficult to measure under stress (Malosetti *et al.*, 2008). Such secondary traits therefore should be strongly correlated with GY both under stress and non-stress environments (Betran *et al.*, 2003).

Higher GY in lines and hybrids is usually associated with shorter ASI, earlier flowering, increased plant and ear height, increased EPP, increased shelling percentage (under drought conditions. Grain yield is strongly positively correlated to ear number per plant and grain number per ear, delayed senescence, and greater leaf chlorophyll concentrations (Bänziger, *et al.*, 2000, Betran *et al.*, 2003, Monneveux *et al.*, 2008).

For a secondary trait to be useful in a program, it must comply with several requirements (Bänziger *et al.*, 2000; Araus *et al.*, 2002; Lafitte *et al*., 2003; Royo *et al*., 2005). One, the secondary trait must be genetically associated with grain yield under drought; two, the trait must be highly heritable than grain yield itself, should be less affected by the environment than grain yield and less genotype by environment (G x E) interaction; three, the trait must show genetic variability within the species; four, it must be stable, rapid, reliable and easy to measure; five, for breeding programs for stress-prone environments, the secondary trait should not be associated with yield loss under ideal growing conditions (Araus *et al*., 2002); and finally six, the trait must lend itself to assessment in individual plants or in very small plots. Evaluation under managed drought conditions with the help of secondary traits in selecting for drought tolerant high yielding maize germplasm applied during inbred line development seems effective in selecting inbred lines with good performance in hybrid combination across drought stress levels (Betran *et al.*, 2003).

2.7 Anthesis-Silking Interval (ASI)

If drought occurs during the reproductive stages of maize silking is considerably delayed, while anthesis is delayed to a lesser extent. Thus, the anthesis-silking interval (time from anthesis to silking) increases, which may be an important reason for crop failure under drought stress, since this trait is highly correlated with kernel set (Magorokosho *et al.*, 2003; Munyiri *et al.*, 2010).

Bolanõs and Edmeades, (1996) concluded that the ASI is a good and easily ascertainable external indicator of yield. The delay in ear initiation observed in dense populations may subsequently impact the number of kernels produced per ear (Sangoi, 2000).

The duration of ASI is an important cause of yield loss and is highly correlated with grain yield, and EPP (Mugo *et al.*, 1998; Richards, 2006). Delayed silking and hence extended ASI, leads to failure in pollination as silks emerge when the tassels have withered or senesced. Silking is delayed due to exhaustion of starch reserves in the ovaries (Richards, 2006).

Time to silking depends on biomass accumulation at the ear level, as silking for each plant is a developmental stage dependent upon ear expansion growth. Because plants within a maize canopy differ in their growth rate around flowering, plants with rapid growth rate reach silking earlier than the ones growing at lower rates. (Borra´s *et al.*, 2007). ASI is negatively correlated to grain yield (Betran *et al.*, 2003) meaning as the ASI increases, the grain yield reduces due to reduced probability of pollination and hence fertilization. The relatively low heritability of GY under drought stress and its strong correlation with ASI and EPP confirm the importance of these secondary traits in breeding for stress (drought) tolerance. When maize germplasm are exposed to drought conditions at two weeks before to two weeks after flowering, ASI and EPP are the best parameters to target (Avan *et al.*, 2008). They are relatively easy to score, fast, and inexpensive to estimate, and they show a strong correlation between inbred and hybrid performance (Bolanõs and Edmeades, 1996, Betran *et al.*, 2003).

To maximize expected genetic gain, drought should be managed very carefully so that mean ASI exceeds 4.5 days and mean ears per plant drops below 0.7, at normal planting densities. During selection, early-flowering escapes should be avoided (Bänziger *et al.*, 2000; Bolanõs and Edmeades, 1996).

Currently other morphological traits which appeared to have little adaptive value for improving performance of maize under drought stress, have assumed greater importance once barrenness is overcome or substantially reduced during early stages of line development and grain yield under stress stabilized as is currently being exercised by CIMMYT. This has made it is possible to use other morphological traits such as reduced tassel size and erect, green, unrolled leaves with enhanced longevity (Bolanõs and Edmeades, 1996).

Given that the genetic variability in ASI seems to be related to variation in biomass partitioning to the developing ear rather than to changes in crop water status, selection for grain yield *per se* may be done more efficiently using carefully managed drought as a selection environment, than by direct selection under unstressed conditions (Bolanõs and Edmeades, 1996; Bänziger *et al.*, 2000).

2.8 Genotype by Environment interactions

The differential response of a genotype for a given trait across environments is defined as the genotype (G) × environment (E) (G x E) interaction. G x E makes it difficult to select the best performing and most stable genotypes. Crops lack the wide environmental gene protection; thus for plant breeders, large genotype by environment (G x E) interaction impede breeding progress. (Smithson and Grisley, 1992).

The tropical regions have witnessed great environmental fluctuations lately due to climate change. Grain yield is a complex trait that is greatly influenced by the environment (Beyene *et al.*, 2011).

In fact, G x E interactions are as much a function of the genotype as they are of the environment and so are partly heritable (Hill, 1975). In breeding programs, genotype stability for yield and agronomic performance is an important breeding objective. There are several methods for evaluating the performance of hybrids and their genotypic interactions with the environment (Crossa and Cornelius, 1997 and Eberhart and Russell, 1966). These methods differ in the parameters used in the assessment, the biometric procedures employed, and the analysis. The sites regression (SREG) (Crossa and Cornelius, 1997) has been suggested as the appropriate model for analyzing multi environmental trials when large yield variation is due to environments. The SREG method supplies a graphical display called genotype plus genotype by environment interaction (GGE) biplot that identifies cultivars that are superior in different environments.

2.9 Alpha-lattice design

Plant breeding trials are typically developed to give an unbiased evaluation of all test entries, and ideally to ensure equal variances of all paired differences. When incomplete block designs are used, achieving the equal variance criteria results in balanced incomplete block designs (BIBD). BIBDs require that all pairs of entries appear together in a block equally often. This is only possible for trials with few entries. These designs require that the number of entries is a square of the block size and achieve balance if enough replicates are possible.

Due to the restriction on the number of genotypes that may be evaluated, there have been a number of proposed lattice type of designs, the most popular being the alpha designs developed by (Patterson and Williams, 1976; Giesbrecht and Gumpertz, 2004; Hinkelman, and Kempthorne, 2006).

Lattice designs group genotypes in incomplete blocks within each replicate and adjust genotype means for incomplete block effects; i.e., soil variation among incomplete blocks within a replicate. Compared to other lattice designs, **alpha lattice design**s (an unbalanced lattice design) pose very few restrictions on numbers of treatments, replicates, incomplete blocks, or spatial layout. Alpha designs are resolvable incomplete block designs where the number of entries is a multiple of block size. Although these designs cannot achieve balance, they are used extensively in plant breeding primarily because they are quite flexible regarding the number of entries to be evaluated and the appropriate size of incomplete block and they allow for good error control. In addition, these designs can be simply adapted to situation where the number of entries is not an exact multiple of block size by omitting treatments from an alpha design with a larger number of treatments. Incomplete blocks group together into “super-blocks” that are complete.

Field designs are based on concepts of replication, control of variation among plots and randomization, where replication allows valid estimation of error variance, control of plot variation reduces error variance and randomization allows unbiased estimates of means and variances. (Giesbrecht and Gumpertz, 2004; Hinkelman and Kempthorne, 2006; Mead, 1990). Block size is determined by the scientist. When soil variation is low, lattice designs with an incomplete block size equal to or slightly smaller than the square root of the treatment number are the most efficient. For example, with 200 treatments, a design of 10 blocks with 20 plots per block would be appropriate when soil variation is low. When soil variation is high, incomplete lattices with a smaller block size are more effective. In the case of 200 treatments, 25 blocks with 8 plots per block would be suitable when soil variation is high (Bänziger *et al.*, 2000). In the CIMMYT low N breeding program, use of such lattice designs increased breeding progress by 20% on average (Bänziger and Lafitte, 1997).

The major reason for grouping plots into uniform blocks is to reduce plot-to-plot variation and to improve the precision of the experiment. Failure to adequately block a field experiment can result in unacceptably large error variance and/or biased estimates of genotype. Effective control of error variance usually requires relatively small blocks. Trials with a large number of entries set out in a complete block experiment where there is considerable variability among plots within a block will likely result in very poor, possibly unusable, information on genotypes. To control field variation, especially with a large number of entries, it is essential to make use of incomplete block designs.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Parental germ-plasm

This study utilized genetic materials developed from an earlier study (Cheserek, 2010). In that study, the following genotypes that had been developed from open pollinated varieties (OPVs) were obtained from Kenya Agricultural Research Institute (KARI), Katumani; KCB, KDV1, KDV2, KDV3, KDV4, KDV5 and ZEWA. All of them are early maturing composites and have a long ASI. Four late –maturing, short ASI CIMMYT genotypes CML440, CML442, CML444 & CML445 were used as male parents. Cheserek (2010), evaluated these KARI OPVs under drought stress and the best high yielding ones (KDV2 & KDV4), were adopted as females and crossed to the CIMMYT inbred male genotypes as shown in Table 4.

Table 4: Mean AD, SD, EPP, ASI, EPP, and GY of the parental genotypes

Genotype	Anthesis date (AD)	Silking date (SD)	ASI	EPP	GY	Male/Female
CML440	60.00	62.67	2.67	0.73	2.91	Male
CML442	67.00	70.00	3.00	0.58	1.03	Male
CML444	70.00	73.00	3.00	0.78	1.41	Male
CML445	62.00	66.00	4.00	0.72	1.28	Male
KCB	47.33	58.00	10.67	0.69	1.17	Female
KDV 1	51.00	59.33	8.33	0.76	1.64	Female
KDV2	49.33	56.67	7.67	0.79	2.42	Female
KDV 3	49.33	57.67	7.67	0.64	1.45	Female
KDV 4	53.00	60.33	7.67	0.74	1.98	Female
KDV 5	51.00	60.33	9.33	0.63	1.33	Female
ZEWA	51.00	59.00	8.00	0.71	1.98	Female

Source: Cheserek, 2010

When the parental genotypes were subjected to drought stress (when available moisture is close to permanent wilting point), CIMMYT materials (males) were late maturing (60 to 70 days) but had short ASI (2.67 to 4 days). The OPVs (females) were early maturing (47 to 53 days) but with long ASI (7.67 to 10.67 days). Two OPVs (KDV 2 & KDV 4) were consequently adopted as females for generating F1 populations since they were high yielding, with a higher EPP ratio and smaller ASI compared to other OPVs in the experiment.

3.2 F_1 Generation

Again in the study by Cheserek, (2010), crosses were made between all the CIMMYT genotypes (CML440, CML442, CML444 and CML445) as males and the best two performing OPVs (KDV2 and KDV4) as females. An additional genotype K64R from Zimbabwe which is high yielding but late maturing was also introduced as female genotype. Crosses were therefore developed from KDV2, KDV4, and K64R (genotype from Zimbabwe) and CIMMYT genotypes to make F1 generation as shown in Table 5.

Table 5: F1 Generation Crosses Developed from Male and Female Genotypes

Female	Male	F1 Generation
KDV2	CML440	KDV2/CML440
	CML442	KDV2/CML442
	CML444	KDV2/CML444
	CML445	KDV2/CML445
KDV4	CML440	KDV4/CML440
	CML442	KDV4/CML442
	CML444	KDV4/CML444
	CML445	KDV4/CML445
K64R	CML440	K64R/CML440
	CML442	K64R/CML442
	CML444	K64R/CML444
	CML445	K64R/CML445

Source: Cheserek, 2010.

3.3 F_2 Generation

Similarly, the F2 generation was developed by selfing F1 generation genotypes on a single row plot during the dry season period of 2010. Each ear in F1 generation constituted a row (plot) i.e. ear to row seed multiplication. The F2 germ-plasm formed 12 populations of crosses that had genotypes segregating for long and short ASI; and/or early and late maturity period. The F2 genotypes were advanced to F3 generation by selfing only early maturing genotypes with a short ASI. They constituted 887 F2 genotypes/ears.

3.4 Experimental site

This experiment was conducted at Kenya Agricultural Research Institute (KARI) experimental station in Kiboko, during the dry seasons of 2011 (Year 1) and 2012 (Year 2). The Kenya Agricultural Research Institute (KARI) Kiboko Research Centre is situated about 2.3°S and 37.8°E, 1000 m above sea level on the foot of Mwailu Hill (KARI, 2010). Its soils are sandy loams that have a very high drainage (Gichuki, 2000) with bimodal rainfall patterns of less than 500mm per annum. The short rains come in the months of March to April and while the long rains come in the months of October to December.

3.5 F_3 Generation

Eight hundred and eighty seven F_2 generation genotypes possessing both early maturing and short ASI traits were selected from 12 population of crosses/families at F2 generation and selfed in order to advance them to F3 generation under well watered nurseries in 2011 season with each ear representing an entry/plot (ear to row layout).

Table 6 Genotypes which have a short ASI and are early maturing at F2

Genotype	Early maturing (%)	Maturity period (≤56 days to anthesis)	ASI (≤2 days)	Early maturity and short ASI (%)	Number of genotypes
KDV2/CML440	80	49-56	-2 – 2	53	100
KDV2/CML442	74	49-56	-2 – 2	75	158
KDV2/CML444	49	46-56	-4 – 2	86	134
KDV2/CML445	72	50-56	-2 – 2	89	94
KDV4/CML440	60	50-56	-4 – 2	88	166
KDV4/CML442	28	47-56	-3 – 2	87	17
KDV4/CML444	32	52-56	-3 – 2	98	41
KDV4/CML445	53	50-56	-2 -9 2	65	80
K64R/CML440	24	50-56	-3 – 2	97	54
K64R/CML442	4	55-56	-1 – 2	85	5
K64R/CML444	1	57	0 – 2	100	19
K64R/CML445	12	56-56	-2 – 2	92	19
Total genotypes with short ASI and early maturing at F2					**887**

Each plot consisted of 9 plants, with spacing of 75cm between rows and 25 cm between plants in a completely randomized design. The planting depth was 3-5cm deep. Five (5) CIMMYT single crosses were also planted alongside the F2 seeds as checks for ASI and time to maturity. The CIMMYT single crosses used were: CML440/CML445 (early maturing), P300/CML78 (late maturing), P100C6/CML78 (late maturing), CML395/CML444 (medium maturing) and CML312/CML442 (early maturing). At harvesting, each plant/cob was harvested and stored separately without bulking the seed.

With the addition of the checks, the 892 entries (plots) were planted for seed increase through selfing F2 generation to F3. Selection in F3 generation was made in the field basing on yield, days to maturity, ASI, yield, ear aspect, and plant aspect. Only genotypes that had short ASI (≤3days), were early maturing (≤56 days) at F3 generation and had enough seed for all the trial sites and replications were selected for evaluation under drought stress and well watered trials. Out of the 887 F3 progenies, one hundred and thirty five genotypes were selected for drought stress evaluation. Each F3 generation cob was harvested and stored separately

3.6 F3 family evaluation under Contrasting Stress Environments

In the 2012 dry season, two trials, each consisting of 135 F3 selected genotypes and 5 checks (CML440/CML445, P100C6/CML78, CML312/CML442, Duma 43 hybrid and Local Katumani composite) were laid out, under imposed drought condition and well-watered condition separately in an alpha (0,1) lattice design of (a x b) (Patterson and Williams, 1976; Bänziger *et al.*, 2000), replicated three (3) times **.** The genotypes were randomized, replicated and blocked in the trials using Fieldbook (xField-book 8.4.9) computer program (Bindiganavile *et al.*, 2007) with respect to the design.

Experimental plots were sown in one row of 3.75m long plots with 16 hills for well watered (fully irrigated throughout the season) field and in one row of 5m long plots with 21 hills for the drought stressed field, with one plant per hill. The hills were hand made to a depth of 3-5cm deep. The intra and inter- row spacing was 25cm x 75cm respectively for well-watered and drought stressed environments.

Plots were over-planted with two to three plants per hill but these were later thinned to one plant per hill fourteen days after emergence to give an established plant density of 56 888 and 56 000 plants/ha under well-watered (field with readily available moisture) and drought stressed (moisture level close to permanent wilting point) fields respectively. High population density is considered to increase drought stress by increasing mutual shading and competition of plants (Bruce *et al*., 2002). The trial fields were irrigated before ploughing to sprout volunteer seeds and after sowing to ensure uniform emergence. All the trials were irrigated at night by overhead irrigation according to Bänziger *et al.*, (2000).

Plots under well-watered field were irrigated after every 4 days for three- hour duration every day up to physiological maturity (R6 growth stage) (Lafitte, 1994). Plots under imposed drought stress treatment were irrigated for three hours after every 4 days, right from germination stage until one week (7 days) before anthesis, when water was withdrawn. Two additional irrigations were applied for the drought stressed trial; one 14 days after 50% anthesis and the second one; 26 days after 50% anthesis (Bänziger *et al*., 2000). The water volume was pumped at approximately 15 litres per second from the water source and at 12.5 litres per second at the experimental field hydrant for the two trials.

Maize plants show first symptoms of drought stress when 50-65% of the plant-available water is used (Bänziger *et al.*, 2000). In this experiment, irrigation of the field under drought -stress was stopped when the crop was one week to flowering.

The field trials were conducted during a rain-free period and irrigation regime was designed basing on Bänziger *et al*., (2000) so that;

- Leaves were rolled at flowering
- Anthesis-silking interval was maintained at between 3 to 8 days during the stress period

- 0.3 to 0.7 ears per plant were produced
- Grain yields averaged < 1 t/ha
- Leaf senescence was accelerated

Nitrogen fertilization for both trials was applied at two dates (before sowing and at the V6 stage), using a dose of 8g per hill for di-ammonium phosphate (DAP 18:46:0) translating to a rate of 25kg for N and 60kg for P_2O_5 per hectare. Top dressing was done at the V6 stage (Lafitte, 1994) using a dose of 10g per hill of calcium ammonium nitrate (26%N) translating to a rate of 40kg N per hectare.

Bulldock® (5% cyfluthrin) an insecticide was applied to maize funnels 15-20 days after emergence to control maize stalk borer. Hand-weeding was performed three weeks after emergence and two weeks to anthesis. Bird and monkey damages were curbed by a group of persons specially assigned to scare them away.

3.7 Water use efficiency Measurement

Water Use Efficiency (WUE) and effective Water Use (WU), and soil water measurements were recorded from sowing onwards during crop growth.

Soil water content was measured at depth of 75 cm and this represented a proxy for average soil water content in the root zone (Craine *et al.,* 2002). The selected samples from freshly irrigated fields and drought stressed field were placed in moisture cups and their weight taken. They were then filled with water to saturation point and left to soak for 2 days until each pore was completely soaked with water in the soil moisture laboratory. Excess water was drained off to leave the soils to at field capacity. The weight of each moisture cup was taken before being filled with the soil sample. The excess water was drained off and the wet soil weighed. The wet soil samples in moisture cups were placed in an oven at 105°C for 48 hours to completely drain out soil moisture. The weight of dry soil sample was also taken. The difference between the wet soil and the dry soil sample gave the available soil moisture that can be used by the plant, soil moisture at permanent wilting point and soil moisture at field capacity respectively. These soil water content readings were converted to volumetric soil water content (in millimeters of water per 100mm of soil).

Plant biomass, data on stover yield was taken by weighing of two stalks along with husks of each plot (entry) at harvest and averaged. Potential evapo-transpiration (ETo) data was collected from the computerized weather station at KARI Kiboko. Crop evapotranspiration (ETc) was calculated using the maize crop coefficient (Kc) at maturity stage (Doorenbos and Kassam, 1979).

WUE was calculated basing on the formula WUE = Biomass/ETc.

3.8 Data Scoring and Recording

Yield components and flowering traits were measured both under well-watered and drought conditions, while secondary traits and physiological parameters related to grain yield were assessed under drought conditions only. Days to anthesis (DA) and days to silking (DS) were recorded at 50% flowering and 50% silking respectively in each plot. A plant was considered as having reached anthesis or silking if at least one extruded anther (pollen shading) or one silk was visible respectively.

$$\text{Grain yield} = \frac{(100\text{-Moisture content}) \times \text{FEW} \times \text{Shelling co-efficient}}{\text{Plot area (ha)}} \text{ x } 10{,}000$$

Where: MC = Percent moisture in grains at harvest; FEW = Fresh ear weight (kg) at harvest; Shelling co-efficient = Shelling percentage / 100.

This grain yield formula is incorporated in Fieldbook computer program.

ASI was calculated as DS - DA. Plant aspect at R4 stage (Lafitte, 1994) was scored on a scale from 1 (very good) to 5 (very poor). Senescence during milk-dough stage (Lafitte, 1994) was estimated by visual notation and/or by counting the number of green leaves below the ear according to Bänziger *et al*., (2000) and Binford & Blackmer (1993). A score of 1-10 was used where 1 was when 10% of leaves below the ear senesced and 10 was when 100% of the leaves below the ear senesced (Bänziger *et al*., 2000).

Leaf rolling (LR) was assessed 2 weeks after anthesis and scored on a scale from 1 to 5. 1 (unrolled), 3 (leaves have a V-shape) and 5 (completely rolled), according to Bänziger *et al*., (2000).

Plant height was measured at maturity, as the distance between the ground surface and the node bearing the flag leaf. Plant height was recorded on randomly selected 10 plants (excluding the outer plant at both ends) per plot and averaged. Each plot was hand harvested.

Ears were counted (an ear was defined as having one or more grains on it) and the number of ears per plant was calculated. Ear aspect was scored on a scale from scale from 1 (clean uniform large well filled ears with distinct rows) to 5 (small, variable and poorly filled ears with no distinct rows). Moisture content for each plot was taken in the field and zero rated to 12.5°C (to avoid bias in weight) and grain weight further converted to tons/ha by the Fieldbook computer software program (Bindiganavile *et al.*, 2007). Grain weight per plot was used to calculate grain yield per hectare. All weights were expressed on a dry weight basis i.e. at 12.5°C grain moisture content.

ETc was taken to be 0.119mm i.e. ETc = ETo x Kc = 0.17 x 0.7 (late season maize coefficient) = 0.119mm. Late season Kc was adopted since it was the time crop biomass was collected.

To compare the intensity of stress in each genotype, drought stress indices were calculated for all the genotypes grown under stressed conditions as described in Section 3.9 below.

3.9 Plant attributes measured to compute Selection Indices for drought adaptation

From the phenotyping protocol described for field conditions, the following drought stress indices related to grain yield were quantified:

Yield stability index (YSI)

YSI = Ysi / Ypi (Lin *et al*., 1986)…………………………………………..…………. (i)

Stress susceptibility index (SSI)

SSI = [1-YSI]/SI (Fischer and Maurer, 1978).. (ii)

Yield index (YI)

YI = Ysi/Ys (Gavuzzi *et al*., 1997, Lin *et a.,l* 1986)………………………...………… (iii)

Stress tolerance index (STI)

STI = (Ypi x Ysi)/Yp^2 (Fernandez, 1992; Ramirez-Vallejo *et al.*, 1998)……………... (iv)

Geometric mean productivity (GMP)

GMP = sqrt (Ypi x Ysi) (Fernandez, 1992; Kristin *et al.*, 1997)……………………..….. (v)

Tolerance index (TOL)

TOL = Ypi – Ysi (Hossain *et al.*, 1990; Rosielle & Hamblin, 1981)…………………. (vi)

Mean productivity (MP)

MP = (Ypi + Ysi)/2 (Hossain *et al.*, 1990)... (vii)

Stress intensity (SI)

SI = 1-(Ys /Yp) (Fernandez, 1992).. (viii)

Ysi = yield of genotype under stress condition
Ys = total mean yield under stress condition
Ypi = yield of genotype under optimum condition
Yp = total mean yield under optimum condition

3.10 Statistical analysis

The analysis of variance was calculated considering genotypes as fixed, and replicates, plots and incomplete blocks within replicates as random factors by using PROC GLM procedure from SAS 9.2 computer program (SAS Institute, 2000), GenStat program (GenStat 14th edition) to establish differences in genotypes and environment. A probability level of ≤0.05 is considered statistically significant. Bi-plot analysis was done by Sigma Plot program (Sigma Plot 10.0).

Simple-Pearson phenotypic correlations were calculated to estimate the relationship among traits and drought indices with respect to yield within drought stress environment using PROC CORR procedure SAS 9.2 (SAS Institute, 2000). A probability level of ≤0.05 was considered statistically significant.

Pictorial view of the field trials

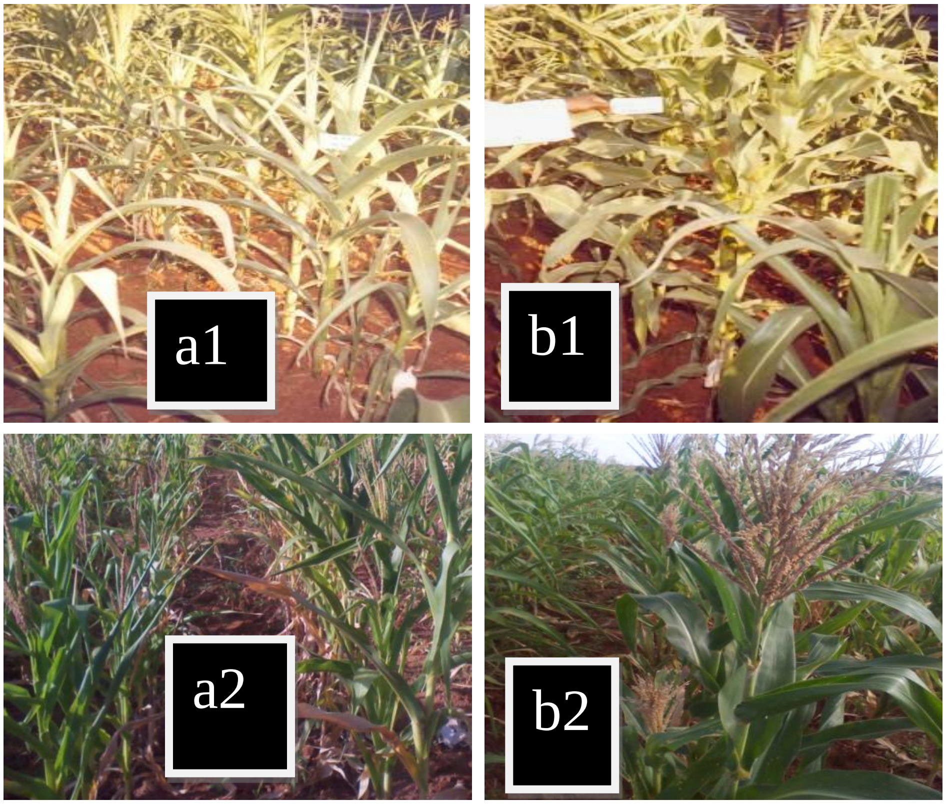


Plate 1: Leaf rolling under moisture stresses for two different genotypes one week after irrigation withdrawal one week to flowering and 26 days after flowering (a1 and a2) drought susceptible (b1 and b2) drought tolerant

Plate 2: Digital weather recording station at KARI Kiboko

CHAPTER FOUR

4.1 RESULTS

From nursery data of F2 populations, genotypes from KDV2/CML440 and KDV2/CML444 crosses emerged as most early maturing and high yielding. Progenies from K64R from Zimbabwe when crossed to CIMMYT genotypes were high yielding under well-watered environment but late maturing.

The F3 Genotypes showed significant differences (P<0.001) for GY under the two contrasting environments. Under drought stress (when soil moisture dropped to below 13mm), the genotypes gave lower yields as shown in Figure. 3 compared to those under well-watered environment as would be expected.

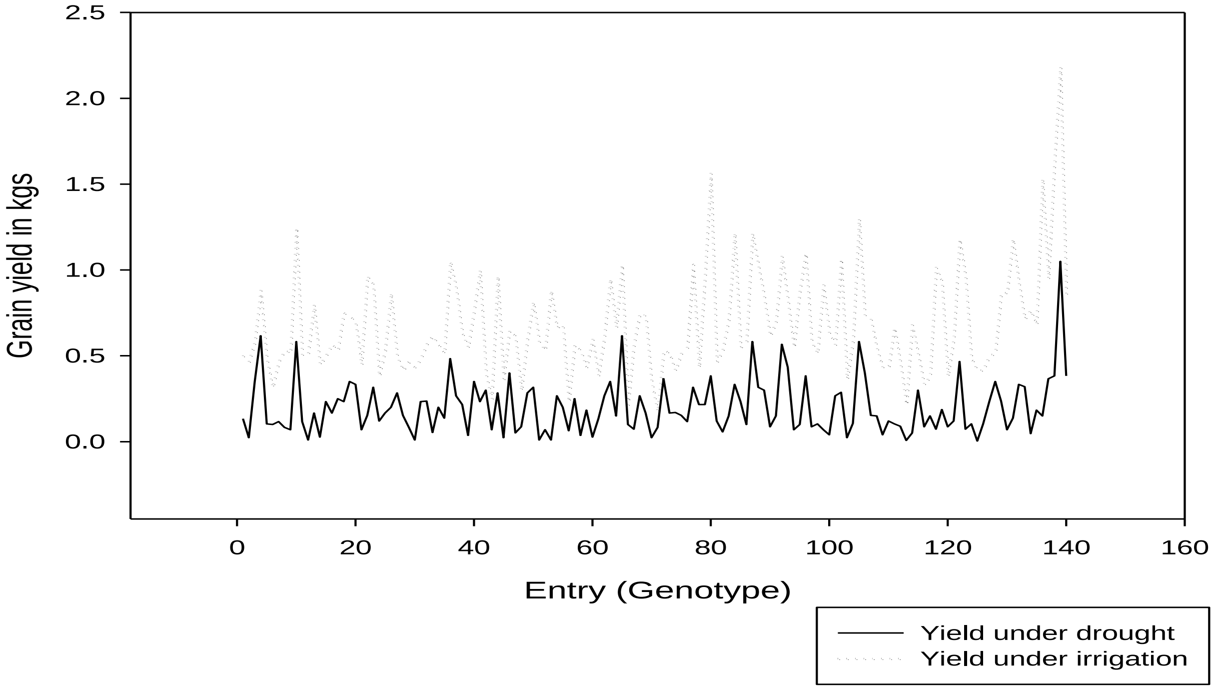


Figure 3: GY Performance of F3 genotypes under drought and well-watered conditions.

Figure 4, also shows the ASI under both drought stress and well-watered conditions. Under drought stress, genotypes showed increased interval between anthesis and silking. When the same genotypes were grown under well-watered conditions, the ASI gap was reduced and in some cases the ASI was in the negative, meaning that the plants silked before anthesis.

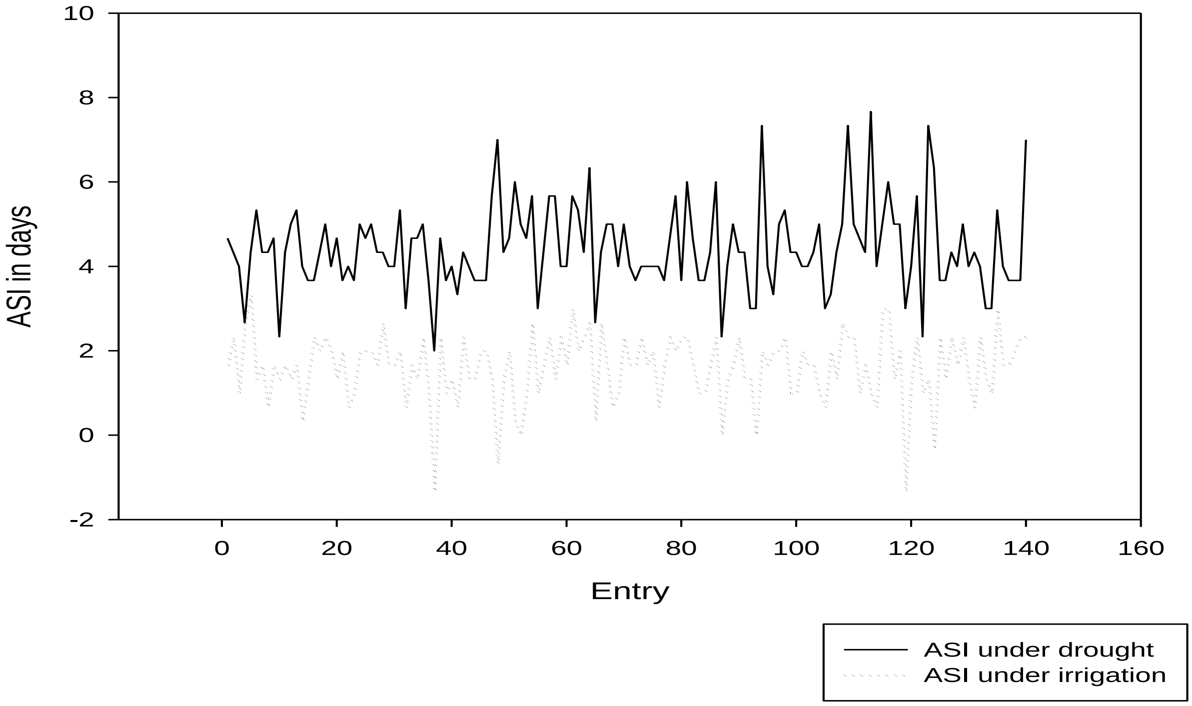


Figure 4: ASI performance of F3 genotypes under drought stress and well-watered environments

Due to water stress, days to maturity reduced significantly (P<0.01) as shown in Figure. 5, as would be expected. Days to maturity averaged to 52.69 days under drought stress but rose to an average of 57.04 days under well watered (irrigated conditions).

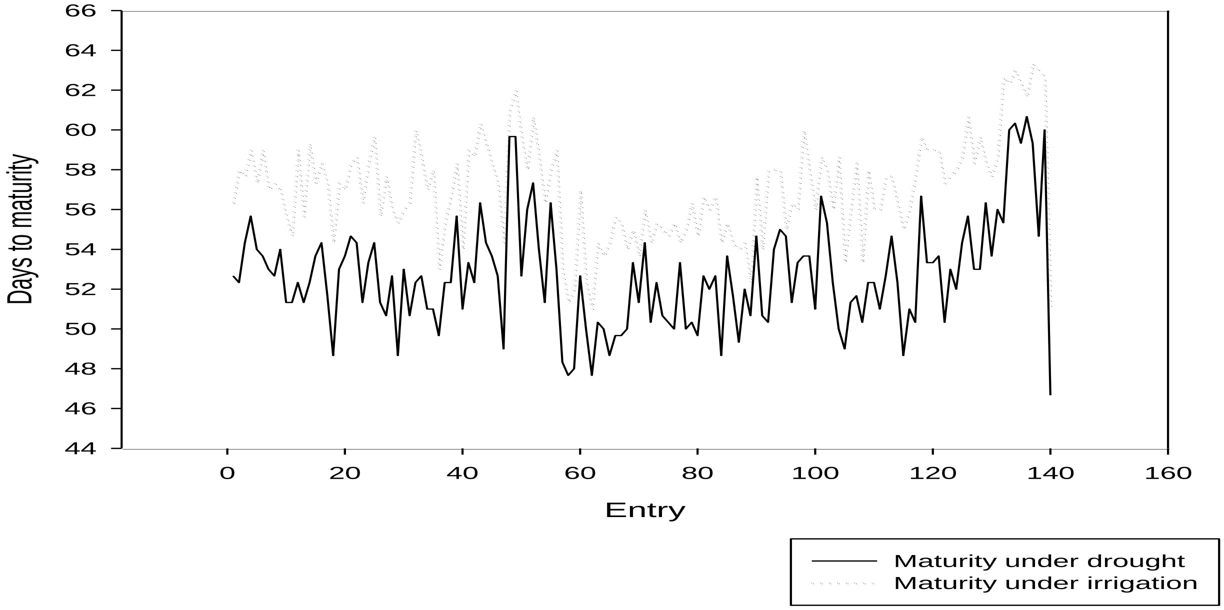


Figure 5: A graph showing grain days to maturity under two contrasting environments.

Table 7 shows that there were significant differences in ASI, days to maturity grain yield and ear aspect across all genotypes at $\alpha_{0.05}$ under drought stress. The results showed that there were no significant differences among genotypes in leaf rolling and senescence under the drought stress conditions.

Table 7 ANOVA for grain yield and other agronomic traits under drought stress

Source of variation	DF	Mean squares							
		ASI	AD	PA	EPP	GY	SEN	LR	EA
GENOTYPE	139	1.188*	4.843***	0.391	0.024	0.022*	0.224	0.343	0.583*
REP	2	0.061	9.562**	3.700**	0.277*	0.150**	0.365	0.379	1.144
BLK	83	0.372	18.273*	5.214**	0.261*	0.151**	0.378	0.318	1.37
REP*GENOTYPE	278	1.032	2.457*	0.367	0.022	0.016	0.207	0.336	0.526
R-square		0.835	0.933	0.771	0.645	0.833	0.703	0.729	0.783
%CV		20.382	2.583	20.974	67.769	68.268	12.747	16.703	19.806
Root MSE		0.897	1.361	0.617	0.204	0.137	0.467	0.621	0.666
Mean		4.400	52.697	2.940	0.301	0.200	3.662	3.719	3.364

* P<0.05; ** P<0.01; *** P<0.001 DF = Degrees of Freedom; ASI = Anthesis-silking interval; AD = Anthesis Date; PA = Plant Aspect; EPP = Ears per Plant; GY = Grain Yield; SEN = Senescence; LR = Leaf Rolling; EA = Ear Aspect

Table 8 shows an ANOVA table for traits under well -watered (non-stress) conditions. Under such conditions, ASI and AD did not differ significantly among the F3 genotypes. Grain yield, EPP were however highly significant at $\alpha_{0.001}$ and $\alpha_{0.01}$ respectively.

Table 8 ANOVA for grain yield and other agronomic traits under well watered conditions

Source of variation	DF	Mean squares						
		ASI	AD	PA	EPP	GY	SEN	EA
GENOTYPE	139	1.111	4.909	0.649**	0.039**	0.082***	0.190***	0.432*
REP	2	1.496	2.353	0.001	0.046	0.013	0.00007	0.026
BLK	83	2.307	2.439	0.415	0.005	0.004	0.002	0.126
REP*GENOTYPE	278	1.195	3.28	0.836	0.02	0.027	0.087***	0.224
R-square		0.744	0.851	0.829	0.887	0.932	0.972	0.905
%CV		59.807	3.514	20.222	22.247	22.191	7.508	16.109
Root MSE		0.987	2.005	0.624	0.150	0.151	0.155	0.431
Mean		1.650	57.050	3.087	0.672	0.683	2.069	2.676

* $P<0.05$; ** $P<0.01$; *** $P<0.001$ DF = Degrees of Freedom; ASI = Anthesis-silking interval; AD = Anthesis Date; PA = Plant Aspect; EPP = Ears per Plant; GY = Grain Yield; SEN = Senescence; EA = Ear Aspect

The combined analysis of variance for days to maturity (AD) and ASI showed that they were highly significant ($P<0.01$) at $\alpha_{0.01}$, (Table 9). The analysis of variance in Table 9, also showed significant interaction ($P<0.001$) between genotype and environment for ASI. There was also significant interaction ($P<0.001$) between genotype and environment at $\alpha_{0.001}$ for AD. Due to these interactions, genotypes under imposed drought stress environment matured faster and had longer ASI compared to their performance under non stress environment.

Equally, there were significant differences among genotypes for ASI, AD, GY, LR, SEN and EPP (Table 9). There were significant interactions with the environment for GY and ASI at $\alpha_{0.001}$, PA and EPP at $\alpha_{0.01}$; and AD and EA at $\alpha_{0.05}$ EPP differed significantly across the two environments ($P<0.001$) an indication that drought stress had a significant effect on the prolificacy of the maize crop.

Table 9: Combined ANOVA of the two contrasting environments for GY, ASI and other agronomic traits

Source of variation	DF	Mean squares							
		ASI	AD	WUE	EPP	GY	SEN	LR	EA
ENV	1	615.77***	1397.68***	8.46***	10.30***	17.54***	201.95***	603.48***	29.712***
GENOTYPE	139	1.31**	4.92**	0.18*	0.03**	0.04***	0.17*	0.20	0.415**
REP	2	0.015	0.94	0.01	0.02	0.0003	0.02	0.52	0.080
REP*GENOTYPE	278	1.49	3.03	0.16	0.07*	0.02	0.13	0.33*	0.303
ENV*GENOTYPE	139	0.95***	3.80*	0.005***	0.02**	0.07***	0.44***	0.22***	0.530*
BLK	83	0.04	0.27	0.15	0.04	0.01	0.01	0.59	0.352*
BLK*GENOTYPE	139	0.94	2.97	0.20	0.03*	0.02	0.13	0.23	0.311
R-square		0.911	0.932	0.783	0.878	0.943	0.953	0.974	0.850
%CV		31.147	3.057	45.747	36.556	33.933	12.400	17.12	19.621
Root MSE		0.942	1.678	0.369	0.178	0.150	0.355	0.404	0.593
Mean		3.025	54.874	0.807	0.487	0.441	2.867	2.361	3.020

* P<0.05; ** P<0.01; *** P<0.001 DF = Degrees of Freedom; ASI = Anthesis-silking interval; AD = Anthesis Date; PA = Plant Aspect; EPP = Ears per Plant; GY = Grain Yield; SEN = Senescence; LR = Leaf Rolling; EA = Ear Aspect

Table 10 shows there were significant differences for evaluated traits under two contrasting environments. Under water stress (WS) conditions, days to silking, leaf rolling intensity, senescence and ASI increased while days to anthesis, number of ears per plant, plant biomass and grain yield decreased.

Table 10: Effects of water stress at flowering on the phenotypic characters of the selected maize genotypes evaluated at Kiboko.

Traits	Water Regimes			
	Water Stresses (WS)		Well Watered (WW)	
	Mean	Range	Mean	Range

Days to anthesis	52.698	46 – 63	57.040	50 – 65
Days to silking	57.226	47 - 72	58.971	51 - 68
ASI (days)	4.426	1 – 9	1.6	-1 – 6
Leaf rolling (1-5)	3.719	2.5 – 5.0	1	1 - 1
Grain yield (tons/ha)	0.533	0.011 – 2.80	2.425	0.628 – 7.763
EPP	0.301	0.093 – 0.93	0.672	0.099 – 1.176
Plant height (m)	146.386	70 – 177.5	139.038	63 – 178.75
Senescence	3.662	2.0 – 4.5	2.074	1 – 3
Above ground biomass	0.075	0.015 – 0.330	0.117	0.043 – 0.670

The bi-plot analysis in Figure 6 shows genotypes that are high yielding under both drought and under well watered conditions. The grain yield of the genotypes varied significantly across the environments. Genotypes KDV4/CML440-226, KDV2/CML440-224, KDV2/CML444-243 and KDV4/CML440-483 were high yielding under both environmental conditions (Figure. 6-upper right quadrant). Their yields ranged from 1.2-1.6 tons/ha under water stress and 4.2-4.6 tons/ha well watered (a three times difference in yield) conditions. These genotypes are likely to exhibit less genotype x Environment (G x E) interactions and may have stable yields across environments. Genotypes, KDV2/CML444-14, KDV2/CML440-66 and KDV2/CML444-234 were high yielding under stress (1.51-1.64 tons/ha) and yielded between 3.1-3.8tons/ha which was above average (2.45 tons/ha) under well watered environment (Figure. 6 lower right).

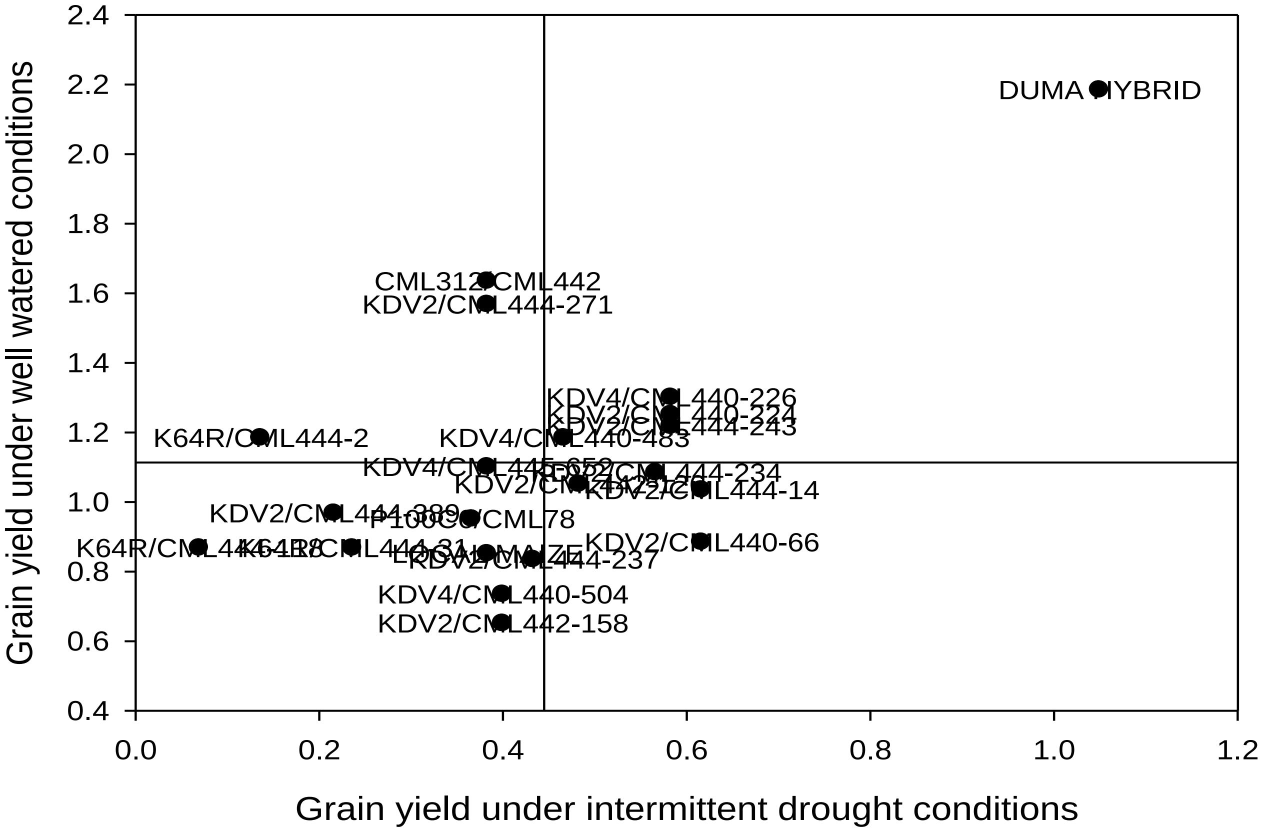


Figure 6: A Biplot showing grain yield under drought stress and well watered environments.

Vertical and horizontal lines represent trial mean yield under drought stress (x-axis) or under well watered (y-axis) conditions. Resulting quadrants are an indication of yield response under drought and well watered conditions.

The results shown in Fig. 7 demonstrate that the same genotypes (KDV2/CML444-14, KDV2/CML444-234, KDV4/CML440-226, KDV2/CML440-224, KDV2/CML444-243 and KDV4/CML440-483) that are high yielding under drought-stress had a very short ASI of not more than 3 days. Whereas, genotype, K64R/CML444-2 gave high yields under non-stress conditions (4.2tons/ha) it performed poorly (0.36tons/ha) under stress environment (Figure. 5).

The genotypes that had short ASI but were also early maturing are represented in the lower left quadrant of Figure.7. Genotypes KDV2/CML440-224, KDV2/CML440-504, KDV2/CML444-234, KDV4/CML440-226, KDV2/CML444-237, KDV2/CML440-66, KDV2/CML442-126, KDV2/CML444-271, KDV4/CML440-483, KDV2/CML444-243 and KDV2/CML444-14 had a short ASI (<3.6days) and were early maturing (<53days).

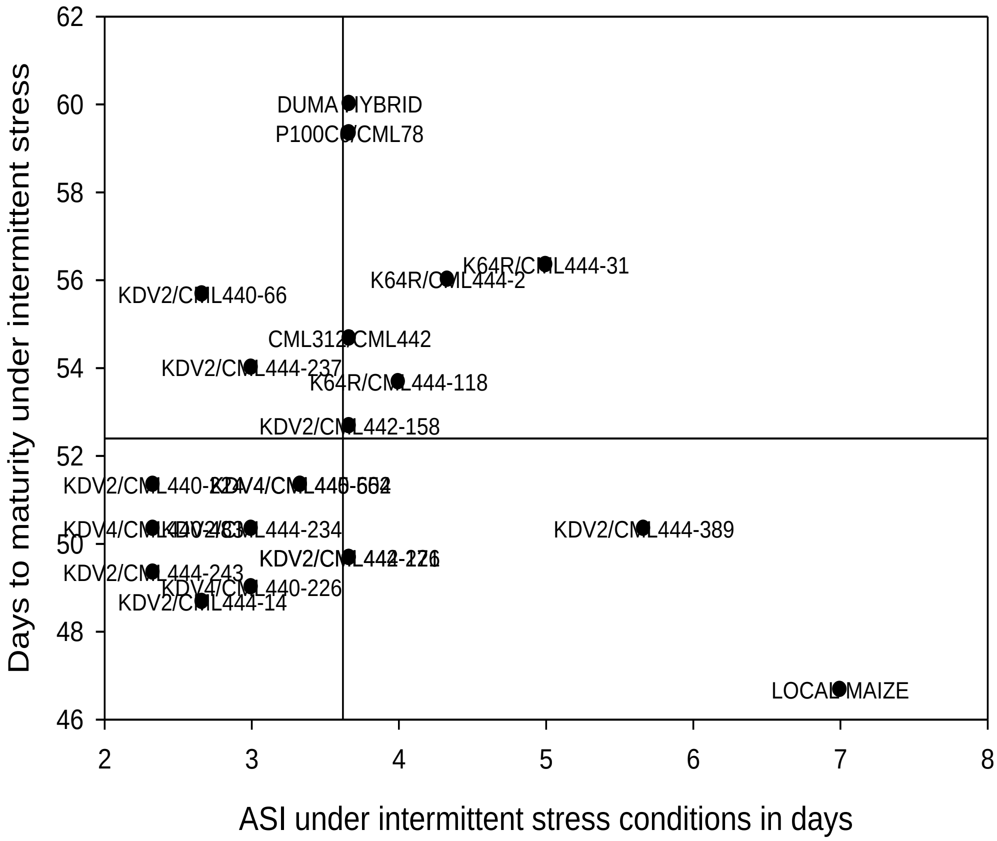


Figure 7: A Biplot showing a comparison between ASI & days to maturity under drought stress.

Vertical and horizontal lines represent trial mean ASI (x-axis) and AD (y-axis) under drought stress conditions. Resulting quadrants are an indication of ASI/AD response under drought stress conditions.

From the scatter plot in Figure 8, there was no clear relationship between grain yield and ASI under well-watered conditions. However medium drought stress, there was a negative relationship between ASI and yield of the genotypes. As the ASI increased, the grain yields were significantly reduced.

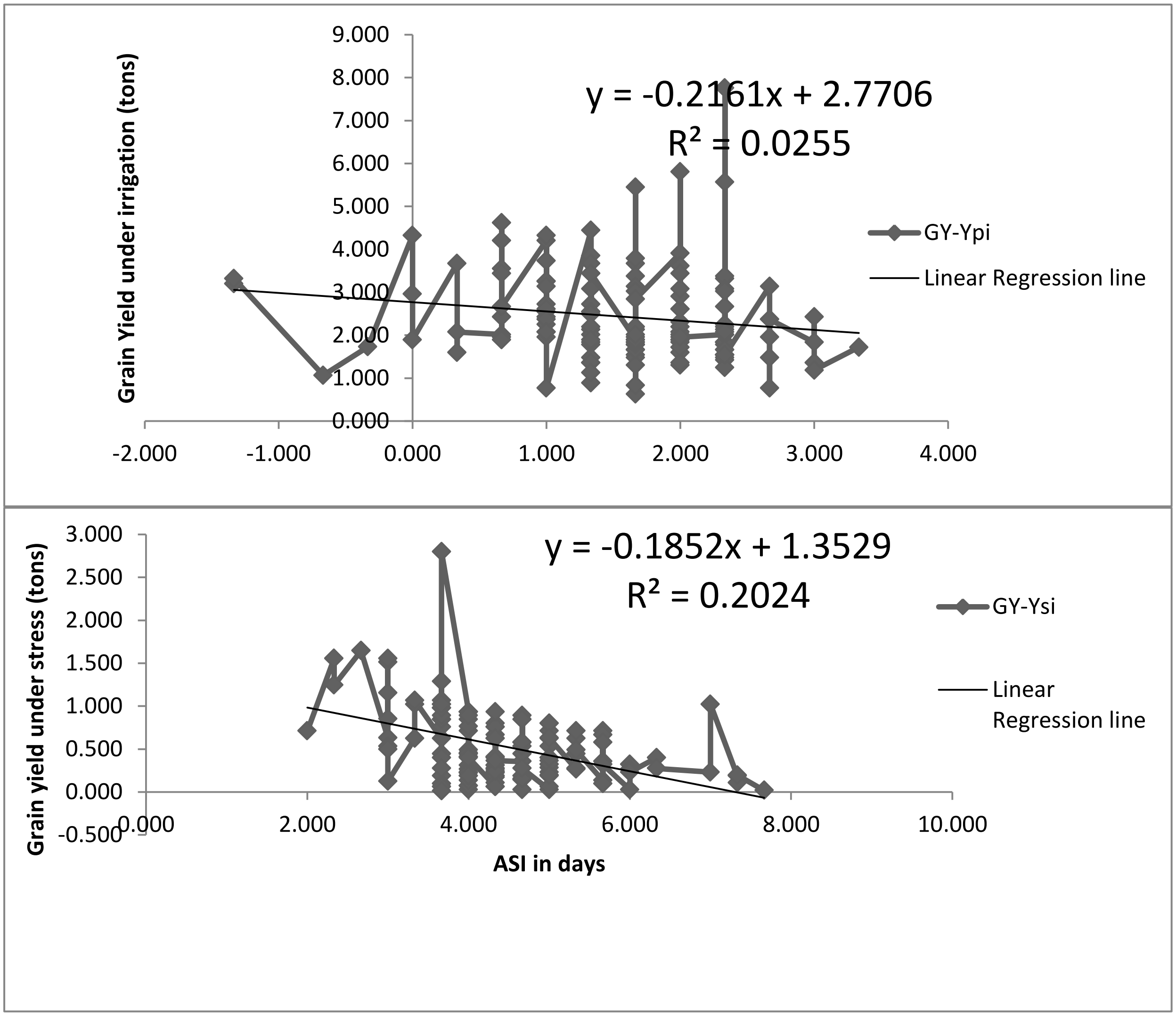


Figure 8: scatter plot showing the relationship between yield and ASI under stress

There was an increase in grain yield with the increase in stress tolerance index (STI), as shown in Figure. 9. Genotypes KDV2/CML440-224, KDV2/CML444-14 and KDV2/CML440-66 had very high STI value (0.88-1.18) compared to the average (0.272). These genotypes also had high yields under drought stress and performed equally well under optimum conditions. They (genotypes KDV2/CML440-224, KDV2/CML444-14 and KDV2/CML440-66) had low SSI values. Genotypes KDV4/CML440-442 and KDV4/CML440-87 had very high values of SSI and these genotypes had significantly low yields.

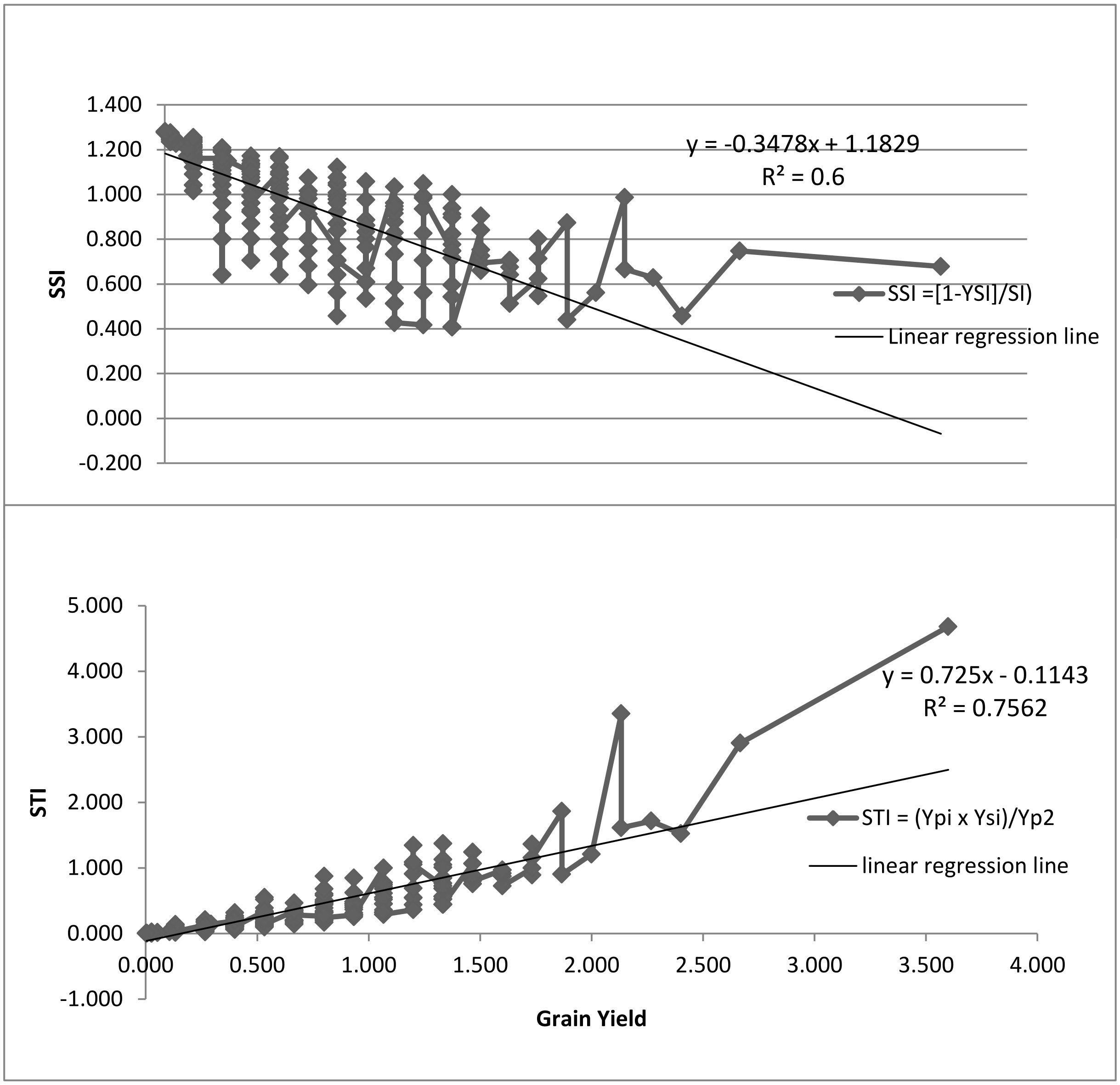


Figure 9: shows the relationship between grain yield and stress tolerance index [STI = (Ypi x Ysi)/Yp2] and stress susceptibility index [SSI = [1-YSI]/SI)]

A table of means (Table 11) for the top 20 genotypes with respect to yield under drought stress showed that even early maturing genotypes can be high yielding under drought and non stress conditions. Genotypes KDV2 CML444-14, KDV2 /CML440-224, KDV2/CML444-243, KDV4/CML440-226, KDV2/CML444-234, KDV2/CML442-126, KDV4/CML440-483, KDV2/CML444-237, KDV2/CML442-158, KDV4/CML440-504, KDV2/CML444-271 and KDV4/CML445-652 were early maturing (≤54days) and high yielding. These genotypes had an average yield of 1.308ton/ha under drought stress which was 59.25% above average mean yield (0.533tons/ha) of all the genotypes under drought stress. Under non-stress, the same genotypes had an average yield of 3.85tons/ha which was 37.01% above average mean yield (2.245tons/ha) of all genotypes under non stress conditions.

Table 12 shows the mean grain yield of the 20 superior genotypes and the GY variation across the contrasting environment. Genotype KDV2/CML442-66 was the most stable across the environments amongst the superior genotypes. It yielded 1.64 and 3.14 under drought stress and well watered conditions respectively. It ranked second in terms of grain yield stability (47.64%) amongst all the 140 genotypes evaluated for drought stress. The most stable genotype had variability of 43.75% but had very low mean productivity of 1.11tons/ha. It is however interesting to note that this genotype (KDV2/CML442-66) was medium maturing. Genotypes KDV2/CML444-14 and KDV2/CML442-224 that were high yielding had a variability of 55.24% and 65.00% respectively. However, this was far much better than the mean variability (78.51%) of all the genotypes. In the same Table 12, it is also interesting to note that under drought stress, the genotypes that yielded higher had a high WUE index. However, not all genotypes with high WUE index yielded highly in most cases.

WUE, BIO, STI, GMP and EPP are highly and positively correlated to grain yield ($P<0.001$) under water stress. ASI, SSI, LR and SEN had strong and negative correlation ($P<0.001$) with grain yield under stress. ASI had a strong positive relationship with SSI under water stress while it had a strong negative correlation with GMP and STI (Table 13).

Table 11: Mean values of yield in non-stressed (Ypi), yield in stressed (Ysi), ASI under stress (ASI-DRT), ASI under non-stress (ASI-IRR), AD under stressed (AD-DRT), AD under non stress (AD-IRR), and drought indices

Ysi Rank	Genotype	ASI-DRT	ASI-IRR	AD-DRT	AD-IRR	Ysi	Ypi	YSI = (Ysi / Ypi)	SSI =[1-YSI]/SI	YI = Ysi/Ys	STI = (Ypi x Ysi)/Yp2	GMP = √(Ypi x Ysi)	TOL = Ypi – Ysi	MP = (Ypi + Ysi)/2
1	DUMA HYBRID	3.67	2.00	60.00	62.67	2.80	7.76	0.36	0.82	5.25	3.70	4.66	4.96	5.28
2	KDV2/CML444-14	2.67	0.33	48.67	54.33	1.64	3.67	0.45	0.71	3.09	1.03	2.46	2.03	2.66
3	KDV2/CML440-66	2.67	2.67	55.67	59.00	1.64	3.14	0.52	0.61	3.09	0.88	2.27	1.50	2.39
4	KDV2/CML440-224	2.33	1.33	51.33	55.67	1.56	4.44	0.35	0.83	2.92	1.18	2.63	2.89	3.00
5	KDV2/CML444-243	2.33	0.00	49.33	54.00	1.56	4.33	0.36	0.82	2.92	1.14	2.59	2.77	2.94
6	KDV4/CML440-226	3.00	0.67	49.00	53.33	1.56	4.62	0.34	0.85	2.92	1.22	2.68	3.07	3.09
7	KDV2/CML444-234	3.00	1.33	50.33	58.00	1.51	3.85	0.39	0.78	2.84	0.99	2.41	2.34	2.68
8	KDV2/CML442-126	3.67	1.00	49.67	53.00	1.29	3.73	0.35	0.84	2.42	0.82	2.19	2.44	2.51
9	KDV4/CML440-483	2.33	1.00	50.33	57.33	1.24	4.21	0.30	0.90	2.33	0.89	2.29	2.96	2.73
10	KDV2/CML444-237	3.00	0.00	54.00	58.00	1.16	2.96	0.39	0.78	2.17	0.58	1.85	1.81	2.06
11	KDV2/CML442-158	3.67	2.00	52.67	57.33	1.07	2.31	0.46	0.69	2.00	0.42	1.57	1.24	1.69
12	KDV4/CML440-504	3.33	2.00	51.33	56.00	1.07	2.61	0.41	0.76	2.00	0.47	1.67	1.54	1.84
13	CML312/CML442	3.67	2.00	54.67	63.00	1.02	5.81	0.18	1.06	1.92	1.01	2.44	4.79	3.41
14	KDV2/CML444-271	3.67	2.33	49.67	54.67	1.02	5.57	0.18	1.05	1.92	0.97	2.39	4.55	3.30
15	KDV4/CML445-652	3.33	2.00	51.33	56.33	1.02	3.91	0.26	0.95	1.92	0.68	2.00	2.89	2.47
16	LOCAL MAIZE	7.00	2.33	46.67	51.00	1.02	3.02	0.34	0.85	1.92	0.53	1.76	2.00	2.02
17	P100C6/CML78	3.67	1.67	59.33	63.33	0.98	3.38	0.29	0.91	1.83	0.56	1.82	2.40	2.18
18	KDV2/CML444-352	3.67	1.67	50.33	54.33	0.98	1.90	0.52	0.62	1.83	0.32	1.36	0.92	1.44
19	KDV2/CML442-138	4.00	1.33	51.00	54.00	0.93	2.73	0.34	0.84	1.75	0.43	1.60	1.79	1.83
20	KDV2/CML440-182	4.00	1.00	54.33	57.67	0.93	2.07	0.45	0.70	1.75	0.33	1.39	1.14	1.50
	LSD	**1.669**	**1.879**	**2.360**	**3.083**	**0.552**	**0.940**	**0.241**	**0.309**	**1.036**	**0.344**	**0.684**	**1.075**	**0.553**

ASI under stress (ASI-DRT), ASI under non-stress (ASI-IRR), AD under stressed(AD-DRT), AD under non stress (AD-IRR), tolerance index (TOL); YI = Yiled index; STI = Stress Tolerance Index; BIO = Plant Biomass; GMP = Geometric Mean Productivity; SSI = Stress Susceptibility Index; YSI = Yield Stability Index; Ysi = Yield under stress; Ypi = Yield under non-stress, MP = Mean Productivity

Table 12: Mean grain yield (MP), GY variation and WUE tested under two contrasting environments

Ysi Rank	Genotypes	Ysi (tons/ha)	Ypi (tons/ha)	MP = (Ypi + Ysi)/2	TOL = Ypi – Ysi	GY variation (%)=(TOL/Ypi)*100	ASI-DRT	ASI-IRR	WUE-DRT	WUE-IRR
1	DUMA HYBRID	2.80	7.76	5.28	4.96	63.93	3.67	2.00	1.16	1.59
2	KDV2/CML444-14	1.64	3.67	2.66	2.03	55.24	2.67	0.33	1.33	0.90
3	KDV2/CML440-66	1.64	3.14	2.39	1.50	47.64	2.67	2.67	1.06	0.93
4	KDV2/CML440-224	1.56	4.44	3.00	2.89	65.00	2.33	1.33	2.80	1.06
5	KDV2/CML444-243	1.56	4.33	2.94	2.77	64.04	2.33	0.00	0.91	1.07
6	KDV4/CML440-226	1.56	4.62	3.09	3.07	66.35	3.00	0.67	0.72	1.26
7	KDV2/CML444-234	1.51	3.85	2.68	2.34	60.77	3.00	1.33	0.85	0.99
8	KDV2/CML442-126	1.29	3.73	2.51	2.44	65.48	3.67	1.00	0.99	1.04
9	KDV4/CML440-483	1.24	4.21	2.73	2.96	70.42	2.33	1.00	1.11	0.97
10	KDV2/CML444-237	1.16	2.96	2.06	1.81	61.00	3.00	0.00	1.23	0.83
11	KDV2/CML442-158	1.07	2.31	1.69	1.24	59.09	3.67	2.00	0.69	0.88
12	KDV4/CML440-504	1.07	2.61	1.84	1.54	53.85	3.33	2.00	0.68	0.97
13	CML312/CML442	1.02	5.81	3.41	4.79	82.40	3.67	2.00	0.74	1.35
14	KDV2/CML444-271	1.02	5.57	3.30	4.55	81.65	3.67	2.33	0.71	1.14
15	KDV4/CML445-652	1.02	3.91	2.47	2.89	73.86	3.33	2.00	0.61	0.95
16	LOCAL MAIZE	1.02	3.02	2.02	2.00	66.18	7.00	2.33	0.56	0.79
17	P100C6/CML78	0.98	3.38	2.18	2.40	71.05	3.67	1.67	2.36	1.12
18	KDV2/CML444-352	0.98	1.90	1.44	0.92	48.44	3.67	1.67	0.59	1.00
19	KDV2/CML442-138	0.93	2.73	1.83	1.79	65.76	4.00	1.33	0.57	1.30
20	KDV2/CML440-182	0.93	2.07	1.50	1.14	72.37	4.00	1.00	0.67	1.16
	LSD	**1.669**	**0.552**	**0.940**	**0.553**		**1.075**	**1.879**	**0.74**	**0.41**

Ysi = Yield under stress; Ypi = Yield under non-stress; ASI under stress (ASI-DRT), ASI under non-stress (ASI-IRR); MP = Mean productivity

Table 13: Correlation coefficients between Yp, Ys and drought tolerance indices

	ASI	AD	Ysi	Ypi	SSI	STI	GMP	MP	WUE	LR	SEN
ASI	1										
AD	-0.102^{NS}	1									
Ysi	-0.303^{***}	-0.067^{*}	1								
Ypi	-0.366^{NS}	0.110^{NS}	0.091^{NS}	1							
SSI	0.304^{***}	0.167^{*}	-0.100^{***}	-0.089^{NS}	1						
STI	-0.378^{***}	0.054^{NS}	0.418^{***}	0.790^{***}	-0.417^{***}	1					
GMP	-0.448^{***}	-0.029^{NS}	0.579^{***}	0.831^{***}	-0.578^{***}	0.918^{***}	1				
MP	-0.419^{***}	0.063^{NS}	0.295^{***}	0.974^{***}	-0.294^{***}	0.880^{***}	0.93296	1			
WUE	-0.365^{***}	0.035^{NS}	0.431^{***}	0.383^{***}	-0.431^{***}	0.478^{***}	0.56499	0.472^{***}	1		
LR	0.219^{***}	0.242^{**}	-0.539^{***}	-0.322^{***}	0.534^{***}	-0.443^{***}	-0.55623	-0.426^{***}	-0.373^{***}	1	
SEN	0.153^{*}	0.083^{NS}	-0.067^{NS}	0.174^{*}	0.069^{NS}	0.073^{NS}	0.08502	0.143^{NS}	-0.014^{*}	-0.087^{NS}	1

^{NS} = Not Significant; * P<0.05; ** P<0.01; *** P<0.001 STI = Stress Tolerance Index; WUE = Water Use Efficiency; GMP = Geometric Mean Productivity; SSI = Stress Susceptibility Index; YSI = Yield Stability Index; Ysi = Yield under stress; Ypi = Yield under non-stress

From Figure. 10, it is evident that WUE index becomes of key importance under drought stress conditions. Genotypes that had a higher WUE had a short ASI. And from Table 13, ASI is stongly negatively correlated with GY. Thus genotypes that had a high WUE index under drought stress had a higher chance of having a short ASI. There was a zero relationship (R^2 = 0.000) between ASI and WUE under well watered condition. Under drought stress, there was a negative relationship between ASI and WUE of which 13.4 % (R^2 = 0.134) change in ASI was due to genotype response to WUE index.

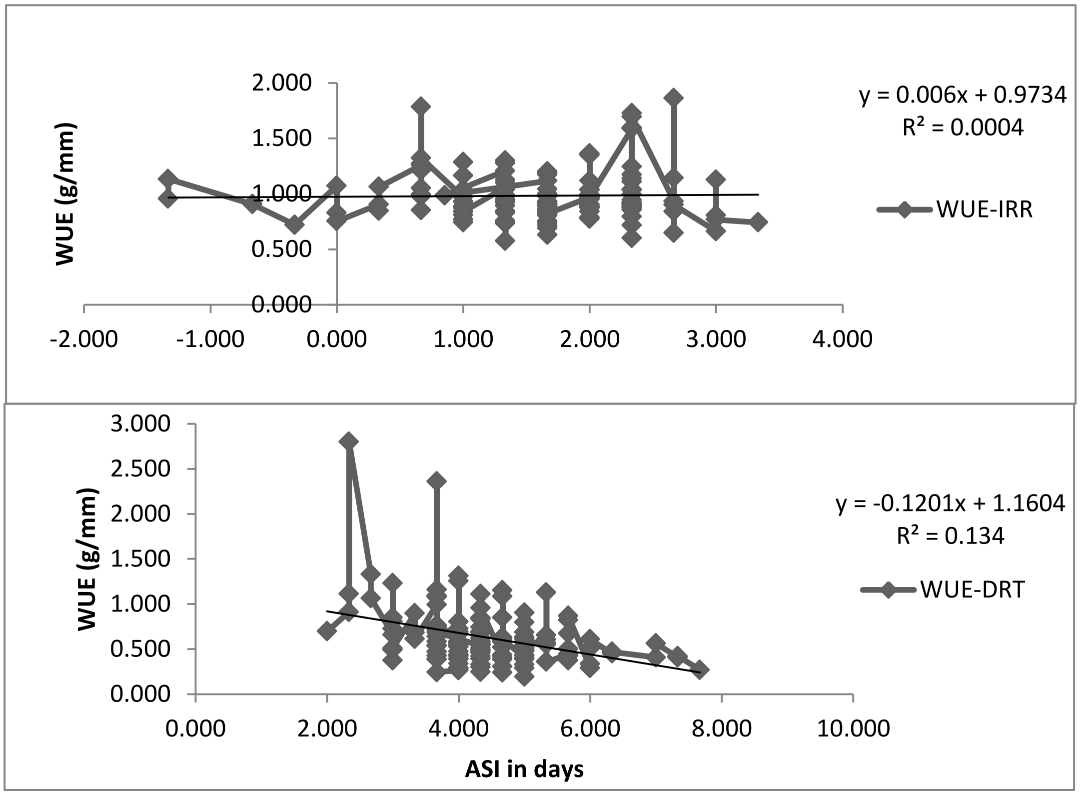
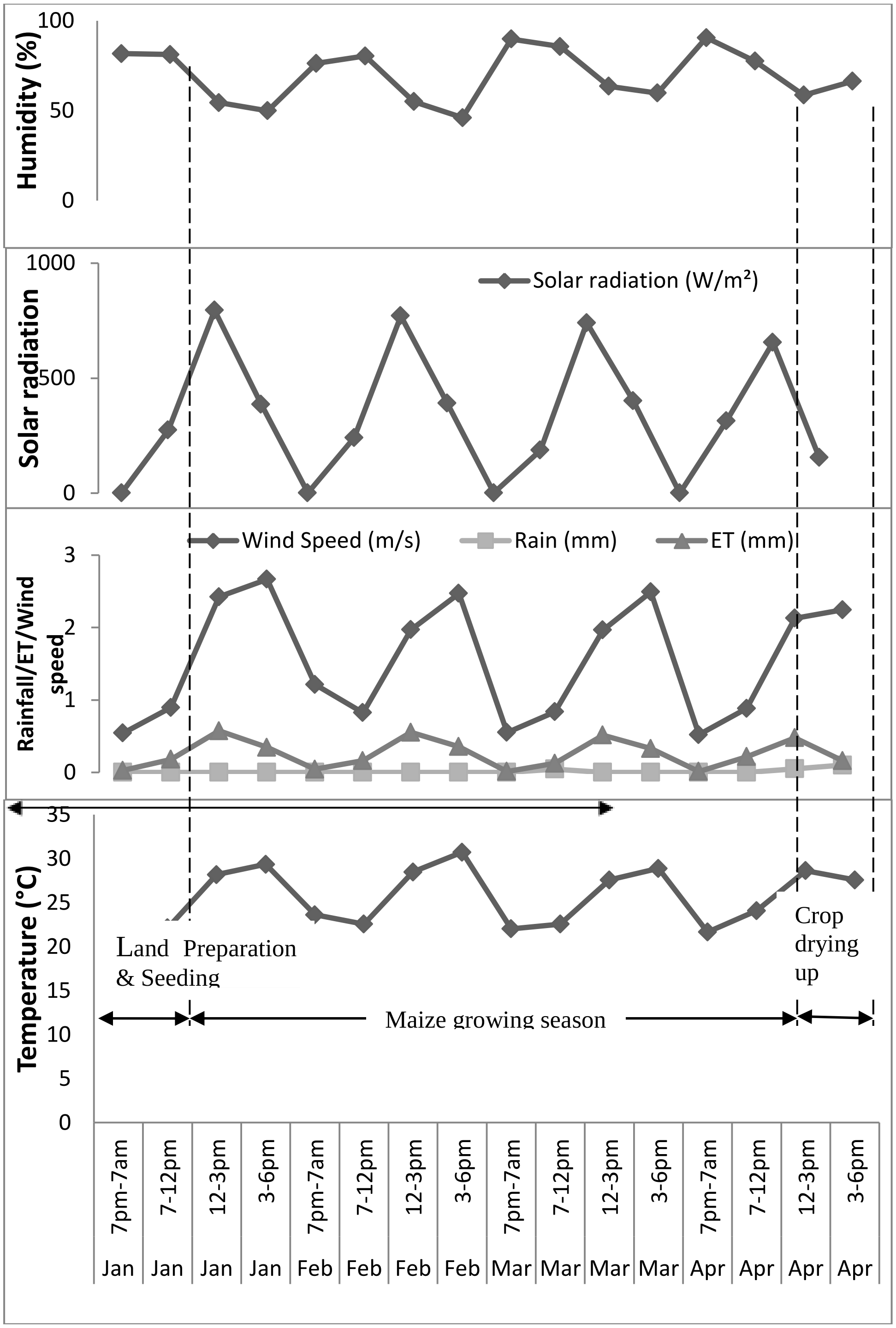


Figure 10: A relation between WUE and ASI under drought stress (WUE-DRT) and well watered (WUE-IRR) conditions

Figure 11 shows change in humidity with respect to temperature changes at different times of the day. At night when the temperatures are low, humidity rises. And during the hot hours of the day i.e. at 3-4pm, air humidity drops significantly. Evapotranspiration (ETo) was high during the day when the temperatures were hot and low at night when the temperatures dropped. Wind speed and solar radiation was directly proportional with evapotranspiration. When wind speed was maximum (≥2.5m/s) at around 3pm, relative humidity dropped to below 50%. Evapotranspiration rose to ≥0.5mm. At this time of the day solar radiation reached maximum (≥800W/m^2). At this particular time, the temperatures were ≥30°C. This shows that ETo was inversely proportional to relative humidity but directly proportional to solar radiation, temperature and wind speed.



Source: ICRISAT weather station-KARI Kiboko

Figure 11: Mean monthly temperature and humidity patterns at different times of the day

Table 14 shows the moisture levels of the soils at field capacity, permanent witling point and just before and after irrigation. Planting was done when the moisture levels were at permanent wilting point. Well watered fields soil moisture was maintained between field capacity and permanent wilting point. Most of the genotypes suffered water stress and leaves were severely rolled when soil moisture in 100mm soil depth dropped to below 13mm. This is the point when irrigation was applied when moisture levels tended towards permanent wilting point.

Table 14 Soil moisture levels in the field at field capacity and field conditions after irrigation

Field	**Sample number**	**Moisture in 100mm soil at permanent wilting point (mm)**	**moisture in 100mm soil at field capacity (mm)**	**Average Soil moisture just before irrigation (mm)**	**Average moisture in 100mm soil just after irrigation (mm)**
1	1	11.63	28.52	13.88	25.250
	2	10.23	22.99	11.39	17.137
	3	9.89	27.47	10.92	16.865
	4	10.66	19.23	11.33	11.882
	5	9.78	23.35	11.01	20.631
	6	10.51	26.40	12.15	21.969
	7	10.01	27.60	11.63	12.759
	8	9.45	24.74	10.97	12.774
	9	9.87	24.08	10.69	11.549
	10	8.99	37.95	10.42	14.992
Mean soil moisture in 100g of soil at field 1		10.10	26.23	12.24	15.78

	Sample number	**moisture in 100mm soil at field capacity (mm)**	**Average moisture in 100mm soil just after irrigation (mm)**
Field 2	1	24.40	15.501
	2	29.60	14.669
	3	24.02	14.690
	4	22.25	13.134
	5	27.94	17.522
	6	19.90	14.039
	7	27.73	15.615
	8	21.69	16.760
	9	25.95	17.856
	10	28.78	18.461
Mean soil moisture in 100g of soil at field 2		25.23	16.58

4.2 DISCUSSION

4.2.1 Anthesis to Silking Interval:

ASI has been reported to be a valuable diagnostic trait for cultivar performance under drought stress than days to silking per se, since it is largely independent of maturity differences among cultivars and highly correlated to yield (Magorokosho *et al.*, 2003).

Under drought stress, ASI increased up to 7.667 days from an average of 1.6 days under non stress. ASI was also negatively correlated with grain yield, and the number of ears per plant. Thus, Anthesis-silking interval is one of the most important secondary traits that can be used to indicate maize genotype's tolerance to drought stress (Mugo *et al*., 1998; Richards, 2006). The delayed silk emergence that occurs during drought stress and results into a longer ASI leads to failure in pollination hence lack of grain formation. This is in tandem with Richards' (2006) findings who reported that under moisture stress the ASI period was negatively correlated with grain yield. Bolanos and Edmeades (1996), Bolaños and Edemeades, (1993b) linked a high grain yield under stress to a short ASI. Mugo *et al.*, (1998) and Frova *et al*., (1999) similarly found that when drought stress occurs just before or during the flowering period in maize, a delay in silk emergence is observed resulting in an extended ASI. The results from this study (Figure 8, Tables, 6, 8, 9, 10, and 11) confirmed that indeed this was the case as previously reported. The ASI proved to be the most important key secondary trait that determined differences in grain yield potential of the genotypes under moisture deficit.

4.2.2 Days to Maturity:

Earliness is a desirable trait in drought prone areas especially with the changing climate and prolonged and unpredictable drought spells. It is generally recognized that longer maturity is associated with high yields due to long durations in vegetative period and metabolic transformation into grain (Wang *et al.*, 2011). Early maturing varieties on the other hand, are smaller and have fewer leaves with low grain yield compared with late cultivars (Kamara *et al.*, 2009; Wang *et al.*, 2010). Hence, the expectation is that under, drought stress, grain yield and earliness would have to be negatively correlated. Grain yield and earliness are important traits that can be used in ranking genotypes for their suitability as cultivars especially in drought prone areas (Olaoye *at al.,* 2009). In this study, under drought stress, days to maturity were an average of 52.698days in contrast to 57.04 days for all the genotypes under well watered conditions.

Earliness to anthesis and silking allows short growth duration and maturity and short ASI. This aspect constitute important attributes of drought escape and drought tolerance which make early maturing maize genotypes adapt better to late season moisture stress than late maturing ones and which may ultimately result into higher grain yields (Table 11).

4.2.3 Grain Yield:

Grain yield is the primary trait that every breeder and farmer is interested in during selection. Yield reduction under moisture stress ranged from 25% in KDV2/CML442-98 to 99.040% in KDV4/CML440-87. A large fraction of the yield potential was not realized in many genotypes under moisture stress (Table 10). Duma 43 Hybrid yielded significantly higher compared to all the genotypes and other checks in the trial under both environmental conditions as would be expected of a hybrid variety. Nevertheless, genotypes, KDV4/CML440-226, KDV2/CML440-224, KDV2/CML444-243 and KDV4/CML440-483 were also high yielding under both drought stress and well-watered environmental conditions and had almost similar grain yields as Duma-43 (Figure. 6-upper right quadrant).

Yield is fundamental aspect in maize production. Under drought stress environments, selection for earliness, short ASI and high grain yield, should be the ideal criterion of constituting a dry-land ideotype. As the results here show, under drought stress, grain yield decreased due to delayed silking, leaf rolling and reduced photosynthetic activity as shown in Figure. 4. Bänziger *et al.*, (2000) and Mungai *et al.,* (2001) found that moisture stress leads to a sudden reduction in yield due to delayed silking, increased abortion and reduced photosynthetic activity. This reduced photosynthetic activity in turn lead to reduced yields under drought stress. Under drought stress there is accelerated leaf rolling among all the genotypes (Table 4). The results reported here concur with those of Monneveux *et al*., (2005) who associated leaf rolling with a reduction in photosynthesis and therefore reduced grain yield would be as a result of decreased radiation interception. As shown, in this study, under drought stress, the reduction in the days to maturity of all the genotypes was probably due to accelerated leaf senescence (Figure. 5). Mohammadkhani & Heidari, 2007 and Efeoglu *et al.,* 2009 reported that leaf senescence is accelerated during drought stress, starting with older leaves at the bottom of the plant due to reduced chlorophyll content but with accelerated drought stress even the top leaves are also affected. This accelerated leaf senescence is followed by a reduced life cycle of the plant thus reduces the days to maturity. This consequently reduces biomass yield hence crop failure.

4.2.4 Genotype by Environment (G x E) interactions

Statistically, G x E interactions are detected as a significantly different pattern of response among the genotypes across environments and biologically, this will occur when the contributions (or level of expression) of the genes regulating the trait differ among environments. Where environmental differences are greater, it is expected that the G x E interaction will also be greater (Beyene *at al.,* 2011). Stability of performance is of special importance in Kenya dry lands where environmental conditions vary considerably and means of modifying the environment are far from adequate. Thus, the stability of maize genotypes under different environments is a key selection criterion for maize genotypes in ASALs.

Genotype KDV2/CML442-66 was the most stable across the environment amongst the superior genotypes with 47.64%. Genotypes KDV2/CML444-14 and KDV2/CML442-224 that were high yielding had a variability of 55.24% and 65.00% respectively as shown in Table 12. These genotypes were early maturing and drought tolerant as shown in Table 11. These variations in yield across contrasting environment were much lower than the mean variation of 78.51%. This implies that these genotypes are more stable and high yielding across the two contrasting environments. Due to G x E interactions, there is no relationship between ASI and WUE under well watered conditions. However, under water stressed conditions, a negative relationship between ASI and WUE develops (Figure 10) of which 13.4% genotypic change in ASI was due to WUE.

The genotypes that ranked best yielding under well watered environment (KDV2/CML444-271) was ranked number 14 under drought stress environment. Genotype KDV2/CML444-14 which was ranked the best under drought stress environment was ranked number 15 under well watered conditions. This indicated that the rank of genotype varied from one testing environment to another confirming the presence of G x E interactions. These findings are in agreement with Worku *et al.,* (2001) who stated that the presence of crossover interaction is substantial evidence in favour of breeding for specific adaptation across locations. Butron *et al.,* (2004) and Lee *et al.,* (2003) reported that selection of superior genotypes for grain yield and agronomic traits in maize hybrid performance trials is impacted by G × E. The significant effects of genotypes, environment and the genotype × environment interaction in the ANOVA Table 9 suggested differential response of the genotypes across environments. Similar observations were reported by Butron *et al*., 2002 in which he indicated that G x E effects for grain yield in maize genotypes were mainly due to environmental yield limiting factors.

Analysis of yield stability as measured by G x E biplot (Figure 6) showed that genotypes KDV2/CML442-224, KDV2/CML444-243, KDV4/CML440-226 had above average performance across environments showing the stability in yield across contrasting environment.

Variation due to genotype (G) was almost equal to G x E interaction for GY but was less than that due to the G x E interaction for ASI (Table 9), indicating that the differences among genotypes vary across environments. This high G x E interactions than G for grain yield and ASI have also been reported by Epinat-Le Signor *et al*., (2001) while working with early maize hybrids tested in about 30 locations in northern France.

4.2.5 Water Use Efficiency and Water Use:

Among the genotypes evaluated for drought stress tolerance, KDV2/CML444-14, KDV2/CML440-66, KDV2/CML440-224, showed superiority for grain yield than others under moisture deficits and also had stable grain yields when grown under well watered (moisture levels close to field capacity) conditions (although the values were lower than those of Duma 43 Hybrid). They were superior to the local Katumani composite. Genotypes, KDV2/CML444-14, KDV2/CML440-224 had a high water use efficiency of 2.801 and 1.331gmm^{-1} respectively when moisture levels were almost at permanent wilting point (PWC). It is likely that these genotypes have a higher genetic photosynthetic capacity than the others leading to higher yield performance. The WUE of these two genotypes were 93.07% and 85.4% better than the poorest genotype (KDV2/CML440-85) under drought stress and well watered conditions respectively. In terms of grain yield, the high yielding genotypes KDV2/CML440-224 KDV2/CML444-14 performed 98.38% and 98.26% under drought stress and well watered conditions respectively than KDV2/CML440-85. Genotype, KDV2/CML440-85 was the second poorest in terms of yield performance. The genotypes under well watered field had easy access to water since the water levels were between field capacity and permanent wilting point.

This then shows that when a genotype with a high WUE index can also have a high grain yield. In addition, the more efficient a genotype is in water use, the higher the rate of conversion of the tapped water to plant biomass.

It is however interesting to note that not all the water irrigated to the crop was utilized by the crop. There was a presumed 0% run off because the experiment was done in fields that had an almost zero gradient.

At initial stages of plant growth, most of the water was lost due to soil evaporation and it was approximated to be about 40-50%. This assumption takes into consideration several work done in semi arid lands of Kenya which was found to range between 40-60%. Kinama *et al.,* (2005) found that in the semi-arid lands of Kenya, water loss due to soil evaporation in mono-cropped maize was 60-65%. Such findings were also recorded by Leuning *et al.,* (1994) who found 50% moisture loss under wheat canopy. Mclntyre *et al.,* (1996) while working in the semi arid lands of Kenya on modeling of evapo-transpiration found that in a maize mono-crop, soil evaporation ranged between 42-58% on flatlands. When the crop formed the canopy, the 40-50% water loss was due to transpiration from the crop and not soil evaporation.

Drought tolerant species or varieties distinguish themselves from sensitive ones by their higher photosynthetic rates (Skingh and Tsunoda, 1978). Grain yield in the genotypes across environments differed depending on their response to available soil moisture regime.

The local OPV check (Katumani composite), which was early maturing had yielded averagely (1.022 tons/ha) under drought stress despite having a long ASI. This was because of its ability to escape stress by maturing early. Edemeades *et al.*, (1997b) noted that early maturity usually allows cultivars to escape the consequences of terminal drought. Thus, performances of the early maturing local variety included in this trial for grain yield was due to escape of drought stress rather than drought tolerance. The local OPV check (Katumani composite) performance was inferior to that of F3 genotypes that were as early if not earlier maturing and had a short ASI. These F3 genotypes arising from the generation of crosses made here demonstrated that indeed there is room to select for early maturity, short ASI, high grain yield and high WUE.

Yield stability is a measure of variation between potential and actual yield of a genotype across changing environments and could result from genetic heterogeneity, yield component compensation, stress tolerance, water use efficiency, and capacity to recover rapidly from stress or a combination of these factors (Henrich *et al*., 1983).

4.2.6 Leaf Rolling and Senescence:

There were significant differences in leaf rolling and senescence across the contrasting environments. Genotypes under water stress had accelerated leaf rolling and leaf senescence than genotypes under well watered conditions. Monneveux *et al*., (2005) found that there was reduction in grain yield due to reduced light interception from increased leaf rolling. Genotypes, KDV2/CML444-14 and KDV2/CML440-224 had the least leaf rolling and average senescence incidences, meaning that these genotypes are less likely to escape drought stress than the others. But it is interesting to note that these same genotypes were superior to all others in terms of grain yield, WUE and had short ASI. This is therefore a significant finding that confirms that these genotypes were not just escaping drought stress but indeed they possess a drought tolerance mechanism. In related studies, Monneveux *et al*., (2005) related reduction in grain yield to reduced light interception due to increase in leaf rolling. Bolanos and Edmeades (1996) found significant correlation between leaf rolling and senescence. They however stated that the correlation between the two traits and grain yield is not consistent and they classified leaf rolling as a stress adaptive trait necessary for drought breeding progress. This is also supported by Banziger *et al.*, (2000) who stated that leaf rolling had a medium to high heritability and a medium to low correlation with grain yield under stress. Furthermore, leaf senescence had a medium correlation to grain yield under drought stress at the grain filling stage.

Leaf rolling has also a negative effect on leaf use efficiency (LUE). The lower the LUE, the lower the photosynthetic rate. This leads to reduced crop yield (Kinama *et al.*, 2005).

4.2.7 Correlations and Drought Stress Selection Indices

There was very strong inverse relationship between ASI ($r=-0.312^{***}$), LR ($r = -0.503^{*}$), and SEN ($r = 0.199^{*}$) and grain yield under drought stress. Genotypes that had a shorter ASI had a higher chance of yielding better than genotypes with a longer ASI. This was the case in genotypes KDV2/CML440-224, KDV4/CML440-226 and KDV2/CML444-14 that demonstrated short ASI and they were superior to other genotypes in respect to grain yield. The relationship between grain yield and ASI from this study encompassing 140 progenies as shown in Table 13 was similar to that established for Tuxpefio Sequla (Bolanõs and Edmeades, 1993b) and Bolanos and Edmeades (1996) while working with 3509 progenies.

Genotypes KDV2/CML440-224, KDV2/CML444-14 and KDV2/CML440-66 had high STI compared to the rest. As shown in Table 13, grain yield and STI are highly correlated (r = 0.870^{***}). Grain yield under both drought stress (Ysi) and well-watered condition (Ypi) was highly positively correlated with Stress Tolerance Index (STI); r = 0.890^{***} and r = 0.990^{***}; Geometric Mean Productivity (GMP); r = 0.961^{***} and 0.831^{***}, and Mean Productivity (MP); r = 0.819^{***} and 0.934^{***} respectively. However, grain yield and Yield Stability Index (YSI) was only significantly positively correlated with grain yield under drought stress (Ysi) but was not significantly correlated to grain yield under well-watered conditions. WUE was positively correlated with grain yield under drought stress but not with grain yield under well-watered conditions. This is an implication that, these two parameters would be useful criteria in selecting genotypes that are adapted to drought stress. It is also a measure of the drought tolerance exhibited by the genotypes in general. On the other hand, ASI showed negative correlations with most drought tolerance indices, except for the Stress Susceptibility Index (SSI) with which it had a positive correlation. This again is an indication that the longer the ASI the more drought stress susceptible a genotype is (Table 13). A general linear model of GY under drought stress against STI (Figure. 9) showed a strong positive relationship (R^2 = 0.756) which helps to confirm that the genotypes that had high grain yields also had high STI value under drought stress (Table 11). These genotypes that had high STI value also had low SSI values. The STI indeed showed a strong relationship (R^2 = 0.6) with grain yield (Figure. 9). These genotypes also showed high STI values under well-watered conditions. This finding confirms that STI values constituted in this study can be used to select for drought tolerance. The higher the STI value, the better the tolerance of the genotype under drought stress. These results agree with those of Khayatnezhad *et al., (*2010) who worked on drought stress in wheat and reported similar incidences for SSI and STI values with respect to grain yield. In the same way, Mhike *et al.,* (2012) while working on secondary maize traits reported the similar relationships for STI and SSI with maize grain yield.

Table 13, showed there was a negative non significant correlation between grain yield and days to maturity under stress but significant negative correlations with ASI under drought stress (-0.448) and well watered conditions (0.366). This is a confirmation that ASI is a valuable phenotypic and genotypic measure of performance of a genotype under stress and that, a breeder would rather use ASI to measure drought tolerance rather than days to maturity. Genotypes, KDV2/CML444-234, KDV2/CML444-14, KDV2/CML440-224 and KDV4/CML440-226 performed significantly better in grain yield and their days to maturity ranged from 48.667 days to 51.333 days under stress. The ASI for these genotypes ranged from 2.333 to 3 days. Furthermore, the magnitude of association between these two parameters (AD and GY under stress) was considerably low (r = -0.063). This weak negative relationship between Grain yield and days to maturity under stress shows that a delay in maturity might not necessarily lead to higher yield. This is in agreement with the findings made by Muhammad *et al.,* (2011) who reported genotypic correlations between the two parameters to be -0.05. Sujiprihati *et al.,* (2003) and Beyene, (2005) also reported negative association between days to maturity and grain yield. But it is interesting to note that, in as much as the days to maturity was not significantly negatively correlated with grain yield, these traits are expected to be positively correlated under non-stress circumstances (Hussain *et al*., 2011; Wang *et al*., 2011; Farhatullah, 1989) This is because the delay in maturity provides more dry matter accumulation towards grain development for extended period, resulting in higher yield. Bello *et al.,* (2012) in their comparison between the early and late/intermediate maturing genotypes showed that most of the late/intermediate varieties out yielded early varieties. This was because the late/intermediate varieties took long duration in metabolic transformation into grain yield and stover. This negative correlation may be due to drought stress where lateness in maturity meant more exposure of the genotype to stress and hence more abortions and thus reduced yields.

CHAPTER FIVE

5.1 CONCLUSION

From the beginning, this study had hypothesized that in developing maize that is tolerant to drought for the semi-arid areas of Kenya, it is possible to combine both drought escaping mechanisms such as earliness hitherto used in maize breeding and drought tolerance mechanisms such as ASI. The results reported here not only concurred with several earlier findings but also confirmed that indeed, it is possible to combine both earliness, ASI and develop maize genotypes that are high yielding and high water use efficient and that are adapted to the semi-arid agro-ecological zones of Kenya.

Genotypes, KDV2/CML444-14, KDV2/CML440-224 consistently demonstrated that they combine alleles for short ASI, earliness, high yield and high WUE values. These genotypes demonstrated that under drought stressed conditions, they are capable of utilizing the limited moisture present efficiently and converting to high grain yields. Unlike, the Katumani composites developed for the semi-arid areas of Kenya, these genotypes are drought tolerant and not drought escaping, are earlier maturing and would yield higher.

The study also confirmed that ASI is indeed a consistent genetic selection trait under drought stress. Genotypes with short ASI are the most drought tolerant ones. Ears per plant, and days to anthesis would be useful secondary traits for selecting genotypes adapted to drought stress. Stress Tolerance Index (STI), Stress Susceptibility Index (SSI) and WUE should be considered as useful tools for selecting drought tolerant maize genotypes.

The F3/F4 generations of crosses bred in this study using ASI as a selection criterion presents to breeders a valuable germ-plasm not hitherto developed for further improvement of drought tolerant maize in Kenya.

5.2 RECOMMENDATIONS

This study recommends that the early maturing F3 generation genotypes with short ASI evaluated for drought stress tolerance be further selfed and/or sibbed to F4 generation to allow for further segregation and selection of earliness and short ASI.

We also recommend that once the genotypes have been selfed to F4 generation, these genotypes should screened further for drought stress tolerance and in different locations (multi-locational trials) which will help determine the adaptability, tolerance and G by E of each genotype. This will help identify high yielding drought tolerant genotypes adapted across several drought prone environments in Kenya.

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