COMBINING ABILITY STUDIES OF AREX AND CIMMYT, MAIZE (*Zea mays* L.) INBRED LINES UNDER STRESS AND NON STRESS CONDITIONS

BY

XAVIER MHIKE

A dissertation submitted to the School of Agricultural Sciences of the University of Zambia in Partial Fulfillment of the requirements of Master of Science Degree in Agronomy (Plant Breeding) Crop Science

University of Zambia

Lusaka

June 2007

DECLARATION

I, **Xavier Mhike** hereby declare that this dissertation represents my own work and that it has not previously been submitted for the degree at this or another University.

29/06/07

Signature

APPROVAL

The University of Zambia approves this dissertation for **Xavier Mhike** as fulfilling the requirements for the award of the degree of Master of Science in Agronomy.

Examiner's Signature	Date
.....	29/06/2007
.....	04.07.2007
.....	.....

ABSTRACT

Maize (*Zea mays* L.) is the staple food crop in Zimbabwe with a per capita consumption of 103kg. It is grown in a wide range of environments with 80% being produced by the smallholder farmers who occupy more than 90% of the marginal areas of the country. Marginal area production has seen a high hybrid variety turnover on the market hence the need to develop hybrids with stable yields under diverse environments. National program use of inbred lines as testers has had shortcomings in the early identification of good inbred lines, resulting in slow variety development, poor seed production and eventual delayed variety release for farmer use. The objectives of this study were to develop single-cross hybrid testers among Agriculture Research and Extension(AREX) and CIMMYT lines as well as determine the heterotic relationship among the two sets of inbred lines. In the study, testcross development was done using ten elite inbred lines each from AREX and CIMMYT programs. Using North Carolina Design II, the resultant 100 hybrids were evaluated under optimum and stress (low N and drought) environments. An Alpha (0,1) lattice design was used in the evaluation process with traits such as flowering dates, standability, disease tolerance scores, plant heights and grain weight being recorded. An across site analysis was done and results showed that there were significant differences ($p<0.05$) for environments, genotypes and genotype x environment interactions. Significant general combining ability (GCA) effects for all the traits ($P<0.05$) measured except for plant heights and stem lodging were observed, with five lines being identified as having good (positive) GCA effects for grain yield. Non-additive genes were also predominant in most traits except for anthesis dates, anthesis silking interval and ear heights. A total of 39 testcrosses were assigned heterotic groups basing on the N and SC heterotic groups. Tester identification was based on good GCA for grain yield, stability under diverse environments and maturity of genotype. In the N heterotic group, genotype LT52 (NAW5885/CMML442) was identified as a potential single cross tester in the intermediate maturity group while in the SC heterotic group genotype LT26 (SC5522/ZM621A-BBBB) was identified as another intermediate maturity group tester. In the early maturing category LT99 (RS61P/CML508) which is in the SC heterotic group was identified. The study also showed that there were heterotic group overlaps of the N and SC groups in relation to CIMMYT's A and B heterotic groups as some genotype combinations had to be assigned new heterotic groups or had their group unidentified resulting in the need for further evaluation.

DEDICATION

To my parents, Cletus and Christina; Wife and kids, Gloria, Kudakwashe and Tinotenda.

ACKNOWLEDGEMENTS

I am highly indebted to Dr. Bindi Vivek at CIMMYT Zimbabwe for his support and guidance throughout this study. Special thanks also go to my supervisor Dr M Lungu, the academic and technical staff at the University of Zambia for their unwavering support during the course of my study. I also extend my appreciation to my fellow 2005 MSc students for their support and encouragement. A special mention also goes to the AREX Maize Breeding Team for the support rendered during field evaluations.

I also extend my gratitude to the Government of Zimbabwe for granting me study leave to pursue this MSc programme. Finally I wish to acknowledge the financial support from the Rockefeller Foundation.

Table Of Contents

LIST OF TABLES

LIST OF APPENDICES

CHAPTER 1

1.0 INTRODUCTION

Maize (*Zea mays* L.) is the world's most widely grown cereal and is the primary staple food in many developing countries (Nass *et al.,* 2000). It ranks first in Latin America and Africa but third after rice and wheat in Asia (Doswell *et al.,* 1996). Maize is grown at varying latitudes from the Equator to approximately 50^0 North and South. Its grown from sea level to over 3000m above sea level, from heavy rainfall areas to semi arid conditions, and from cool to very hot climates with growing cycles ranging from 3 to 13 months. The area devoted to maize production is largest in developing countries. It is estimated that 64% of world maize area is found in developing countries, which account for only 43% of the world's total production (Doswell *et al.*, 1996). This is mainly due to marginal area production with very limited production such as fertilisers and improved varieties

In Sub Saharan Africa and maize is one of the most important food crops in this region. It is the staple food for Eastern and Southern Africa. History seems to indicate that in Southern Africa maize production was initially linked to the spread of commercial mining (Byerlee and Heisey, 1997). Its increase in popularity was due to its palatability and yield potential which is higher than that of sorghum and millets. Maize continues to be the dominant food crop in Sub Saharan Africa. It is estimated that maize demand in Sub Saharan Africa is expected to increase from 27 million tonnes in 1995 to 52 million tonnes in 2020 (Pingali and Pandey, 2001). There is therefore a need to increase the maize productivity to meet the growing food demand. This may be achieved through the

development of better adapted varieties, increased seed security, adoption of better agronomic practices through extension messages and intensification of fertilizer use especially in the smallholder sector. The latter option has been found to be very difficult since most of the smallholder farmers are resource poor, and cannot afford fertilizer application to optimum levels.

In Zimbabwe, maize production accounts for 80% of the total cereal crop production. The crop is widely grown in varying environments with a total of 1.2 million ha having been put to maize during the 2004/05 season (AREX, 2004). Normal annual production ranges from 1.8 to 2.1 million tonnes with a yield average of 1.2 t/ha and 4.5t/ha in the smallholder and large scale commercial sectors respectively. In the last 30 years maize production has more than doubled largely due to an average annual area expansion of 1.8% and yield increase of 0.7% (Dowsell *et al.*, 1996; Machida 1997). Technical innovations for maize, especially improved germplasm, played a major role is the expansion of production with the adoption of hybrids and fertiliser use giving a 70% yield increase in the 1980s.

The main maize production constraint in the country has been the use of poorly adapted varieties since most of the previous maize breeding work was focusing on high input environments. Droughts, low soil fertility and increasing disease incidences, especially maize streak virus and gray leaf spot *(Cercospora zea maydis)* have resulted in further yield reduction especially in the smallholder sector which occupies 91% of the semi arid areas of the country. According to CIMMYT (1990) improved yields, variety yield

stability, pest and disease resistance, tolerance to drought and low soil fertility, generally produce yield improvements of 30-50%. There is therefore a need to develop stress tolerant varieties especially for the smallholder, stress prone environments.

The national maize breeding program in Zimbabwe has been trying to solve some of the production constraints highlighted, through the development of maize varieties with drought, low N and disease tolerance. Since 1909, when maize breeding was initiated in the country, maize open pollinated and hybrid varieties have been developed for production in different ecological niches. Exotic germplasm from CIMMYT, IITA, USA, Europe, the SADC and other African countries have been used in combination with local germplasm. It is from these sources that twenty eight composites have been constituted and are being improved by various recurrent selection methods.

Currently the main focus of the breeding program is to develop drought, low soil fertility and disease tolerant maize varieties (hybrids and synthetics) with the pedigree method being used in inbred line development. Inbred line development is being done through recycling of elite lines, selections from populations, selfing of elite commercial hybrids and introductions from CIMMYT and Southern Africa Development Community (SADC) Regional National Agriculture Research Systems (NARS). Segregating populations are screened through managed drought, low soil fertility and disease stresses. The pedigree breeding method employed led to the establishment of two heterotic groups namely the SC and N group that are being used. Artificial inoculation of major diseases namely gray leaf spot (*Cercospora zea maydis)*, maize streak virus and maize leaf blight

(*Exsorhilium. turcicum*) is done and tolerant inbreds are then used in constituting new single, three-way hybrids and synthetic varieties. Currently the two inbreds N3.2.3.3 and SC5522 are being used as testers in the national program and have been seen to have some shortcomings especially in seed production and three way hybrid development. According to Pixley (1994), the inbred line testers N3.2.3.3 and SC5522 also have a shortcoming in that they fail to clearly separate their testcrosses into distinct heterotic groups.

The general objective of this study therefore was to identify single cross testers that have desirable traits, such as drought, low N and disease tolerance and ideal maturity to complement and/ or later substitute the inbred lines currently in use. The developed testers will also define the heterotic relationships between the national and CIMMYT germplasm.

The specific objectives of this study were:

1. To identify single cross hybrid testers among National Agricultural Research and Extension (AREX) and CIMMYT lines.
2. To determine the heterotic relationship among AREX and CIMMYT inbred lines.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Maize Production In Zimbabwe

Maize (*Zea mays* L.) ranks first in terms of the number of hectares grown and total cereal production in the country. It is the staple food and an important cash crop. The country requires 1.8 m tonnes of maize and 300 000t as national strategic reserves per annum. This requirement is divided into the following proportions, 64% for human consumption, 22% for livestock and poultry and 14% for other industrial uses (Mashingaidze, 2006). White maize is preferred for human consumption while yellow maize is used for livestock feeds.

Maize production varies annually according to rainfall pattern and input support programmes. The total communal, resettlement and small scale commercial production contribution to the overall national maize production, increased from 7.6% during the 1979/80 season to approximately 80% in the mid 1990s. This increase in the post independence maize production can be attributed to increases in the area planted to maize, better yields and improved support services. Maize yields in the dryland farming smallholder sector increased significantly from 0.7 t/ha in the 1980s to 1.5 t/ha in 2004 (Mashingaidze, 2006).

Zimbabwe maize breeding has been a success story over the years with hybrids being developed for both small scale and commercial production. According to Mashingaidze (2006) commercial adoption of hybrids in terms of area planted increased from 22% (1949/50) to 88% (1960/61) and 93% (1966/67). Adoption was however slower in the

communal lands before independence. The Mangwende communal area for instance had a hybrid adoption of 42% in 1975 but by 1985 it stood at 99% (Mashingaidze, 2006). Currently 90% of the total production area is planted to hybrids with the remainder being planted to other products such as OPVs, synthetics and recycled seed.

2.1.1 Production Constraints

Maize is relatively more sensitive to moisture and nutrient stress compared to crops such as sorghum and millets. Drought and low soil fertility are however ubiquitous production constraints on small scale farmers fields in Africa (Edmeades *et al* 1998). Diseases and pests are also other production constraints of note in the maize production process. Annual maize production losses due to diseases and pests were estimated at 13% of the total production in East and Southern Africa. With regards to biotic stresses, maize streak virus (MSV) affects an estimated 60% of the area planted to maize. This ranks MSV as the most widespread biotic constraint to maize production in Africa (De Vries *et al.,* 2001).

2.2 History of Maize Breeding in the National Agriculture Research System

Research to develop improved varieties was key in increased maize yields in Zimbabwe. Decades of intensive and sustained breeding led to the development of a range of adapted maize varieties for both low and high rainfall areas of the country. The maize-breeding program evolved through four phases, namely, Open Pollinated Variety (OPV), double cross hybrid, single cross hybrid, and the three-way hybrid development phases. Formal maize breeding started in 1909 at Salisbury Research Station, with the aim of developing open pollinated varieties (OPVs) that were high yielding and ecologically adapted to the

different regions where maize was being grown. The first breeding phase was characterized by the development of OPVs such as Hickory King, Salisbury White and Southern Crosses (Olver, 1988).

The search for good yielding varieties saw a major shift from OPV to hybrid development in the early 1930s. The hybrids were developed with inbreds being isolated from the locally adapted OPVs. This led to the development of double cross hybrids, with SR1 being the first commercially grown hybrid during the 1948/49 season and was released for planting during the 1949/50 season. These double cross hybrids were on average 30%-44% higher yielding than the best OPV (Mashingaidze 2006) .

The initial hybrid program was mainly focusing on high yielding varieties targeting high input environments. The hybrid era saw the landmark release of SR52 in 1960, which was the first commercial single-cross in the world (Mashingaidze, 2006). Parental lines of this hybrid were derived from the OPVs, Salisbury White (N.3.2.3.3) and Southern Cross (SC5522) respectively. The single cross hybrid SR52 was successful because it was developed for high potential areas with adapted parents which had excellent response to high management levels. This hybrid was not suitable for the marginal rainfall areas of ecozones 3 to 5 which are characterised by short rainy seasons with frequent intermittent droughts, where the majority of the smallholder farmers are found.

Since the early 1970s, there has been a paradigm shift in the national breeding program. The development of three way hybrids with abiotic stress tolerance of drought and low

soil fertility is now being incorporated into the inbred line and variety development process. The drought tolerance focus is the development of early maturing drought escaping heterogeneous hybrids. The pre-independence era (before 1980) saw the development of varieties such as R200, R201 and R215 which offered drought escape, long pollen shedding period (14-18days), excellent nicking and tolerance to heat stress, while the post independence era saw varieties such as ZS251, ZS255, ZS257, ZS259 and ZS261 being released. This was done in order to address the smallholder farmers' concerns. The 1990s however saw most of the varieties developed succumbing to diseases such as grey leaf spot (*Cercospora zea maydis*) and maize streak virus. As a result of these problems the national program sought external germplasm with resistance to these diseases. The quick hybrid turnover due to biotic stresses meant that new hybrids had to be developed faster, and therefore the development of single cross testers were to hasten variety identification and seed production.

Current food security concerns have prompted the National Maize Breeding program to continue focusing on both the smallholder and commercial sectors but with special attention being given to the smallholder farmer. This priority breeding approach for both biotic and abiotic stresses has also seen the breeding program taking OPV (synthetics) development as a high priority in order to increase the farmers' variety choices. Recent studies have also shown that in low potential environments (<2 t/ha), a hybrid has no comparative yield advantage over an OPV. As a result the use of cheaper OPV seed in low potential areas, is being encouraged to enable the farmer to save some money to buy other inputs such as fertilizer (Banziger, 2002).

2.3 BREEDING AND SCREENING FOR ABIOTIC STRESS

2.3.1 Why Breed For Marginal Conditions

Maize in the tropics is exposed to drought and low nitrogen (N) stress. The stress may increase due to global climate changes and the displacement of maize production to marginal environments by high value crops. It is also due to reduction in soil organic matter, leading to reduction in soil fertility and water holding capacity. Fertility and water availability varies greatly within many farmers' fields especially in the tropics, which therefore means that a single variety must be able to withstand a wide range of drought stress and N availability.

Farmers are reluctant to use fertiliser in marginal environments because they cannot afford, or because the fertiliser is allocated to better environments or more profitable crops. The main reason is risk aversion by farmers, because in very dry years there will be no crop irrespective of fertiliser application and farmers will lose the additional investment made in fertiliser.

Irrigation has a potential impact even greater than fertiliser but water is a non- renewable resource. Irrigation may also result in problems of salinization. Therefore, irrigation can only be a partial solution to the problem of drought even in developing countries (Ceccarelli, 1996). Water and nutrient resources are often limited and economic and environmental problems are likely to restrain their use. Accordingly it is possible to increase agricultural production at country level and at the same time serve small scale, resource poor farmers by recognizing that their environments need separate breeding

programs, with different objectives, methodologies and types of germplasm (Ceccarelli *et al.*, 1996 and Banziger, 2002).

Most varieties are specifically adapted to conditions which are at or near the optimum for crop growth. The superiority of these varieties is lost in sub optimal environments. According to (Simmonds, 1991) breeding for low yielding environments requires that selections be conducted in low yielding environments. Similarly (Smith *et al.,* 1990) concluded that selection in low input conditions is essential if significant yield gains for such conditions are to be achieved. Therefore response to selection is maximized when selection is conducted in the same target environments where future varieties will be grown (Ceccarelli *et al.,* 1996). Several other workers have investigated the usefulness of evaluating genotypes under stressed conditions. They concluded that breeding progress might be increased if abiotic stresses in the target environment are included during selection (Altin and Frey, 1990; Banziger *et al.*, 1997).

Results from (Banziger *et al.,* 1986-95) showed that genetic correlation between grain yields under low and high nitrogen were generally positive. Selection under high N for performance under low N was significantly less efficient than under low N leading to the conclusion that low N selection environments should be included in order to maximize selection gains for environments where N stress is important. Banziger *et al.* (2006) carried out trials in Zimbabwe between 2000 and 2002 with over one thousand hybrids, under optimum, low N stress and managed drought with yield ranges from 1t/ha to 10t/ha. Selection differentials were largest between 2-5t/ha and they became less

significant at higher yield levels. An Eberhart-Russell, stability analysis, estimated a 40% advantage at 1t/ha yield level, which decreased to 2.5% at the 10t/ha yield level (Banziger, 2002). It is from this work that they concluded that selection under carefully managed high priority abiotic stresses, including drought in a breeding program and with adequate weighing can significantly increase maize yields in highly variable drought prone environments and especially at lower yield levels.

2.3.2 The Challenges of Breeding for Drought and Low N Tolerance

One of the challenges is to find ways of guaranteeing good selection progress. The conceptual framework therefore implies that the breeder needs to:

- Have useful variation in the germplasm in characteristics that confer drought and low N tolerance.
- Be able to assess precisely drought and low N tolerance under relevant conditions that are similar to the target environment.
- Be able to apply a high selection intensity when selecting for tolerance to the two stresses.

2.3.3 Effects of Drought On Maize Development

Drought affects maize production on approximately 60% of the land area in the tropics. It is estimated to reduce maize yield by about 15% annually in lowland tropics and subtropics which results in a loss of 16 million tonnes of grain per annum (Edmeades *et al.*, 1999). Production is seldom with irrigation in the tropics and natural variability in the amount, and distribution of rainfall means that drought stress can occur at any point in the

crop's life cycle. Maize is thought to be more susceptible than other crops at flowering because the florets develop at the same time and are borne on a single ear or a single stem. The male and female flowers are separated by approximately 1m, while the stigmas and pollen are exposed to otherwise dry and hostile atmosphere for pollination to occur.

Drought severity is quantified based on the extent of soil drying, reduction in transpiration relative to potential evapotranspiration and plant water status. On the other hand the impact of restricted water availability is influenced by crop growth stage, crop history, leaf area, rooting volume, atmospheric vapour pressure deficit , temperature and radiation, hence it's difficult to compare drought across years (Banziger *et al.*, 2000).

In maize production, drought affects maize grain yield at almost all growth stages but the crop is most susceptible during the flowering period. At crop establishment seedlings die and plant population is reduced. Maize has no tillers hence no compensation. During the vegetative stage drought is not very lethal. However it slows leaf area development and accelerates leaf senescence.

Stomata closure may occur, resulting in photosynthesis and respiration decline due to photo-oxidation and enzyme damage. At flowering extreme sensitivity is confined to the period -2 to 22 days after silking with the peak at 7 days. Complete bareness can occur if the maize plants are stressed in the interval just before tassel emergence to the beginning of grain filling (Banziger *et al.*, 2000). Grain production is reduced due to impaired pollination. Silk growth is sensitive to low plant water status, while tassel growth is not affected much hence late emerging silks may not be pollinated. Delay in silk emergence

may lead to failure of pollen tube growth or abortion of the newly formed zygote. Abortion occurs because the flux of assimilates from current photosynthesis to developing grain is inadequate. Drought or high temperature during the early stages of seed growth increase concentration of ABA in the endosperm and this reduces the number of endosperm cells and starch grains initiated. Cytokinins are also important in establishing kernel sink potential and their level in plant tissues decline with drought (Edmeades *et al.,* 1998) .

At grain filling drought results in incomplete filled kernels and assimilate fluxes to growing organs are reduced. Kernel and ear abortion increases and plants may become barren. This bareness may lead to complete loss of grain yield. Female reproduction structures are the most affected with tassel blast occurring with temperature exceeding 38^0C. Lodging occurs because too much of the stalk carbohydrate reserves are mobilized to the grain when the rate of photosynthesis is limited by moisture stress(Banziger *et al.,* 2000).

Drought stress affects some key physiological traits at cellular level which include accumulation of abscisic acid (ABA) which is a plant growth regulator generated in the roots. This causes leaf wilting, stomata closure and accelerated leaf senescence. It also causes inhibition of cell division and expansion which manifests itself in reduced leaf area expansion, reduced silk growth, reduction in stem elongation and finally decreased root growth, leading to the intensification of the stress. In addition, osmotic adjustment through the formation of osmotically active substances in the cytoplasm and vacuole may

occur. This leads to the plant taking up more water and maintaining turgor and cell function for a longer time under drought.

Osmotic adjustment is apparent in sorghum, wheat and rice but less in maize (Banziger *et al.,* 2002). Proline accumulation is seen under severe drought stress. This proline acts as an osmolyte or protects protein structure as turgor is lost. The photo-oxidation of chlorophyll is through loss of synchrony between Photosystems 1 & 2. The loss of synchrony leads to release of free electrons in the leaf resulting in reduced or loss of photosynthetic capacity which is seen by the bleaching of leaves exposed to direct sun under drought conditions. Enzyme activity is reduced under drought which affects starch accumulation since sucrose conversion to starch is reduced because of reduced activity of the enzyme acid invertase.

On the other hand silk growth and kernel number depend directly on the flow of photosynthates during the 3 weeks bracketing flowering (Banziger *et al.,* 2000). When photosynthesis per plant at flowering is reduced by drought, silk growth is delayed, leading to an increase in anthesis silking interval (ASI), kernel and ear abortion (Edmeades, 1999; Banziger, 2002). However once kernels enter the linear phase of biomass accumulation (2-3weeks) after pollination, they develop sink strength needed to attract reserve assimilates stored in the stem and husk and will grow to approximately 30% of weight of kernels of unstressed plants even with increased drought severity (Edmeades *et al.,* 1999).

2.4 Breeding Strategies for Drought Prone Environments

2.4.1 Drought Escape

Breeding may aim at developing cultivars that escape drought by being early in maturity so as to complete their life cycle within a given season length. Season length is defined as the time when rainfall is equal to or exceeds 50% potential evapotranspiration as determined by radiation, wind and temperature. In mid-altitude areas the minimum seasonal rainfall for successful maize cultivation (> 1t/ha) is about 350-400mm (Banziger *et al.,* 2000). Physiological maturity is a highly heritable trait and therefore selection for earliness can easily be achieved. Earliness however has a yield penalty when rainfall is above average since yield will be limited by the amount of radiation the cultivar can capture.

2.4.2 Drought Tolerance

Tropical rains are variable and unpredictable, hence a successful maize variety must be able to withstand some variation in rainfall from season to season. According to Banziger *et al.* (2002), drought tolerant cultivars are characterised by increased production under drought, implying that survival with no grain is of little use, except at the seedling stage. Grain yield and secondary traits are employed in conjunction with each other in screening for drought tolerance (Banziger *et al.*, 2000). Yield is the main trait while secondary traits include ASI, leaf senescence, tassel size, ears per plant and leaf rolling. Selection indices are used in bringing together the different scores from the different traits (yield and secondary traits) and identifying the best materials. Secondary traits are valuable because of the following reasons:

- They can demonstrate the degree to which a crop was stressed by drought.
- If observed before or at flowering, they can be used for selecting desirable crossing parents.(In this instance two blocks are planted, one for selections to be made and the other for crossing parents. The crossing parents block is planted slightly later than the block for selections. The parents to be used in crosses are identified in the selection block and crosses made in the crossing parents block.)
- They improve the precision with which drought tolerant genotypes are identified compared to measuring grain yield only under drought. The precision is lower when using grain yield alone because heritability of grain yield decreases under drought or stress conditions, generally. This is because the error variance is linked to the stress effect itself.

The stress effect makes the plant more sensitive to other environmental factors thereby inflating the error with which the response to the specific stress factor is being measured, more so the high stress levels required for selection purposes. Thus, these high stress levels cause a large increase in the error variance and, at the same time, reduce the heritability of the trait under selection, often to an extent that very little or no advance is made (Geerthsen, 1984). Heritability of suitable secondary traits is less or not affected by stress (Banziger and Lafitte, 1997).

For efficient identification of drought tolerant genotypes, the secondary traits used must fulfill the following criteria:

- Be genetically associated with grain yield under stress.
- Highly heritable.

- Genetically variable.
- Cheap and fast to measure.
- Be stable within the measurement period.
- Not associated with yield penalty under stressed conditions
- Observed at or before flowering so that undesirable parents are not crossed.
- Be a reliable estimator of yield potential before final harvest (Edmeades *et al.*, 1998).

Greater progress has been shown to be made in breeding under drought or N stress using grain yield and secondary traits than from using grain yield alone. The secondary traits, which are recommended for use in a drought-breeding program in their order of decreasing importance, are as follows: grain yield, ears per plant, anthesis–silking interval (ASI), leaf senescence, tassel size and leaf rolling (Banziger *et al.*, 2000).

2.4.3 Selection for High Yield Potential

High yield potential (including heterosis) is a constitutive trait that often gives increased yield under moderate drought condition, that's when drought stress reduces yields by less than 50%. Estimation of spillovers from one environment to another can be done by looking at the genetic correlation for yields of the same cultivar in two environments. Spillover effects can be expected when the genetic correlation (r_G) between yield in stressed and well watered sites is positive and significant. If r_G is weakly positive, zero or negative, selection for yield potential alone does not affect drought tolerance much (Banziger *et al.*, 2000).

2.4.4 Drought Screening

Screening procedure for genetic differences, in drought tolerance include:

- Defining practical objectives of the screening process
- Selection of environments and stress occurrence to be targeted in the program
- The design and operation of field physical facilities and experimental methods to apply a uniform, repeatable drought stress.

Drought tolerance can be approached through:

- Crop yield stability under stress
- Response to stress indicative of tolerance
- Biology underlining the responses
- Genes and alleles governing the presence or expression of the responses.

The ability to yield well in dry environments may be due to drought avoidance, drought tolerance or both mechanisms. Approximately 95% of the maize area in the tropics is dependent on rainfall. This varies considerably from season to season, and maize is most vulnerable to moisture stress that occurs two weeks before and after flowering. During this period drought depresses yield potential by limiting the number of kernels and ears that develop. Moisture stress during flowering lengthens the ASI and reduces the number of silks that are viable for pollen germination to fertilize the embryos. The plant aborts ears and grain, and concentrates its limited energy to assure male flowering and pollen shed, thus increasing the odds of some pollen fertilizing surrounding plants that are not moisture stressed.

2.5 Soil Fertility

Farmers in Sub Saharan Africa use by far the least amount of fertiliser in the world. Removal of subsidies in the 1980s led to a decline in inorganic fertiliser use, especially in the smallholder sector resulting in a yield decline from 1,3t/ha to around 0.7t/ha for most of East and Southern Africa Countries (Jayne *et al*, 2004). The most limiting nutrient in the smallholder sector in the SADC region is nitrogen. This is as a result of continued soil mining through mono-cropping of maize. In addition the majority of the smallholder farmers are found in the semi arid areas of the country where they do crop production in granite derived sandy soils that are inherently low in organic matter and mineral N. Production is worsened by the fact that the majority of the farmers are resource poor and cannot afford loans to buy inputs such as fertilisers.

2.5.1 Nitrogen and The Maize Plant

Nitrogen is a common enzyme component hence neccesary for plant growth and development. Ninety five percent N in the field is not readily available to plants as its bound by soil organic matter (Banziger *et al.*, 2000). Mineral N in the form of NO^-_3 and NH^+_4 ions is increased through mineralization. The mineral N pool is reduced by plant uptake, microbial immobilization, leaching and clay mineral fixation.

Nitrogen deficiency is almost universal in the tropics except on recently cleared land (Paliwal *et al.*, 2000). As a result N required in the crop must be met by addition of organic or inorganic fertilisers. Nitrogen is second only to drought as a constraint in tropical maize production. Weed competition may also result in N deficiency. The N

deficiency symptoms include reduced shoot growth, yellowing and eventual senescence of lower leaves, reduced kernel sink capacity at flowering. In addition N deficiency is associated with reduced levels of cytokinnins and increased ABA in the plant (Paliwal *et al.*, 2000).

2.5.2 Maize Breeding and Crop Response under Low N Stress:

Nitrogen stress affects photosynthesis through reduced leaf area development, and accelerated leaf senescence. Fifty percent of all leaf N is directly involved in photosynthesis either as enzymes or as chlorophyll (Banziger *et al.*, 2002). Nitrogen stress also influences root growth. Plants favour root growth over shoot growth under N stress and the root/shoot ratio increases. However absolute root amount is lower than under normal N development. There is limited information about N stress on reproductive development. However severe N stress delays pollen shed and silking but silking delay is more such that ASI becomes greater.

Breeding strategies for nitrogen stressed environments aim at selecting genotypes under conditions of severe nitrogen stress, especially if the attained yield in the target environment is ideally 25%-35% of the yield obtained under well-fertilized conditions (Banziger *et al.*, 2000). The reason for this is that the correlation between genotype performance under low nitrogen and well-fertilized conditions diminishes with an increase in the severity of nitrogen stress. Thus, there is no relationship between genotype performance under well-fertilized environments and environments severely stressed for nitrogen (Banziger *et al.*, 1997).

The use of secondary traits in low nitrogen stress selections is recommended for the same reasons as those for screening for drought tolerance. The secondary traits recommended are as follows, in their order of decreasing importance: grain yield, ears per plant, leaf senescence and anthesis-silking interval. With grain yield, selection is for high grain weight. Measurement of the grain weight is done on shelled grain adjusted for moisture. The grain weight is then used to calculate grain yield. Selection for ears per plant is aimed at identifying genotypes with no barren plants or genotypes with at least one ear. An ear is defined here as a cob having at least one fully developed grain. Leaf senescence is visually scored on two to three occasions, seven to ten days apart during the latter part of the grain filling period. For anthesis silking interval, selection for this trait is aimed at a reduced or negative value.

2.6 COMBINING ABILITY

The combining ability estimate is a measure of the value of genotypes based on performance of their offsprings, produced in a definite mating system (Allard 1960). It can also be described as a phenomenon where some parents produce superior F1s or progenies from crosses while others do not. These genotypes can be populations, inbreds or varieties. The combining ability enables the prediction of performance, but the genotype performance cannot be predicted for traits that are polygenic. The performance of a hybrid is related to the general (GCA) and specific (SCA) combining abilities of the inbred lines involved in the cross. The concept of GCA and SCA was introduced by Sprague and Tatum (1942) and its mathematical modeling was set about by Griffing

(1956). A combining ability estimate serves as a useful guide in the selection of parents for hybridization programs.

2.6.1 General Combining Ability

The GCA is the mean performance of a line in all its combinations expressed as a deviation from the overall population mean. GCA is associated with additive effects of the genes. The deviation can either be positive or negative and is trait specific. In maize yield, GCA was found to be more important than SCA in unselected populations, whereas SCA was found to be more important for previously selected lines. The GCA test is used in the early screening of segregating populations in a breeding program. In the process lines with poor GCA are discarded. GCA is also used to identify types of gene interactions governing traits of interest. A high GCA indicates additive gene action. Plant breeders have used measures of GCA and SCA effects to establish heterotic patterns among populations and pools.

2.6.2 Specific Combining Ability

Specific combining is the deviation of a particular cross performance from that predicted on the GCA basis. SCA is related to dominance and epistatic effects (non-additive effects) of the genes. It indicates the value of inbred combinations and helps in the identification of specific inbred line performances. A high SCA indicates a non additive gene action. In addition SCA estimates can be used to determine heterotic relations among different genotypes. However it should be noted that yield only is used to determine heterotic relations among the different genotypes.

According to Hallauer and Miranda (1988), SCA & GCA estimates are relative to and dependent on a particular set of materials (inbreds or populations) used in the hybrids under evaluation, hence any new germplasm introduced in a breeding program has to be tested for GCA and SCA. The value of any population depends on its potential per se and its combining ability in crosses (Malik *et al.,* 2004). Two factors are considered important for the evaluation of an inbred line in the production of hybrid maize namely, characteristics of the line itself and behaviour of the line in a particular hybrid combination. The superiority of a line on the basis of combining ability estimates can only be decided precisely after knowing the purpose of a certain breeding program output, whether to develop

1. Open Pollinated Varieties, where a line with higher GCA effects can be used in synthetic development.
2. Hybrids, where specific combinations are desired hence SCA effects would help in selection of parental material for hybridization.

However, Rojas & Sprague (1952) verified that the variance of SCA also contains deviations due to the interaction between genotypes and environments, in addition to those that come from dominance and epistasis. Increasing the number of environments reduces the contribution of both the pooled error and the additive by environment interaction to the phenotypic variance, whereas replications only reduce the pooled error contribution (Eberhart *et al.,* 1995). Hallauer and Miranda Filho (1988) pointed out that external environmental factors such as weather, soil, pests and diseases probably have a greater effect on single crosses than other types of hybrids. This was supported by Troyer

(1996) who stated that single crosses usually interact with the environment more than double cross hybrids.

2.7 Heritability & Heterosis

Heritability is a ratio that describes the amount of phenotypic variation that can be attributed to the differences in the additive genetic merit of individuals in a population (Singh 2003). Additive genetic action exists, if individuals have different alleles at loci that contribute to measurable differences in performance. Two types of heritability can be estimated namely

- Broad sense heritability; It is a ratio of total genetic variance to the phenotypic variance. The total genetic variance is made up of additive, dominance and epistatic variances, where dominance is the intralocus value while epistasis is the inter loci value.
- Narrow sense heritability; is the ratio of additive genetic variance to total phenotypic variance.

It should however be emphasized that heritability being an estimate is specific to the population and environment one is analyzing. This estimate is also a population and not an individual parameter. In addition heritability does not indicate the degree to which a trait is genetic, but measures the proportion of the phenotypic variance that is the result of genetic factors. On the other hand realized heritability is an estimate of what the heritability needs to be, for one to observe the rate of divergence given the selection practiced. This estimate is used by breeders to decide the efficacy of selection, especially phenotypic selection. Direct phenotypic selection for traits with low heritability is not

promising. Use of phenotypes from relatives and selection indices can be employed to determine more accurately the underlying genetic merit.

Plant breeding has been responsible for the development of new varieties with superior traits such as better disease and insect resistance, drought and low soil fertility tolerance. Exploitation of heterosis is one of the reasons for this success (Singh, 2003). Heterosis has been considered as superior hybrid compared to the parents and is dependent on heterozygosity and dominance (Hallauer and Miranda, 1988). Heterosis is also known as hybrid vigour. It is the phenomenon in which the progeny of crosses between inbred lines or purebred populations are better than the expected average of the two populations or lines for that particular trait. Thus heterosis is the complement of inbreeding depression and usually appears in traits that show depression of performance under inbreeding.

Heterosis is usually small or absent in traits that are influenced by additive genetic effects. In its most basic form, additive gene action is the summation of many genes 'adding up' together to bring about a total result. Heterosis is then one of several genetic effects that are part of the non additive genetic effects. The magnitude of additive gene effects then becomes important in how heritable a trait is. On the other hand, heritability in the broad sense is simply what proportion of differences in a trait are due to genetic differences rather than the environment differences. In the narrow sense heritability is the proportion of differences from additive genetic effects versus overall phenotypic variations, or how a trait actually looks. Therefore non additive effects like heterosis will express themselves in traits that are lowly heritable (www.cau.edu.cn).

The benefits of crossbreeding include heterosis and genotype complimentarity which is the optimum combination of genotype to use strengths of genotype and hide their weaknesses. (www.cau.edu.cn). The effective use of heterosis involves the development of populations or parental lines with high combining ability (Griffing 1956, Vasal *et al.,* 1992). In maize, inbreds are low yielding but their hybrids exhibit a high degree of heterosis for yield as well as other traits such as plant height, flowering and maturity (Duvick, 1999). However, high yielding hybrids owe their yield not only to heterosis but also to other heritable factors that are not necessarily influenced by heterosis. Hybrids are continuously improved in yield limiting traits such as disease and insect resistance, low soil fertility, standability, drought tolerance and many other traits.

2.7.1 Heterotic groups

A heterotic group contains genotypes, which show similar heterosis because of similar allelic frequencies. Genotypes in a group will usually show no or very little heterosis when crossed to each other because they are generally closely related. There are exceptions to this rule because high heterosis from germplasm derived from within a heterotic group has been observed in some experiments (Vasal *et al.*, 1999). Heterotic groups thus generally represent broad sources of germplasm, which exhibit optimum heterosis when crosses are made between the groups.

The distinction between heterotic groups is not absolute, because a heterotic group can be made from germplasm of different heterotic groups. Heterotic groups are said to be open-ended since more materials of tested affinities can be added to them. These new materials

could be introducing traits of interest like disease resistance or any other trait. As new challenges in the production of maize emerge, new heterotic groups will be identified and developed to give suitable genotypes and old groups might be included or done away with altogether. Heterotic patterns developed in one region can be moved to a different region and used as they are, if they are adaptable. Where they are not adaptable, they are crossed to native materials to adapt (Hallauer *et al.*, 1988).

2.8 TESTERS

In inbred line evaluation a good tester is one that correctly classifies relative performance of lines and discriminates efficiently among lines under test (Rawlings and Thompson, 1962). According to Vasal *et al.* (1997), a desirable tester must facilitate discrimination among genotypes for combining ability and desirable traits, simultaneously identify useful hybrid products for direct use and be compatible with a practical breeding program. Hallauer, (1975) states that a suitable tester should include simplicity in use, provide information that correctly classifies the relative merit of lines and maximize genetic gain. In terms of practicality there is need to use the same testers for evaluating combining ability under drought or low N stressed conditions, as they are used for evaluating combining ability under well watered and well fertilised conditions.

The use of testcrosses in maize breeding has the following objectives:

1. Evaluation of combining ability of inbreds in a hybrid breeding program.
2. Evaluation of breeding values of genotypes for population improvement.

In each instance a problem of choice of tester is essentially the same, and is that of finding a tester that provides the best discrimination among genotypes according to the

purpose of selection. In general a tester should be poor in the traits for which the lines are analysed. Moreover the testers should be highly adapted to environmental variability. In selection for GCA, a broad based heterogenous population is used as a tester. In this case the tester can either be the parental population or any broad genetic base synthetic or OPV, or an unrelated population. In all instances genotypes are tested with a representative sample of genotypes in the tester. When a tester has narrow genetic base (inbred or single cross) selection among testcrosses is for SCA.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Germplasm and Testcross Development

Twenty four elite inbred lines from AREX and CIMMYT were crossed in winter 2005 at Gwebi VTC (Table 3.1). The Design II method (Line x Tester) was used in the crossing program to give a total of 144 crosses, with reciprocal crosses being bulked. Four of the inbred lines were removed from the evaluation and analysis due to seed shortage at planting. As a result inbred lines N3.2.3.3 & SC5522 (national) and CML312 & CML395 (CIMMYT) were used in the design as standards for the heterotic group classifications. The removal of CML206, CML312, FR17 and RA150P led to the evaluation of 100 testcrosses. These testcrosses were then evaluated under two stress and two non stress environments.

Table 3-1: Pedigree, Heterotic Groups and Maturity of Parental Materials Used In Testcross Development

Inbred	Pedigree	Source	Heterotic Group	Maturity
1	N.3.2.3.3	AREX	N	Late
2	SC5522	AREX	SC	Late
3	2Kba	AREX	SC	Early
4	K64r	AREX	SC	Early
5	NAW5885	AREX	N	Intermediate
6	SV1P	AREX	SC	Early
7	WCOBY1P	AREX	SC	Intermediate
8	2N3d	AREX	N	Late
9	RS61P	AREX	SC	Intermediate
10	RA214P	AREX	N	Late
11	CML395	CIMMYT	B	Late
12	CML442	CIMMYT	A	Intermediate
13	CML444	CIMMYT	B	Late
14	CML202	CIMMYT	B	Late
15	CML445	CIMMYT	B	Late
16	ZM621-A-BBBB	CIMMYT	A	Intermediate
17	CML505	CIMMYT	A	Early
18	CML504	CIMMYT	A	Early
19	CML508	CIMMYT	A	Early
20	CML509	CIMMYT	A	Early

N and SC: National heterotic groups from inbred lines N.3.2.3.3. and SC5522

A and B: CIMMYT heterotic groups that correspond to N & SC respectively

3.2 EVALUATION SITES

The sites used were Harare Research Station (Harare; 17.48 S, 31.04 E, 1506 masl), Gwebi Variety Testing Centre (Harare; 17.13^{0}S, 31^{0}E, 1406masl) and Save Valley Experiment Station (Middle Sabi; 20^{0}S, 33^{0}E, 455masl). The soil types (FAO classification) and rainfall data for the sites are as follows: Harare Research Station and Gwebi VTC have Rhodustalf greater group soils with an ICG texture code. The soils are medium grained sandy clays (35-55% clay content). Gwebi VTC has an average annual rainfall of 920mm/annum while Harare has an average of 880mm/annum. Save Valley Experiment Station soils are of the Sandy soil type and the site has an annual average rainfall of 425mm/annum.

3.2.1 Simulation of Drought Stress

In the study water stress implied drought. As a result the Save Valley site, drought was managed through irrigation at critical times only. A total of 280 mm irrigation was applied in the first 8weeks of crop's growth. This resulted in drought coinciding with flowering and grain filling. The stress level projected to be achieved in this trial was a yield of about 15% to 20% of yields achieved under well-watered conditions. This stress level delays silking and causes ear abortion in non-stress tolerant genotypes.

3.2.2 Simulation of Nitrogen Stress

The Harare low N site has been depleted of mineral nitrogen by continuously growing maize and irrigated wheat for six years. No nitrogen was applied at this site and N supply to the crop was dependent on soil mineralization. The low N block soil analysis results showed 4ppm N in the top 30cm which translates to approximately 30kg N per hectare

which is about 25% of the required N under optimum conditions. Available P_2O_5 was 57ppm which is ideal (>50ppm) for optimum plant growth hence no phosphorus (P) was added. Exchangeable cations me/100g were 0.24 for potassium (K), 8.74 for calcium (Ca) and 4.99 for magnesium (Mg). All were above the threshold for optimum plant growth in a reddish brown clay soil but a maintenance dressing of 20kg/haKSO_4 was applied.

3.3 TRIALS HUSBANDRY

The 100 single cross hybrids were planted in four trials across three locations. The trial set was planted under optimum conditions at Harare and Gwebi VTC. Low soil N stress tolerance evaluation was also done at Harare in N depleted red clay soil. Mid season drought stress evaluation was done off season, during winter at Save Valley. The testcross evaluation was done using the Alpha (0,1) lattice design. Trials were replicated three times, with each entry being planted in one row plots 4m long, while a 90cm between rows x 30cm between plants within rows was used. Two seeds per station were planted and later thinned to give a plant population of 48 000 plants/ha.

Basal fertilizer was broadcast by hand and disced into the soil before planting. The rates differed with sites. Harare and Gwebi VTC optimum trial sites received 400kg/ha maize fertilizer (N-8, P-16, K- 8); The Harare's low nitrogen site received no phosphorus and 30kg/ha Muriate of Potash only as per the soil analysis results, while at Save Valley , 400kg/ha maize fertilizer was applied. Top dressing rates were the same for all sites except in the low N trial where no N fertiliser was applied. Split applications of 350kg/ha

ammonium nitrate were done; the first at four weeks after crop emergence and the second at eight weeks after crop emergence.

Furadan at 20kg/ha and regeant, to control soil pests were applied into the planting holes before the seed during planting. The pests targeted were ants, termites and other soil pests. This is particularly important because seed-dressing chemicals were not applied onto the seed. Two seeds were planted per hole and later thinned to one per station. Thinning was carried out at between 3 – 4 weeks after plants emerged, for a target plant population of 48 000 plants/ha. Irrigation was applied to field capacity soon after planting to aid crop germination. Where a soil crust formed before the crop emerged, another light irrigation was applied to soften and assist plant emergence.

After crop emergence, the major pest of interest was stalk borer (*Buseola fusca*). Two applications of Dipterex 2.5% granules into the funnel of each plant were done at 3 and 6 weeks after crop emergence at all sites except Save Valley. The rate of application used was 4kg/ha. A full cover spray of Carbaryl 85% wettable powder was done weekly at Save Valley from 4 weeks after crop emergence due to pest pressure. Confidor was also used for the control of termites at Save Valley.

3. 4 DATA COLLECTION AND ANALYSIS

Raw data for flowering dates (at 50% anthesis and 50% silking), plant and ear height, plant standability, leaf senescence, disease scores, field and grain weight were recorded. Some derived traits such anthesis-silking interval (ASI), lodging percentage, ear per plant (EPP) and yield per hectare (at 12.5% moisture adjustment) were also calculated.

Table 3-2: Table showing measured and derived traits

Trait	Procedure
Anthesis date (AD)/Silking Date (SD)	Taken as number of days after planting to when 50 percent of plants start shedding pollen or had extruded silks.
Anthesis- silking interval (ASI)	Derived from anthesis date and silking date as follows: ASI= SD - AD
Ears per plant (EPP)	It is calculated as a ratio of the number of ears with at least one fully developed grain divided by the number of harvested plants.
Plant height (PH)	Measured as the height between the base of a plant and the insertion of the first tassel branch.
Ear height (EH)	Measured as the height between the base of a plant to the insertion of the top ear.
Ear position (EPO)	Calculated as EH divided by PH.
Root lodging (RL)	Measured as a percentage of plants that showed lodging by being inclined 45^0
Stem lodging	Measured as a percentage of plants that were broken below the ear.
Leaf senescence	Number is leaves that are yellow below the ear as a percentage
Disease Score	Taken using a 1-5 score with 1 being resistant and 5 being susceptible
Field Weight	It was calculated from unshelled cobs weight per plot, adjusted to 12.5% grain moisture.
Grain yield (GY)	It was calculated from shelled grain weight per plot adjusted to 12.5% grain moisture.

Individual sites analysis of variance (ANOVA) was done before a combined analysis using the North Carolina Design II method. The main criterion used for the choice and grouping of the materials was the performance of the testcrosses made between the known heterotic groups. The performance measurements of the testcrosses were based on the values of General Combining Ability (GCA) and Specific combining Ability (SCA) effects.

Table 3-3: Form of ANOVA for Design II

Source	Df	Mean Squares
Males	m-1	$\sigma^2_e+r\sigma^2_{fm}+rf\sigma^2_m$
Females	f-1	$\sigma^2_e+r\sigma^2_{fm}+rm\sigma^2_f$
Males*females	(m-1)(f-1)	$\sigma^2_e+r\sigma^2_{fm}$
Error	(r-1)(mf-1)	σ^2_e
Total	rmf-1	

Analysis of variance was conducted for all the measured traits on individual plot data for each environment and then combined across environments. The Gardner-Eberhart (1966) model for combining ability analysis was used.

$X_{ikj}= u+g_i+s_{ij}+e_{ijk}$

Where: X_{ijk}= performance of the cross between the i^{th} and the j^{th} genotypes in the k^{th} replication,

u= overall mean,

g_i= GCA effects for the i^{th} and j^{th} parents respectively,

s_{ij}= the SCA effect for the cross between the i^{th} and j^{th} genotypes,

e_{ijk}= error effect associated with the ijk^{th} observation.

Across site analysis was done using SAS (SAS Institute, 2001) and this enabled the performance of the crosses to be assessed under stress and non-stress conditions.

In the calculation of heritability and assigning inbred lines to heterotic groups, positive SCA effects between inbred lines generally indicates that inbred lines are in opposite heterotic groups while inbred lines in the same heterotic group tend to exhibit negative SCA effects when crossed together (Vasal *et al.*,1992). The GCA of lines is the average value of a line estimated on the basis of its performance in hybrid combination with other lines. It is mainly due to additive gene effects and higher order interaction. On the other hand SCA is the performance of a certain hybrid relative to expectation of the average performance of the parent inbred lines included (Sprague and Tatum, 1942). Positive SCA effects between inbred lines generally indicates that lines are in the opposite heterotic group while negative effects show that lines are in the same heterotic group.

3.5 NORTH CAROLINA II MATING DESIGN

The design was developed by Comstock and Robinson in 1948. This mating design is used for the purpose of obtaining genetic information from experimental populations. In developing the experimental progenies different sets of parents are used as males and females. Equal numbers of males and females are randomly selected from the F2 population and each male (m) is crossed with each female (f). The total number of crosses will be an (m x f) product. In this design both maternal and paternal half sibs are produced. The design is cross classified in terms of analysis. In this design the genetic expectations for males and females are equivalent to general combining ability (GCA), while the male x female interaction is equal to specific combining ability (SCA).This design separates the variance of progenies into three fractions, namely, variance due to

males, variance due to females and variance due to the male and female interaction. Appropriate F tests can thereafter be made to test for the differences among males, females and for interaction.

Although Design II has not been used extensively in maize compared to the diallel, Hallauer and Miranda (1988) found some merits of this design over the diallel designs which include:

- more parents can be included for a given level of resources
- two independent estimates of additive genetic variance are available
- an estimate of dominance variance is determined directly from the mean square
- a greater number of parents can be included by subdividing parents into sets

CHAPTER 4

4.0. RESULTS

All the trials under discussion were conducted in Zimbabwe. The 2005/06 season in which the evaluation of the testcrosses was conducted was characterized by a wet spell, with even rainfall distribution. Harare Research station and Gwebi VTC sites received 928 mm and 1024 mm of rainfall respectively. However Harare Research station had a dry spell towards the end of February and early March such that 30mm of irrigation water were was applied for both the optimum and low N stress trials. The mean monthly temperatures at these sites were 25.4 and 24.8 ^{0}C respectively. The moisture stress trial at Save Valley was planted in winter 2006 and irrigated for the first 8 weeks with a total of 280 mm having been applied at critical growth stages only. The site had an average temperature of 29.7^{0}C during the period of evaluation.

4.1 Analyses of Variance (ANOVA)

Individual sites analysis of important traits such as grain yield, secondary traits of anthesis date, anthesis silking interval and ears per plant were reported. Combined analyses of variance across the stress and non stress environments for all measured traits were done and the study mainly focused on identification of genotypes that perform across diverse environment (general adaptation). Two parents on either sets of lines and testers were dropped due to seed shortage as a result of poor synchronization. This discussion report is therefore based on the 10 x 10 line and tester analysis.

4.2 INDIVIDUAL SITES ANALYSES

4.2.1 Optimum Conditions

Table 4-1 below shows the analysis of variance for grain yield (GY) under optimum conditions, with significant differences (P<0.001) being observed for testcrosses, lines, tester and line x tester interactions.

Table 4- 1 ANOVA for Grain Yield under Optimum Conditions

Source	DF	SS	MS	F	P
Testcross	99	418.33	4.23	3.11	***
Line	9	73.79	8.20	5.91	***
Tester	9	150.26	16.70	12.04	***
Line *Tester	81	188.63	2.33	1.68	***
Error	199	275.87	1.39		
CV %	14.3				

4.2.1.1 SCA Effects of Grain Yield under Optimum Conditions

Optimum trial results in Table 4-2 show that there were significant differences for testcrosses and line x tester interactions (p<0.05) with the best three SCA effects being obtained in genotypes LT27 (13.2t/ha), LT16 (13.03t/ha) and LT93 (11.84t/ha). The lowest yielding testcross was LT81 (5.59t/ha). Line and tester means were also calculated with the highest mean yield being for L10, (9.6t/ha) and the best mean for testers being for T6 (9.94t/ha) with the site mean yield being 9.23t/ha. The average GY among testcrosses due to testers ranged from 8.00 to 9.94t/ha while that due to lines ranged from 8.73 to 9.60t/ha. Most testers conferred higher grain yield in the testecrosses than the mean of the trial except T1, T2 and T8. The average line GY also shows that most lines conferred higher yield than the mean of the trial except L3, L4, L7 and L8.

Table 4-2. Mean Yield (t/ha) under Optimum Conditions

	TESTER										
LINE	1	2	3	4	5	6	7	8	9	10	MEAN
1	8.45	9.18	8.61	10.01	10.49	13.03	7.82	10.12	9.37	8.85	9.59
2	6.25	10.99	8.70	10.41	6.88	10.97	13.20	9.00	8.85	9.25	9.45
3	7.43	8.39	9.47	10.24	11.48	8.39	9.48	8.72	8.42	8.37	9.04
4	8.05	7.59	8.65	7.93	9.56	9.07	10.00	9.60	11.11	8.24	8.98
5	9.60	10.35	8.92	9.74	10.68	9.84	7.83	9.00	8.11	10.71	9.48
6	6.52	6.88	11.24	9.57	7.79	9.19	9.34	11.49	10.42	10.30	9.27
7	8.00	8.42	9.61	8.03	11.43	8.91	9.81	6.25	9.00	7.82	8.73
8	5.59	10.53	8.66	8.35	8.34	9.91	11.87	7.21	9.21	10.19	8.99
9	10.42	7.58	11.84	9.74	9.92	9.22	7.78	7.73	7.87	10.18	9.23
10	9.73	7.79	11.24	9.14	9.22	10.91	10.18	7.40	8.63	11.74	9.60
MEAN	8.00	8.77	9.69	9.32	9.58	9.94	9.73	8.65	9.10	9.57	9.23
LSD0.05	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57

4.2.1.2 Secondary Traits

Table 4-3 shows the analysis of variance for secondary traits that are also used to aid in testcross selection under diverse environments. The results show that there were differences observed for testcrosses, lines, testers, line x tester interactions for AD and ASI. However for EPP there were no significant differences observed for testcross and line x tester interactions.

Table 4-3 ANOVA for AD, ASI and EPP under Optimum Conditions

Source	AD				ASI			EPP		
	DF	MS	F	P	MS	F	P	MS	F	P
Testcross	99	42.51	7.13	***	12.09	2.19	***	0.01	2.19	ns
Line	9	8.20	5.91	***	263.30	44	***	291.17	4.72	***
Tester	9	16.70	12.04	***	127.97	21.39	***	188.27	3.05	***
Line*Tester	81	2.33	1.68	***	8.42	1.41	**	59.00	0.96	ns
Error	199	1.39			5.98			61.64		
CV %			13.6			2.8			32.7	

4.2.2 Low Soil N conditions

Grain yield under low N conditions had significant differences for testcrosses, lines, testers and line x tester interactions as shown in Table 4-4.

Table 4- 4 ANOVA for GY Under Low N Conditions

Source	DF	SS	MS	F	P
Testcross	99	192.73	1.95	2.23	***
Line	9	49.13	5.46	6.18	***
Tester	9	46.28	5.14	5.82	***
Line*Tester	81	95.67	1.18	1.34	*
Error	200	176.59	0.88		
CV %	35				

4.2.2.1 SCA Effects of Grain Yield under Low Soil N Conditions

Under the low soil N environment (Table 4-5) there were significant differences ($P<0.05$) observed for the SCA effects with the most stress tolerant testcross being the LT93 combination (4.72t/ha) while the least yielding testcross was the LT31 (0. 96t/ha). The average GY among testcrosses due to lines ranged from 3.17 t/ha (L9) to 1.95t/ha (L6). The average GY among testcrosses due to testers ranged from 3.38t/ha (T4) to 2.23t/ha (T9). Six of the lines had conferred higher yield to the testcrosses than the mean of the trial (2.67t/ha) while only four testers conferred higher yield than the mean of the trial to their testcrosses. The mean yield of the trial was 2.67t/ha, which was 28% of the mean yield (9.23t/ha) under optimum conditions.

Table 4-5. Mean Yield (t/ha) Under Low N Conditions

LINE	TESTER										MEAN
	1	2	3	4	5	6	7	8	9	10	
1	1.36	4.34	2.32	3.53	3.97	1.95	2.56	1.67	1.93	2.51	2.62
2	3.09	2.25	4.01	4.13	3.50	1.44	3.63	1.72	2.52	1.91	2.82
3	0.96	2.02	2.07	3.48	1.87	2.29	2.27	2.88	1.43	2.33	2.16
4	2.22	2.47	3.68	2.71	1.83	1.88	1.17	2.39	1.90	2.16	2.24
5	3.20	3.00	2.67	3.59	3.77	3.27	3.01	2.72	3.21	2.13	3.06
6	1.81	2.78	2.92	1.86	2.07	1.55	1.52	1.94	1.72	1.32	1.95
7	2.67	4.09	3.77	4.62	2.26	2.49	2.75	3.42	1.96	3.03	3.11
8	2.97	2.86	2.78	3.40	3.28	2.38	3.03	1.42	1.78	2.91	2.68
9	3.21	3.79	4.72	2.65	3.00	3.51	2.13	2.96	2.88	2.84	3.17
10	2.97	2.97	2.95	3.85	3.10	2.99	2.04	2.41	2.94	2.29	2.85
MEAN	2.45	3.06	3.19	3.38	2.87	2.38	2.41	2.35	2.23	2.34	2.67
LSD0.05	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86

4.2.2.2 Secondary Traits

The secondary traits measured under low N showed significant differences ($p<0.05$) for AD and ASI, for testcrosses, lines, testers and line x tester while for EPP there were no differences observed for testcrosses, testers and line x tester (Table 4-6).

Table 4-6. ANOVA for AD, ASI and EPP Under Low N Conditions

Source	AD				ASI			EPP		
	DF	MS	F	P	MS	F	P	MS	F	P
Testcross	99	54.26	15.04	***	9.44	2.89	***	111.56	1.16	ns
Line	9	7.34	5.13	***	346.55	94.54	***	279.67	2.87	***
Tester	9	8.65	6.05	***	143.51	39.15	***	69.28	0.71	ns
Line*Tester	81	1.94	1.36	*	11.72	3.2	***	95.09	0.98	ns
Error	200	1.43			3.67			97.37		
CV %			43.7			2.6			32.1	

4.2.3 Drought Conditions

Table 4-7 shows the analysis of variance for grain yield under drought conditions. These results show that there were no significant differences for tester and line x tester interaction, with significant differences being observed for testcrosses and lines.

Table 4-7 ANOVA for Grain Yield under Drought Conditions

Source	DF	SS	MS	F	P
Testcross	99	114.85	1.16	1.19	*
Line	9	20.95	2.33	2.31	*
Tester	9	7.00	0.78	0.77	ns
Line*Tester	81	82.88	1.02	1.02	ns
Error	148	148.81	1.01		
CV %	22.8				

4.2.3.1 SCA Effects Of Grain Yield under Drought Conditions

The moisture stress (drought) results in Table 4-8 recorded significant differences ($P<0.05$) among testcrosses for yield. The average grain yield among testcrosses due to lines ranged from 1.63t/ha (L2) to 2.67t/ha (L9). The average grain yield among testcrosses due testers ranged from 2.02t/ha (T3) to 2.61t/ha. The mean yield of the trial was 2.32t/ha which translated to 25% of the mean yield under optimum conditions. In this trial the best yielding testcross hybrid was the LT54 combination (4.03t/ha), with the least tolerant testcross hybrid being the LT27 (0.85t/ha). The LT27 testcross hybrid was the best yielding entry under optimum conditions, which indicates that the hybrid can only perform under optimum conditions.

Table 4-8. Mean Grain Yield (t/ha) under Drought Conditions

	TESTER										
LINE	1	2	3	4	5	6	7	8	9	10	MEAN
1	1.85	2.30	3.13	2.81	2.74	2.56	3.85	2.20	1.98	2.49	2.59
2	1.47	2.35	0.96	1.18	1.61	2.05	0.85	1.90	2.55	1.39	1.63
3	2.95	1.45	1.18	3.29	2.58	2.03	2.97	2.53	1.90	1.60	2.25
4	2.14	2.64	2.68	1.74	2.63	3.41	2.04	3.96	2.40	2.15	2.58
5	1.43	3.84	1.75	4.03	2.25	2.67	2.51	2.44	2.41	2.55	2.59
6	1.41	2.48	1.63	1.74	3.34	2.04	1.95	1.97	3.06	2.80	2.24
7	2.95	1.09	2.65	2.33	2.00	2.54	2.55	2.07	2.14	1.94	2.22
8	2.17	2.11	2.60	1.94	1.96	1.82	1.70	2.57	1.17	2.67	2.07
9	3.34	2.95	2.07	3.26	1.84	3.54	2.76	2.42	2.58	1.90	2.67
10	2.25	2.37	1.57	2.78	3.56	3.47	1.06	2.22	1.85	2.04	2.32
MEAN	2.20	2.36	2.02	2.51	2.45	2.61	2.22	2.43	2.20	2.15	2.32
LSD 0.05	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98

4.2.3.2 Secondary Traits

Testcross hybrids were significantly different for AD and ASI only with lines being different for all the three traits. Testers were however significantly different for ASI and EPP while the line x tester interactions were not different for all traits (Table 4-9).

Table 4-9 ANOVA for AD, ASI and EPP under Drought Conditions

Source	AD				ASI			EPP		
	DF	MS	F	P	MS	F	P	MS	F	P
Testcross	99	46.7	5.31	***	10.77	2.42	***	0.05	1.03	ns
Line	9	2.30	2.33	*	239.36	26.22	***	282.51	2.32	*
Tester	9	1.07	1.09	ns	158.80	17.4	***	541.94	4.45	***
Line*Tester	81	1.03	1.05	ns	12.00	1.31	ns	113.86	0.94	ns
Error	200	0.99			9.13			121.72		
CV %			22.3			3.8			35.7	

4.3 Testcrosses Performance In Stress Environments

Thirteen testcross hybrids were observed to have good yields across all environments with LT26 and LT52 being the best performing testcrosses. An additional fourteen testcrosses were recorded as having good yield performance under stress (low N and drought) environments with testcrosses LT48, LT810 and LT96 being among the best stress tolerant testcrosses (Table 4-10).

Table 4-10: Across & Individual Sites SCA Yield of Line x Tester

ENTRY	LINE	TESTER	OPTIMUM		LOW N		DROUGHT		ACROSS	
			SCA	SCA Rank	SCA	SCA Rank	SCA	SCA Rank	SCA	SCA Rank
1	1	1	-0.01	53	-1.03	97	-0.69	88	-0.80	96
2	1	2	0.11	47	1.34	1	-0.33	68	0.08	38
3	1	3	-1.34	86	-0.82	92	0.83	11	-0.57	87
4	1	4	0.23	39	0.20	41	-0.04	47	0.14	31
5	1	5	0.53	33	1.16	2	0.06	40	0.32	21
6	1	6	2.70	3	-0.37	74	-0.30	64	0.69	8
7	1	7	-2.24	98	0.21	40	1.15	4	-0.14	59
8	1	8	1.04	21	-0.63	85	-0.55	84	0.06	40
9	1	9	-0.11	55	-0.27	69	-0.53	81	0.10	34
10	1	10	-1.07	80	0.22	39	0.06	41	-0.03	48
11	2	1	-2.07	96	0.49	19	-0.12	54	-0.22	68
12	2	2	2.06	10	-0.96	95	0.66	19	0.11	33
13	2	3	-1.10	82	0.67	8	-0.39	74	-0.07	54
14	2	4	0.78	27	0.60	13	-0.73	90	0.77	6
15	2	5	-2.94	100	0.48	22	-0.13	55	-1.01	99
16	2	6	0.79	26	-1.08	99	0.13	33	-0.33	79
17	2	7	3.29	1	1.06	3	-0.91	96	1.80	1
18	2	8	0.06	50	-0.79	89	0.10	35	-0.60	89
19	2	9	-0.49	61	0.11	48	0.99	7	0.10	35
20	2	10	-0.54	64	-0.59	82	-0.10	51	-0.31	78
21	3	1	-0.45	59	-0.98	96	0.70	18	-0.17	65
22	3	2	-0.10	54	-0.53	80	-0.89	95	-0.58	88
23	3	3	0.11	45	-0.61	84	-0.83	93	-0.34	81
24	3	4	1.05	20	0.61	12	0.72	17	0.50	17
25	3	5	2.10	9	-0.48	78	0.19	30	0.55	14
26	3	6	-1.35	88	0.43	28	-0.54	82	-0.40	83
27	3	7	0.01	52	0.36	30	0.55	22	0.63	12
28	3	8	0.23	40	1.03	4	0.07	39	0.03	42
29	3	9	-0.47	60	-0.32	71	-0.32	67	-0.26	71
30	3	10	-0.97	76	0.49	20	-0.55	83	-0.07	53
31	4	1	0.19	42	0.20	42	-0.31	66	0.20	28
32	4	2	-0.88	73	-0.16	61	0.10	34	-0.52	85
33	4	3	-0.70	68	0.92	6	0.46	23	0.19	29
34	4	4	-1.25	85	-0.25	67	-1.03	97	-0.57	86
35	4	5	0.20	41	-0.61	83	0.03	43	-0.06	51
36	4	6	-0.66	67	-0.06	56	0.63	21	0.03	41
37	4	7	0.54	32	-0.82	91	-0.58	87	-0.63	91
38	4	8	1.12	19	0.46	24	1.29	1	0.81	5
39	4	9	2.23	8	0.07	50	-0.03	45	0.77	7

40	4	10	-1.09	81	0.24	37	-0.20	57	-0.27	72
41	5	1	1.31	17	0.33	32	-1.13	99	1.15	4
42	5	2	1.45	16	-0.48	77	1.19	2	-0.62	90
43	5	3	-0.86	72	-0.95	94	-0.57	86	-0.16	63
44	5	4	0.12	44	-0.21	65	1.15	3	0.38	20
45	5	5	0.88	23	0.48	21	-0.46	79	0.07	39
46	5	6	-0.32	56	0.47	23	-0.22	58	-0.29	74
47	5	7	-2.06	95	0.17	44	-0.22	59	-0.22	67
48	5	8	0.08	49	-0.06	55	-0.33	70	-0.14	60
49	5	9	-1.21	84	0.52	16	-0.12	53	-0.03	49
50	5	10	0.95	22	-0.64	86	0.09	37	-0.27	73
51	6	1	-1.64	91	0.08	49	-0.73	91	-0.99	98
52	6	2	-1.88	94	0.44	26	0.26	28	-0.29	75
53	6	3	1.60	13	0.45	25	-0.27	63	0.13	32
54	6	4	0.10	48	-0.80	90	-0.72	89	-0.14	58
55	6	5	-1.86	93	-0.08	57	1.05	6	-0.06	52
56	6	6	-0.83	71	-0.11	59	-0.42	76	-0.33	80
57	6	7	-0.41	57	-0.17	62	-0.36	71	-0.64	92
58	6	8	2.71	2	0.31	33	-0.38	73	1.37	3
59	6	9	1.25	18	0.18	43	0.95	8	0.51	16
60	6	10	0.68	29	-0.31	70	0.76	16	0.45	19
61	7	1	0.30	37	-0.21	64	0.87	10	0.54	15
62	7	2	0.11	46	0.60	14	-1.07	98	-0.12	56
63	7	3	0.43	35	0.14	45	0.81	13	0.57	13
64	7	4	-0.99	77	0.80	7	-0.07	49	-0.17	64
65	7	5	2.23	7	-1.04	98	-0.23	61	0.27	23
66	7	6	-0.65	66	-0.32	72	0.14	31	-0.09	55
67	7	7	0.52	34	-0.10	58	0.31	26	0.00	45
68	7	8	-2.08	97	0.63	10	-0.23	60	-0.67	93
69	7	9	0.28	38	-0.73	87	0.09	36	-0.22	66
70	7	10	-1.35	87	0.24	36	-0.04	46	-0.15	61
71	8	1	-2.41	99	0.51	17	0.23	29	-0.71	95
72	8	2	1.92	12	-0.21	63	0.08	38	1.46	2
73	8	3	-0.83	70	-0.42	75	0.90	9	0.09	36
74	8	4	-0.96	75	0.01	52	-0.31	65	-1.09	100
75	8	5	-1.16	83	0.40	29	-0.12	52	-0.23	69
76	8	6	0.05	51	-0.01	53	-0.44	77	-0.26	70
77	8	7	2.28	6	0.61	11	-0.41	75	0.22	27
78	8	8	-1.41	89	-0.94	93	0.41	24	-0.13	57
79	8	9	0.19	43	-0.49	79	-0.74	92	-0.31	77
80	8	10	0.73	28	0.54	15	0.83	12	0.63	11
81	9	1	2.54	4	0.26	35	0.77	15	0.66	10
82	9	2	-0.91	74	0.23	38	0.29	27	0.19	30
83	9	3	2.48	5	1.03	5	-0.25	62	0.27	25
84	9	4	0.54	30	-1.24	100	0.38	25	0.08	37
85	9	5	0.54	31	-0.36	73	-0.87	94	-0.15	62
86	9	6	-0.53	63	0.63	9	0.65	20	0.27	24
87	9	7	-1.69	92	-0.78	88	0.03	44	-0.70	94
88	9	8	-0.77	69	0.11	47	-0.36	72	0.25	26
89	9	9	-1.02	78	0.12	46	0.04	42	-0.34	82
90	9	10	0.83	24	-0.01	54	-0.57	85	-0.42	84
91	10	1	1.49	15	0.34	31	-0.08	50	-0.03	47
92	10	2	-1.06	79	-0.27	68	-0.05	48	0.00	44
93	10	3	1.52	14	-0.42	76	-0.52	80	-0.01	46
94	10	4	-0.42	58	0.29	34	0.13	32	-0.05	50
95	10	5	-0.52	62	0.05	51	1.08	5	0.28	22
96	10	6	0.80	25	0.43	27	0.81	14	0.69	9
97	10	7	0.34	36	-0.55	81	-1.44	100	0.02	43
98	10	8	-1.46	90	-0.13	60	-0.33	69	-0.94	97
99	10	9	-0.63	65	0.50	18	-0.45	78	-0.30	76
100	10	10	2.03	11	-0.24	66	-0.19	56	0.47	18
LSD 0.05			**0.43**		**0.27**		**0.19**		**0.3**	

4.4 Secondary Traits for Testcross Performance Assessment in Stress Environments

Trait differences ($p<0.05$) were observed to be due to variation in the testing sites or environment. As a result, selection of suitable testcross hybrid with traits that impact greater performance under stress become critical. Stress related traits namely AD, ASI and EPP were therefore assessed.

4.4.1 Anthesis Dates (AD)

Mean anthesis dates are summarized in Appendix A to C. The average AD among testcrosses under optimum conditions due to lines ranged from 65.6 to 67.0 days. The tester range average was from 65.4 to 66.7 days with a trial mean of 66.1 days and LSD ($p<0.05$) of 5.3days. The earliest maturing testcross was LT61 (60days), which flowered significantly different ($p<0.05$) at 66 and 77.5 days under low N and drought conditions respectively. Under low N conditions average AD among testcrosses due to lines ranged from 66.8 to 78.5 days indicating significant different maturity influence among lines. Under drought condition testcrosses flowered later than the other environments, indicating severe stress. Under water stress conditions the average AD among testcrosses due to lines ranged from 75.9 (L6) to 85.8 (L2) while that due to testers ranged from 78.8 (T4) to 85.4 (T7). This indicates that there were significant differences within lines and within testers.

4.4.2 Anthesis Silking Interval (ASI)

Appendix D shows that the average ASI among testcrosses due to lines under optimum conditions ranged from 0.9 to 4.6 days with that due to testers ranging from 2.2 to 4.0 days and a trial mean of 3.2 days. The best nicking testcrosses were LT62 (0.0 days), LT63 (0.5days), and LT65 (0.7 days). The trial mean for ASI under low N was 3.7 days, with the best nicking testcross being LT61 (1day), while the worst was LT71 (8.0 days) as shown in Appendix E. The average ASI among testcrosses due to testers ranged from 2.7 to 5.3 days while that due to lines ranged from 1.4 to 5.7 days. Under drought conditions, (Appendix F), the stress was more severe as evidenced by large ASI values that ranged from 1 day (LT85) to 10 days (LT23). Significant differences ($p<0.05$) were found between L2 average (6.7 days) and L6 average (2.1 days).

4.4.3 Ears Per Plant (EPP)

Significant differences (LSD 0.05 : 0.39) were recorded for EPP trial means across the different environments; 1.22, 0.74 and 0.60 for optimum, low N and drought respectively as shown from Appendix G to I. This is an indication that there was significant stress under drought and low N environments. The average EPP among testcrosses due to lines under optimum conditions ranged from 1.14 to 1.30 cobs with average due to testers ranging from 1.15 to 1.27 cobs per plant. Under low N the best EPP value was recorded for testcross hybrid, LT36 (1.2cobs). The testcross with the best average EPP under drought was LT97 with an average of 0.90 cobs/ plant with the worst being LT82 (0.31cobs/plant) which was below the trial mean of 0.60cobs/plant.

4.5 Combined Analyses of Variance

4.5.1 Grain Yield

Table 4-11 shows the ANOVA for GY of testcrosses, lines, testers and their respective interactions. Highly significant differences (P<0.01) were observed among sites, tescrosses, lines, and testers for GY. Testcross x Site (G*E) interactions were also highly significantly different. Tester x Site and Line x Tester (SCA) interactions were highly significantly different, with the Line x Site interaction being significant (P<0.05) for GY.

Table 4-11. ANOVA for Grain Yield (GY) Across Four Sites:

Source	DF	SS	MS	F	P
Site	3	8659.33	2886.44	1287.3	***
Testcross	99	413.96	4.18	1.83	***
Line	9	62.74	6.97	3.11	***
Tester	9	91.47	10.16	4.53	***
Testcross*Site	297	880.84	2.97	1.3	**
Line*Site	27	97.97	3.63	1.62	*
Tester*Site	27	205.9	7.63	3.4	***
Line*Tester	81	298.72	3.69	1.64	***
Line*Tester*Site	243	569.8	2.34	1.05	ns
Error	747	1706.78	2.28		
CV %	23.4				

SS: Sum of Squares MS: Mean Square F: F Value DF: Degrees of Freedom
ns: not significant *** (P<0.001) ** (P<0.01) *(P<0.05)

4.5.2 Anthesis Date, Anthesis -Silking Interval and Ear Per Plant

The ANOVA data for AD, ASI and EPP are presented in Table 4-12. The table shows that there were significant differences among for sites, lines, and testers for AD (p<0.001). There were also significant interactions among these factors. However, the line x tester x site interaction for AD was not significant. Appendix A also show that there significant SCA effects for AD across all the sites. Differences (P<0.001) were observed among sites, lines, genotypes, testcross x site, site x tester and site x line, with line*tester and site x line x tester interactions being different (P<0.05) for ASI. There

were highly significant differences for EPP due to sites, testcrosses and lines ($p<0.001$), with line x tester differences being significant at $p<0.01$ while tester and site x tester were different at $p<0.05$ level of significance.

Table 4-12. ANOVA for AD, ASI and EPP Across Four Sites:

		AD			ASI			EPP		
Source	DF	MS	F	P	MS	F	P	MS	F	P
Site	3	14719.7	1971.1	***	514.88	152.81	***	21.36	596.82	***
Testcross	99	89.68	12.2	***	14.25	4.28	***	0.06	1.7	***
Line	9	611.22	81.85	***	101.25	30.05	***	0.14	3.91	***
Tester	9	243.58	32.62	***	12.21	3.63	**	0.08	2.12	*
Testcross*Site	297	20.9	2.84	***	6.04	1.81	***	0.04	1.04	ns
Line*Site	27	81.31	10.89	***	20.48	6.08	***	0.04	1.21	ns
Tester*Site	27	64.08	8.58	***	9.57	2.84	***	0.05	1.43	*
Line*Tester	81	17.66	2.37	***	4.53	1.35	*	0.05	1.44	**
Line*Tester*Site	243	7.99	1.07	ns	3.99	1.18	*	0.03	0.88	ns
Error	799	7.35			3.37			0.04		
CV%		3.9			12.3				23.7	

MS: Mean Square F: F Value DF: Degrees of Freedom ns: not significant
*** (P<0.001) ** (P<0.01) *(P<0.05)

4.5.3 Plant , Ear Heights and Ear Position

The plant and ear height traits results are shown in ANOVA Table 4-13. Site, testcrosses, line and tester were significantly different ($P<0.001$) for both PH and EH. Ear Height, testcross x site, line x site and tester x site were also significantly different. Line x tester for EH was also different ($P<0.05$) for the testcrosses evaluated. However there were no significant differences observed in the testcross x site, tester x site, line x tester and line x tester x site interactions for PH.

Table 4-13. ANOVA for Plant heights (PH) and Ear heights (EH) Across Four Sites

		PH			EH			EPO		
Source	DF	MS	F	P	MS	F	P	MS	F	P
Site	3	557498	161.5	***	163719	765.8	***	1.22	381.33	***
Testcross	99	5623.32	1.63	***	1142.99	5.36	***	0.01	2.64	***
Line	9	17527.9	5.08	***	6170.47	28.86	***	0.04	11.53	***
Tester	9	10257	2.97	***	3794.13	17.75	***	0.02	6.91	***
Testcross*Site	297	3811.35	1.11	ns	403.82	1.89	***	0.004	1.37	***
Line*Site	27	5980.74	1.73	**	1202.04	5.62	***	0.009	2.84	***
Tester*Site	27	4283.81	1.24	ns	1268.72	5.93	***	0.009	2.84	***
Line*Tester	81	3820.74	1.11	ns	286.22	1.34	*	0.004	1.19	ns
Line*Tester*Site	243	3494.45	1.01	ns	219.08	1.02	ns	0.003	1.04	ns
Error	799	3452.07			213.79			0.003		
CV %		45.9				18.1			4.5	

MS: Mean Square F: F Value DF: Degrees of Freedom ns: not significant
*** (P<0.001) ** (P<0.01) *(P<0.05)

4.5.4 Root and Stem Lodging

The Table 4-14 shows the standability for root and stalk traits. There were no differences in RL except due to line effects that were significant at ($p<0.05$). However site, testcrosses, lines, tester x site, line x tester were significant ($P<0.001$) while tester, line x site were significant ($p<0.01$) and testcross x site ($p<0.05$). There were no differences for line x tester x site for both traits.

Table 4-14. ANOVA for Root and Stem Lodging Across Four Sites:

		RL			SL		
Source	DF	MS	F	P	MS	F	P
Site	3	25.35	1.94	ns	998.73	12.16	***
Testcross	99	13.96	1.07	ns	184.22	2.24	***
Line	9	37.83	2.89	**	624.41	7.6	***
Tester	9	8.39	0.64	ns	222.9	2.71	**
Testcross*Site	297	12.48	0.96	ns	93.33	1.13	*
Line*Site	27	10.01	0.77	ns	148	1.8	**
Tester*Site	27	9.11	0.7	ns	240.11	2.92	***
Line*Tester	81	11.72	0.9	ns	129.51	1.58	***
Line*Tester*Site	243	13.17	1.01	ns	71.96	0.88	ns
Error	799	13.07			82.29		
CV %		23			16		

4.6 General Combining Ability (GCA) Effects

Significant differences ($P<0.05$) of lines were observed for grain yield, anthesis dates, anthesis silking interval, root lodging, ear heights, ear position, ears per plant and ear rots (Table 4-15a). Lines, L1, L2, L5, L7, L9 and L10 had positive GCA effects for grain yield implying they conferred higher yields to their testcross progenies, with the best GCA effects being recorded for L5 with a GCA effect of 0.363t/ha. However, L3, L4, L6 and L8 had negative GCA effects for grain yield. In the measurement of AD, positive values indicate late maturity while negative values indicate earliness. GCA effects values for AD were positive for L1, L2, L5, L8 and L10 while negative effects were recorded for L3, L4, L6, L7 and L9. Line L6 conferred early maturity to its testcrosses as it recorded the least AD GCA effects of -4.88 days (Table 4-15a). ASI, which is an important trait for measuring stress tolerance had negative GCA effects recorded for L4, L6, L7, L8 and L9, with positive (undesirable) effects being recorded for L1, L2, L3, L5, and L10.

There were no variations of GCA effects for PH. Lines with the poorest values of PH GCA effects were those with positive values such as L2, L10 and L8 with values of 18.189, 17.414 and 5.773cm respectively (Table 4-15a). Besides being tall, L2 and L10 also had positive GCA effects for AD which confirms that they are late maturing. The shortest line, having the smallest GCA effects value for PH, was L6 with a value of -18.218cm (Table 4-15a). Root lodging was recorded least in L3, L10 and L7, with values of -0.603, -0.596 and -0.453% respectively. GCA effects of L6 for RL were positive (1.26%) an indication that the line had poor standability effects on its testcrosses. Shoot

lodging GCA effects were not significantly different (LSD0.05: 10.903%). L6 had the least lodging effects while L10 had the worst shoot lodging effects, an indication that SL is height dependent.

Ear position (EPO) GCA effects were weakly expressed in all the ten (10) lines making selection among lines for this trait very difficult. However L1, L4, L5, L6, L7 and L10 had negative (desirable) GCA effects. The derived trait EPP had positive GCA effects for L7 and L9. Ear rots (ER) had positive GCA effects for L2, L3, L4, L5, L6 and L8 while desirable lines with negative effects were L1, L7, L9 and L10. Assessment of the diseases incidence revealed that the ear rots were mainly Diplodia *spp*. Though results of husk cover are not shown the three lines with negative disease effects were also good on husk cover scores. There were no significant GCA effects for PH and SL. Lines with good GCA effects for all traits inclusive of yield were L5, L7, L9 and L10. Considering traits that are important for stress namely GY, ASI and EPP, L7 and L9 can be said to be superior lines.

Table 4-15a. GCA Effects Of Lines For The Measured Traits

LINE	Yield t/ha	AD days	ASI days	PH Cm	RL %	SL %	EH cm	EPO cm	EPP	ER score
1	0.07	1.67	0.34	5.15	0.35	0.51	2.22	0.00	-0.03	-0.29
2	0.29	2.79	1.51	18.19	0.24	0.69	13.62	0.02	-0.01	0.69
3	-0.22	-0.23	0.29	-5.14	-0.60	0.76	-1.29	0.00	-0.01	1.49
4	-0.37	-0.23	-0.87	-8.06	0.19	-0.23	-3.60	0.00	0.00	0.36
5	0.36	0.31	0.56	3.84	0.02	-1.81	1.58	0.00	-0.02	0.23
6	-0.33	-4.89	-1.64	-18.22	1.26	5.32	-13.03	-0.03	0.00	1.29
7	0.02	-1.59	-0.46	-11.04	-0.45	-2.17	-4.27	0.00	0.04	-1.06
8	-0.05	2.90	-0.27	5.77	-0.03	1.09	8.03	0.02	-0.05	0.08
9	0.15	-0.85	-0.43	-8.12	-0.36	-1.66	-0.61	0.01	0.07	-1.74
10	0.06	0.08	0.96	17.41	-0.60	-2.38	-2.70	-0.02	0.00	-1.02
LSD0.05	**0.03**	**0.11**	**0.05**	**50.82**	**0.19**	**10.90**	**3.15**	**0.00**	**0.00**	**0.67**

Table 4-15b. GCA Effect of Testers For The Measured Traits

TESTER	Yield t/ha	AD days	ASI days	PH Cm	RL %	SL %	EH cm	EPO cm	EPP	ER score
1	-0.26	1.43	0.00	8.57	-0.34	0.01	7.06	0.01	-0.01	0.56
2	0.11	0.76	-0.09	1.96	0.10	-1.33	0.86	0.00	0.01	-0.32
3	0.54	2.55	-0.22	10.63	-0.25	-0.94	10.56	0.03	-0.04	-1.47
4	0.32	-0.26	0.39	-0.86	0.16	0.90	3.53	0.02	0.05	-1.87
5	0.02	-0.02	0.15	-11.50	-0.24	2.42	-7.17	-0.02	0.00	-0.60
6	0.15	-0.01	0.09	12.88	0.49	-2.18	-2.74	-0.01	0.01	1.01
7	-0.01	-0.16	-0.21	-3.64	0.23	-0.03	-1.41	-0.01	0.01	1.55
8	-0.19	0.02	0.58	-0.11	-0.19	0.88	-1.25	-0.01	-0.03	-0.02
9	-0.51	-2.37	-0.17	-16.14	-0.08	-0.83	-6.44	0.00	0.00	-0.63
10	-0.12	-1.87	-0.52	-1.37	0.13	1.15	-2.72	-0.01	0.00	1.65
LSD0.05	**0.03**	**0.11**	**0.05**	**50.82**	**0.19**	**10.90**	**3.15**	**0.00**	**0.00**	**0.67**

GY: grain yield
ASI: anthesis silking interval
RL: root lodging
EH: ear height
EPP: ears per plant

AD: anthesis dates
PH: plant height
SL: stem lodging
EPO: ear position
ER: ear rots

Significant differences ($P<0.05$) among testers were observed for all traits except PH and SL (Table 4-15b). Testers, T2, T3, T4, T5 and T6 had positive GCA effects for yield with Tester 3 recording the height GCA effects of 0.54t/ha. GCA effects of line for AD were negative, hence ideal in T4, T5, T6, T7, T9 and T10. These negative effects for AD indicate the testers conferred earliness to their testcrosses. Anthesis- Silking- Interval, had negative GCA effects recorded for T2, T3, T7, T9 and T10 while EPP GCA effects were desirable in T1, T3 and T8. Testers T2, T3, T4, T5, T8 and T9 conferred desirable GCA effects for ER to their testcrosses hence a reduced disease incidence in these testcross hybrids.

4.7. Specific Combining Ability (SCA) Effects

4.7.1 Combined Sites SCA Effects for GY

Line x Tester (SCA) effects for GY were significantly different ($P<0.05$) for some combinations, as shown in Table 4-16. The best SCA effects were recorded for the Line 2 x Tester 7 (LT27) combination with a positive effect of 1.804t/ha, while the least SCA effects were recorded for the Line 8 x Tester 4 (LT84) combination with a negative effect of -1.086t/ha (Table 4-8). Lines, L1 and L9 had positive SCA effects with six of the testers while L3, L5 and L7 had positive SCA effects with only three testers hence the latter lines are perceived to be poor specific combiners. A positive line x tester combination SCA is an indication that the line and tester are in opposite heterotic groups while a negative SCA effect indicates that the two are in the same heterotic group (Vasal *et al* 1992).

Table 4-16. SCA Effects For Grain Yield In Tonnes Per Hectare

	TESTER										
LINE	1	2	3	4	5	6	7	8	9	10	MEAN
1	-0.80	0.08	-0.57	0.14	0.32	0.69	-0.14	0.06	0.11	-0.03	-0.01
2	-0.22	0.11	-0.07	0.77	-1.01	-0.33	1.80	-0.60	0.10	-0.31	0.02
3	-0.17	-0.58	-0.34	0.50	0.55	-0.40	0.63	0.03	-0.26	-0.07	-0.01
4	0.20	-0.52	0.20	-0.57	-0.06	0.03	-0.63	0.81	0.77	-0.27	-0.00
5	1.15	-0.62	-0.16	0.38	0.07	-0.29	-0.22	-0.14	-0.03	-0.27	-0.02
6	-0.99	-0.29	0.13	-0.14	-0.06	-0.33	-0.64	1.37	0.51	0.45	0.00
7	0.54	-0.12	0.57	-0.17	0.27	-0.09	-0.00	-0.67	-0.22	-0.15	-0.00
8	-0.71	1.46	0.09	-1.09	-0.23	-0.26	0.22	-0.13	-0.31	0.63	-0.03
9	0.66	0.19	0.27	0.08	-0.15	0.27	-0.70	0.25	-0.34	-0.42	0.01
10	-0.03	0.00	-0.02	-0.05	0.28	0.69	0.02	-0.94	-0.30	0.47	0.01
MEAN	-0.04	-0.03	0.01	-0.01	-0.00	-0.00	0.03	0.00	0.00	0.00	-0.003
LSD0.05	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302

4.8 SCA Effects: Heterotic Groups As Determined by Testers N & SC and A & B

Using the N & SC heterotic groups which are similar to the A&B groups, from CIMMYT, the genotypes LT11, LT13, LT17, LT110, LT52, LT53, LT56, LT57, LT58, LT59, LT510, LT81, LT84, LT85, LT86, LT88, LT89, LT101, LT103, LT104, LT108 and LT109 were grouped into heterotic group N, while LT21, LT23, LT25, LT26, LT28, LT210, LT31, LT32, LT33, LT36, LT39, LT310, LT42, LT44, LT45, LT47, LT410, LT61, LT62, LT64, LT65, LT66, LT67, LT72, LT74, LT76, LT78, LT79, LT710, LT95, LT97, LT99 and LT910 were grouped into the SC heterotic group (Table 4-17).

Among the genotypes grouped under heterotic group N, only two namely LT52 and LT103 were found to be good yielding across all environments, while LT110, LT59, LT88 and LT109 had good yields under stress environments. In the SC heterotic group, LT26, LT79 and LT95 had good yield across all environments, while LT25, LT31, LT44, LT65, LT66, LT76, and LT99 had good yield performance under stress conditions.

Table 4-17: Grain Yield SCA Effects (t/ha) and Heterotic Groupings of Hybrids Across Environments

PEDIGREE	HETEROTIC	LINEGCA	TESTGCA	SCA EFFECTS				GY	HETEROTIC GROUP	
	COMBINATIONS			OPTIMUM	LOW N	DROUGHT	ACROSS	t/ha	OLD	NEW
LT41	SC/B	-0.37	-0.26	0.19	2.33	0.21	0.20	8.05	SC	*
LT42	SC/A	-0.37	0.11	-0.88	-0.10	-1.46	-0.52	7.59	*	SC
LT43	SC/B	-0.37	0.54	-0.70	-1.27	2.58	0.19	8.65	SC	*
LT44	SC/A	-0.37	0.32	-1.25	1.03	0.98	-0.57	7.93	*	SC
LT45	SC/A	-0.37	0.02	0.20	-0.47	-0.19	-0.06	9.56	*	SC
LT46	SC/B	-0.37	0.15	-0.66	0.66	-0.02	0.03	9.07	SC	*
LT47	SC/A	-0.37	-0.01	0.54	-0.60	0.32	-0.63	10.00	*	SC
LT48	SC/B	-0.37	-0.19	1.12	0.16	-1.02	0.81	9.60	SC	*
LT49	SC/B	-0.37	-0.51	2.23	0.51	-1.10	0.77	11.11	SC	*
LT410	SC/A	-0.37	-0.12	-1.09	-2.26	-0.27	-0.27	8.24	*	SC
LT61	SC/B	-0.33	-0.26	-1.64	-3.67	-0.15	-0.99	6.52	SC	SC
LT62	SC/A	-0.33	0.11	-1.88	-1.44	-0.33	-0.29	6.88	*	SC
LT63	SC/B	-0.33	0.54	1.60	-3.94	-2.29	0.13	11.24	SC	*
LT64	SC/A	-0.33	0.32	0.10	0.03	-0.55	-0.14	9.57	*	SC
LT65	SC/A	-0.33	0.02	-1.86	0.53	2.28	-0.06	7.79	*	SC
LT66	SC/B	-0.33	0.15	-0.83	0.33	0.45	-0.33	9.19	SC	SC
LT67	SC/A	-0.33	-0.01	-0.41	2.06	-2.13	-0.64	9.34	*	SC
LT68	SC/B	-0.33	-0.19	2.71	0.16	4.78	1.37	11.49	SC	*
LT69	SC/B	-0.33	-0.51	1.25	3.18	-0.55	0.51	10.42	SC	*
LT610	SC/A	-0.33	-0.12	0.68	2.74	-0.63	0.45	10.30	*	*
LT31	SC/B	-0.22	-0.26	-0.45	3.30	3.31	-0.17	7.43	SC	SC
LT32	SC/A	-0.22	0.11	-0.10	-1.80	0.64	-0.58	8.39	*	SC
LT33	SC/B	-0.22	0.54	0.11	0.03	1.01	-0.34	9.47	SC	SC
LT34	SC/A	-0.22	0.32	1.05	-1.00	2.41	0.50	10.24	*	*
LT35	SC/A	-0.22	0.02	2.10	0.16	-1.42	0.55	11.48	*	*
LT36	SC/B	-0.22	0.15	-1.35	-0.37	-2.25	-0.40	8.39	SC	SC
LT37	3.6	-0.22	-0.01	0.01	4.36	-3.25	0.63	9.48	*	*
LT38	SC/B	-0.22	-0.19	0.23	-3.20	-2.92	0.03	8.72	SC	*
LT39	SC/B	-0.22	-0.51	-0.47	-0.86	2.66	-0.26	8.42	SC	SC
LT310	SC/A	-0.22	-0.12	-0.97	-0.63	-0.17	-0.07	8.37	*	SC
LT81	N/B	-0.05	-0.26	-2.41	-1.97	0.11	-0.71	5.59	*	SC
LT82	N/A	-0.05	0.11	1.92	0.26	1.44	1.46	10.53	N	*
LT83	N/B	-0.05	0.54	-0.83	0.76	-1.19	0.09	8.66	*	*
LT84	N/A	-0.05	0.32	-0.96	-0.94	0.88	-1.09	8.35	N	N
LT85	N/A	-0.05	0.02	-1.16	0.90	-1.29	-0.23	8.34	N	N
LT86	N/B	-0.05	0.15	0.05	0.03	-0.45	-0.26	9.91	*	N
LT87	N/A	-0.05	-0.01	2.28	-0.57	1.55	0.22	11.87	N	*
LT88	N/B	-0.05	-0.19	-1.41	2.53	0.55	-0.13	7.21	*	N
LT89	N/B	-0.05	-0.51	0.19	-4.46	-0.87	-0.31	9.21	*	N
LT810	N/A	-0.05	-0.12	0.73	3.44	-0.70	0.63	10.19	N	*
LT71	SC/B	0.02	-0.26	0.30	-3.57	2.01	0.54	8.00	SC	*
LT72	SC/A	0.02	0.11	0.11	0.33	2.34	-0.12	8.42	*	SC
LT73	SC/B	0.02	0.54	0.43	2.50	-1.62	0.57	9.61	SC	*
LT74	SC/A	0.02	0.32	-0.99	-0.54	-0.89	-0.17	8.03	*	SC
LT75	SC/A	0.02	0.02	2.23	0.63	-1.72	0.27	11.43	*	*
LT76	SC/B	0.02	0.15	-0.65	1.10	0.45	-0.09	8.91	SC	SC
LT77	SC/A	0.02	-0.01	0.52	0.16	-0.88	0.00	9.81	*	SC
LT78	SC/B	0.02	-0.19	-2.08	-0.74	0.11	-0.67	6.25	SC	SC
LT79	SC/B	0.02	-0.51	0.28	0.28	1.03	-0.22	9.00	SC	SC

LT710	SC/A	0.02	-0.12	-1.35	-0.16	-0.80	-0.15	7.82	*	SC
LT101	N/B	0.06	-0.26	1.49	3.06	-4.49	-0.03	9.73	*	N
LT102	N/A	0.06	0.11	-1.06	-2.70	-1.49	0.00	7.79	N	*
LT103	N/B	0.06	0.54	1.52	3.13	3.21	-0.01	11.24	*	N
LT104	N/A	0.06	0.32	-0.42	1.43	-1.72	-0.05	9.14	N	N
LT105	N/A	0.06	0.02	-0.52	0.93	0.45	0.28	9.22	N	*
LT106	N/B	0.06	0.15	0.80	-0.27	-1.39	0.69	10.91	*	*
LT107	N/A	0.06	-0.01	0.34	-1.54	3.62	0.02	10.18	N	*
LT108	N/B	0.06	-0.19	-1.46	-3.44	-0.72	-0.94	7.40	*	N
LT109	N/B	0.06	-0.51	-0.63	0.24	0.53	-0.30	8.63	*	N
LT1010	N/A	0.06	-0.12	2.03	-0.86	2.03	0.47	11.74	N	*
LT11	N/B	0.07	-0.26	-0.01	-1.64	-0.65	-0.80	8.45	*	N
LT12	N/A	0.07	0.11	0.11	-0.74	0.34	0.08	9.18	N	*
LT13	N/B	0.07	0.54	-1.34	1.76	-1.29	-0.57	8.61	*	N
LT14	N/A	0.07	0.32	0.23	-1.27	1.11	0.14	10.01	N	*
LT15	N/A	0.07	0.02	0.53	-0.44	-0.72	0.32	10.49	N	*
LT16	N/B	0.07	0.15	2.70	-0.64	0.11	0.69	13.03	*	*
LT17	N/A	0.07	-0.01	-2.24	0.43	1.12	-0.14	7.82	N	N
LT18	N/B	0.07	-0.19	1.04	2.53	1.45	0.06	10.12	*	*
LT19	N/B	0.07	-0.51	-0.11	-0.46	-1.97	0.10	9.37	*	*
LT110	N/A	0.07	-0.12	-1.07	0.44	0.53	-0.03	8.85	N	N
LT91	SC/B	0.15	-0.26	2.54	0.46	-0.37	0.66	10.42	SC	*
LT92	SC/A	0.15	0.11	-0.91	0.70	2.04	0.19	7.58	*	*
LT93	SC/B	0.15	0.54	2.48	0.20	0.91	0.27	11.84	SC	*
LT94	SC/A	0.15	0.32	0.54	1.16	0.31	0.08	9.74	*	*
LT95	SC/A	0.15	0.02	0.54	0.00	0.48	-0.15	9.92	*	SC
LT96	SC/B	0.15	0.15	-0.53	-0.20	-0.35	0.27	9.22	SC	*
LT97	SC/A	0.15	-0.01	-1.69	-1.80	-1.35	-0.70	7.78	*	SC
LT98	SC/B	0.15	-0.19	-0.77	-0.37	-0.35	0.25	7.73	SC	*
LT99	SC/B	0.15	-0.51	-1.02	0.31	0.23	-0.34	7.87	SC	SC
LT910	SC/A	0.15	-0.12	0.83	-0.46	-1.27	-0.42	10.18	*	SC
LT21	SC/B	0.29	-0.26	-2.07	0.93	-1.65	-0.22	6.25	SC	SC
LT22	SC/A	0.29	0.11	2.06	1.83	-5.99	0.11	10.99	*	*
LT23	SC/B	0.29	0.54	-1.10	-0.34	0.05	-0.07	8.70	SC	SC
LT24	SC/A	0.29	0.32	0.78	0.96	-2.89	0.77	10.41	*	*
LT25	SC/A	0.29	0.02	-2.94	0.46	2.95	-1.01	6.88	*	SC
LT26	SC/B	0.29	0.15	0.79	0.60	3.45	-0.33	10.97	SC	SC
LT27	SC/A	0.29	-0.01	3.29	-4.34	5.45	1.80	13.20	*	*
LT28	SC/B	0.29	-0.19	0.06	1.43	-1.22	-0.60	9.00	SC	SC
LT29	SC/B	0.29	-0.51	-0.49	-0.89	0.36	0.10	8.85	SC	*
LT210	SC/A	0.29	-0.12	-0.54	-0.66	-0.47	-0.31	9.25	*	SC
LT51	N/B	0.36	-0.26	1.31	0.76	-0.09	1.15	9.60	*	*
LT52	N/A	0.36	0.11	1.45	3.66	2.91	-0.62	10.35	N	N
LT53	N/B	0.36	0.54	-0.86	-2.84	-1.39	-0.16	8.92	*	N
LT54	N/A	0.36	0.32	0.12	-0.87	0.35	0.38	9.74	N	*
LT55	N/A	0.36	0.02	0.88	-2.70	-0.82	0.07	10.68	N	*
LT56	N/B	0.36	0.15	-0.32	-1.24	0.01	-0.29	9.84	*	N
LT57	N/A	0.36	-0.01	-2.06	1.83	-1.65	-0.22	7.83	N	N
LT58	N/B	0.36	-0.19	0.08	0.93	-0.65	-0.14	9.00	*	N
LT59	N/B	0.36	-0.51	-1.21	1.61	1.93	-0.03	8.11	*	N
LT510	N/A	0.36	-0.12	0.95	-2.33	-0.57	-0.27	10.71	N	N
Mean								9.24		
LSD 0.05								4.57		

*Heterotic Group unidentified

Table 4-18. GCA & SCA Percent SS Entry Contribution, Variances and Heritability of Traits

Trait	GCA		SCA		Heritability
	SS Entry %	Variance	SS Entry %	Variance	%
GY	18.70	1.30	72.00	7.52	21.20
AD	43.50	109.28	16.00	55.04	55.40
ASI	35.50	13.92	26.00	6.24	71.00
PH	22.50	2685.76	55.60	1966.24	31.60
EH	39.70	1252.32	20.50	386.24	70.10
RL	15.10	3.04	68.70	7.20	1.20
SL	20.90	78.48	57.50	251.84	33.40
EPO	27.30	0.01	32.70	0.01	70.60
EPP	16.70	0.02	68.20	0.05	16.90
ER	15.20	15.92	64.60	41.92	15.20

Table 4-18 above shows that there were traits such as AD, ASI, EH and EPO are highly heritable, hence can be passed from parent to offspring with relative ease compared to traits such RL, GY, EPP and ER. Heritability is the proportion of the genetic variance to the total phenotypic variance. It measures the ease with which traits are passed from parents to progenies. The higher, the heritability estimate, the more readily, the trait transmission (Melchlinger, 1998).

CHAPTER 5

5.0 DISCUSSION

5.1 GCA and SCA Mean Squares

Significant differences ($p<0.05$) of GCA (Line and Tester) mean squares were observed for GY, AD, ASI, PH, EH, SL, EPO and EPP. This therefore means that there was variation for additive gene action in the traits measured, which enabled selection to be done. As a result identification of single cross testers, based on these traits from the 100 testcrosses was made possible. Generally testers are selected on additive gene action (GCA) effects especially in GY, with traits such as AD, ASI, EPP and others aiding selection, while SCA effects are used for selecting hybrids. Significant differences ($p<0.05$) for SCA (Line x Tester) mean squares were observed for GY, AD, ASI, EH, SL and EPP (Tables 4-12 to 4-14).However this study mainly focused on determining or confirming heterotic relations and tester identification. Heterotic groups are identified from the positive (+ve) and negative (-ve) of GY SCA effects. SCA effects, differences can be used to measure the degree of relationship between lines making a hybrid (Vasal *et al.*, 1992). Effects close to zero imply a close relationship, where the lines making the hybrid have common or identical alleles while effects significantly different from zero indicate less common alleles hence a distant relationship between the lines making the hybrid.

5.2 GCA and SCA Entry Sum of Squares

Table 4-18 shows that there was a predominance of GCA sums of squares to SCA sums of square for AD, ASI and EH indicating the relative importance of additive gene action (GCA) to non additive gene action (SCA) for these traits as supported by Betran *et al.* (2003). In this study set GY, PH, RL, SL, EPP and ER had a predominance of SCA sums of squares contributing to the total entry sums of squares implying that non additive gene action was relatively more important for these traits. As a result selecting for additive gene effects (GCA effects) was done for AD, ASI and EH while selecting for non additive genes (SCA effects) was done for GY, PH , RL, SL, EPP and ER for hybrid combinations in the trial under study.

5.3 GCA and SCA Variances

In this study three traits namely AD, ASI and EH had a predominance of GCA sum of squares to SCA sums of squares. The traits AD, ASI, EH and PH had a predominance of GCA variance to SCA variance. Melchinger, (1998) stated that if the predominance of GCA sum of squares to SCA sum of squares translates to a ratio where GCA variance predominates SCA variance, then early testing of genotypes becomes more effective and promising hybrids can be selected based on their prediction from GCA effects. It therefore implies that early testing of lines selected from the testcrosses from the study pool can be done for traits AD, ASI and EH because of their predominance of GCA variances to SCA variances (Table 4-18). Early testing of the lines is more effective because additive gene action is not affected by inbreeding depression. Inbred lines that

are under control of additive gene action will therefore not suffer from inbreeding depression, thereby making hybrid development from such lines more efficient and quicker to release for farmer use. In the testcrosses under study, GY, SL, RL, EPP and ER had a predominance of SCA sums of squares to GCA sums of squares as well as a predominance of SCA variance to GCA variance, which confirms that these traits were governed by non additive gene action. This type of gene action could be exploited in hybrids (F1s) since in maize most varieties are F1 hybrids.

5.4 Heritability

In this study narrow sense heritability was reported. Table 4-18 shows that the estimates were GY (21.2%), AD (55.4%), ASI (71.0%), PH (31.6%), EH (70.6%), RL (1.2%), SL (33.4%), EPO (70.6%), EPP (16.9%) and ER(15.2%). The estimates for GY, AD, EPO and EPP compare very well with those reported by Hallauer and Miranda (1981) where they recorded 18.7% for GY, 57.9% for AD, 39% for EPP and 66.2% for EPO. As a result traits such as AD, ASI, EH and EPO can easily be conferred to the hybrids developed from the resultant testcrosses under study.

5.5 GCA Effects

Significant GCA effects were observed for GY which suggest the need of selecting the genotypes from lines with the best positive (+ve) effects for consideration as testers. Table 4-15a shows that L1, L2, L5, L7, L9 and L10 had positive GCA effects, which implies that the lines contributed to an increase in yield for the testcrosses which was

above the mean of the trial. In addition these desirable lines had significant GCA effects among themselves with the exception of L1 and L10, which had similar GCA effects for GY. L3, L4 and L6 had negative (–ve) GCA effects for yield because they were early maturing as evidenced by their negative GCA effects for AD. Early maturing germplasm has been reported to yield less in general due to reduced photosynthetic and assimilate accumulation period. Lines L7 and L9 also had negative GCA effects for AD but positive GCA for GY because they had a longer grain filling period since they are intermediate in maturity hence an above trial mean GCA effect for GY. Half the number of lines evaluated had negative GCA effects for ASI which is a desirable feature in the resultant testcrosses. Negative ASI GCA effects mean that the lines conferred better synchronization to their testcrosses. Despite having a desirable GCA effects for ASI, L4 and L6 yielded low, due to GY penalty that comes with earliness. Intermediate maturing L7 and L9 had negative GCA effects for ASI indicating good nicking properties hence the positive GCA effects for GY. On the contrary L8 had negative GCA effects for ASI but is late maturing hence the below trial mean GY performance associated with late maturity especially under stress environments as evidenced in studies by Edmeades *et al.* (1993).

There were no significant differences for line PH GCA effects while line EH GCA effects were significantly different. However the two traits, PH and EH are interlinked as evidenced by the trend of their GCA effects in Table 4-15a. The lines had the same insignia for both traits implying that if PH GCA effects for a particular line was positive the corresponding EH GCA effects would also be positive and vice versa. Standability

traits (SL and RL) were evaluated in the study with line GCA effects for RL being significantly different ($p < 0.05$). Lines L1, L2, L4, L5 and L6 had GCA effects for RL which were above the trial mean. L6 conferred the worst GCA effects to its testcrosses, implying that above average plants lodged which might further help to explain the poor performance of testcross progenies from this line. GCA effects for SL were not significantly different. However, per se SL lodging values indicate that tall genotypes, such as the ones conferred by L10, had the worst lodging effects, which might mean that SL is height dependent.

Significant differences were observed for GCA effects for EPP. Only L7 and L9 had positive GCA effects for EPP, indicating that testcrosses from these lines were stress tolerant since they had cob numbers that were above the mean of the trial. The two lines' GCA effects for EPP were also significantly different from each other, with testcrosses from L9 having a greater average number of cobs than those produced by L7 testcross progenies. GCA effects for ER were desirable for L7, L9 and L10. The majority of the lines had undesirable GCA effects implying they succumbed to the ER diseases since they recorded disease incidences that were above the mean of the trial. L9 GCA effects for ER were also significantly different from L7 and L10 an indication that L9 is very resistant to ear rots (*Diplodia spp*).

The testers with positive GCA effects for GY were T2, T3, T4, T5 and T6. The tester with the best GCA effects for GY was T3 (0.54) and the one with the most undesirable GCA effects for GY was T9 (-0.51). However out of a possible 30 hybrids from the best

five lines and the best six testers, only nine hybrids were potentially good testers. This implies that the specific combining abilities of most of the best lines and best tester combinations deviated from expectation. It therefore implies that good general combiners are not always good specific combiners. Appendix K shows that when considering the average GCA effects ranks of the respective traits L7 with the least average rank of 2.70 was the best, followed by L9 (3.70) with L10 (4.50) coming third. The highest average GCA rank was recorded for L10 (8.00) implying that L10 is the least preferred line for GCA effects of the measured traits.

5.6 Genotype, GCA and SCA by Environment Interactions

Banziger *et al.* (2000) suggested that, for ideal selection, genotypes are evaluated in the target environments where they will be grown. This is because Genotype x Environment (GxE) interactions occur and they affect genotype stability. In the study there were significant GxE interactions ($P<0.05$) for GY, AD, ASI, EH, EPO and SL. The results, for the interactions observed suggest that, the crosses did not have the same relative performance across locations. This implies that genotypes responded differently to the stress and non-stress environments for the above stated traits. The genotypes under study were single crosses and this explains why all traits except PH, RL and EPP had significant GxE interactions. This trend of GxE interactions of the single crosses under study, are supported by Hallauer and Miranda (1988), who pointed out that external environmental factors such as weather and soil type have a greater effect on single crosses than other types of hybrids and OPVs. Troyer (1996) also observed that single cross hybrids interact more with the environment than double cross hybrids.

In the study GY trial means under managed low N and drought stress environments were 28% and 25% of the optimum trial mean (9.23t/ha) respectively. This implies that genotype performance was retarded under stress conditions. This finding agrees with previous studies by Banziger *et al.* (2000) and Betran *et al.* (2003) who reported a range from 20-33% of GY under stress environments compared to optimum environments. This range of level of intensity of stress observed also falls within the range and stress levels and results obtained in studies by Laffitte and Edmeades, (1994).

The traits AD and ASI are influenced by environment, and are known to increase under stress conditions. The study results show that mean AD under optimum was 66.1days compared to 73.7days under low N and 82.1days under drought conditions (Appendices A to C). This shows that there were significant differences ($p<0.05$) due to environmental effects for AD. Anthesis Silking Interval is also known to increase under stress environments, a phenomenon that was confirmed in this study where average ASI for optimum was 3.2 days while that of drought and low N were 3.8 and 3.7days respectively. There were also GxE interactions for EH and EPO in the different environments. This is the case because if stress is applied to a maize plant, cell elongation is reduced resulting in stunting, which will affect EH and the relative placement of the ear on the stem (EPO). Stem lodging (SL) is bound to increase under low N as a result of weak stem due to lack of nutrients and nutrient imbalance influenced by nitrogen, while under drought, lack of moisture results in lodging which in this study was compounded by strong winds and termite attack in the environment where the study was done.

The study shows that PH, RL and EPP were not affected by environment. This is contrary to findings by Edmeades *et al.* (1998) and Banziger *et al.* (2000). PH is known to be affected by both drought and low N stresses which affect both cell division and elongation. EPP is a derived trait that is used in the selection of superior genotypes under drought and low N stress conditions. The reasons why there were no environmental effects for these traits might be that the stress levels were not severe enough to stimulate response. It might also be due to large error variances due to the environmental variances as the evaluation was done on one site each for drought and low N, whereas in the studies done by Banziger *et al.* (2000) genotypes were evaluated across more than 20 managed drought and low N sites.

Previous studies by Matziger *et al.* (1959) and Pixley & Bjarnasson (1993) have shown that GCA can interact with the environment. In the study under discussion there were significant ($p < 0.05$) GCA*E interactions for all traits measured except RL. This implies that the GCA also known as the differential performance of genotypes of lines and testers for the traits varied with environments. The lines and testers differed in the way they conferred these traits to their progeny under different environments. The testing of lines under different environments ensured that ideal testcrosses that are stable across environments are selected. GCA*E interaction for GY, was observed as the difference in the average yield of a series of hybrids made from a particular line in different environments. As shown in (Tables 4-9 to 4-11), L1 average yield was 9.59t/ha (optimum), 2.62t/ha (low N) and 2.59t/ha (drought); compared to L9 with 9.23t/ha, 3.17t/ha and 2.67t/ha under optimum, low N and drought conditions respectively. The

GCA*E interactions indicate that GCA effects were not the same across all environments. Thus to maximize the yield potential for each environment the choice must be made with testcross GCA effects within each environment.

Significant SCA*E interactions were observed for GY, AD, ASI, EH and SL. This implies that specific testcrosses differed in the way they expressed these traits in the different environments. Traits such as EPO, EPP, ER, RL and PH were not expressed differently by the testcross hybrids in the evaluated environments implying that the variations in the testcross hybrids, were due to other factors other than the environment.

5.7 SCA Effects for Grain Yield and Heterotic Groups As Determined by Testers:

Vasal *et al* (1992) stated that lines in the same heterotic group exhibit –ve SCA effects when crossed to each other while those in different heterotic groups show +ve SCA effects. This was also supported by Gama *et al.* (1995) who reported that on average crosses produced by inter-population lines have more +ve SCA effects than those produced by intra-population lines which tend to have more –ve SCA effects. The –ve SCA effects are due to more common alleles between lines which results in reduction in yield than the mean of the parents (inbreeding depression). In the study two known heterotic groups namely N & SC were used in classifying genotypes into heterotic groups.

Twenty two genotypes were grouped into the N heterotic group. However only 8 genotypes namely LT11, LT13, LT52, LT81, LT84, LT89, LT108 and LT109 had significant across site SCA effects of more than 0.3t/ha (Table 4-18). Under optimum

conditions, GY of the 8 genotypes, were not significantly different ($p<0.05$) from each other and were below the trial mean (9.24t/ha) except for LT52. The other 14 genotypes had less common alleles hence the low –ve values for SCA effects. In the SC heterotic group 17 genotypes had significant –ve SCA effects which confirms that their parents had more common alleles. Genotype LT26 which was identified to be good across all environments was among the elite SC group.

5.8 GCA Effects for GY and Selection of Single Cross Testers

As shown in Table 4-15a, L1, L2, L5, L7, L9 and L10 were found to have the desired GCA effects. This implies that these lines had good general combining ability with the different tester used hence their progenies had good performance across environments. Lines L1, L5 and L10 are in the N heterotic group, while L2, L7 and L9 are in the SC heterotic group (Tables 3-1 & 4-17).

In the N heterotic group the line with the best GCA effects was L5 which conferred a yield of (0.36t/ha) above the across site mean yield. Testcross LT52 which is intermediate in maturity (66 days) under optimum environments, was identified as a potential tester because it has been noted to have good GCA effects for GY and stability in GY under diverse environments. Testcrosses LT56 and LT57 which are also intermediate maturing can also be potential tester as they have Good GCA effects for GY which is above the mean of the trial under optimum conditions. Line L1 with a GCA effect of 0.07t/ha is the second best general combiner in the N group series. Two genotypes LT11 and LT13 can be selected to be good bets for testers. However their

average yields under optimum conditions were below the trial mean of 9.24t/ha. The GCA effects for L10 were 0.06t/ha above the grand mean, with testcross LT103 being the only possible tester candidate.

Lines L2, L7 and L9 were the lines with the best GCA effects in the SC group. Testcrosses developed from L2 had the best GCA effects (0.29 t/ha) above the across site trial mean. Testcross LT26 was the best across all environments, with LT25 being the best candidate for a tester under stress environments. Testcrosses from L9 had a GCA effect of 0.15t/ha and LT95 is the best option for a tester. It is a good yielder under optimum conditions under which seed production is done as well as a good performer under stress environments. LT99 can also be considered for its stress tolerance and early maturity with L72 and LT79 being other possible tester candidates in the L7 series of genotypes.

CHAPTER 6

6.0 Conclusion

Heritability estimates given in the discussion are specific to the germplasm and environments under study. The North Carolina Design II was effective and ideal in the identification of lines with good GCA effects which consequently enabled the identification of potential single cross testers. In the intermediate category LT52 (N group) and LT26 (SC group) can be used as tester while in the early maturing range only genotype LT99 was identified as possible single cross tester. In the study non additive genes are predominant in most traits with additive gene effects being predominant in AD, ASI and EH only.

The study however did not managed to confirm the distinctness between N and SC heterotic groups in relation to CIMMYT's A and B heterotic groups as some combinations had to be reassigned new heterotic groups. As a result further investigations on inbreds and single crosses that showed positive GCA is needed to confirm their performance and confirm heterotic groupings. Traits used to assess stress tolerances especially ASI and EPP were also used in aiding the identification of potential single cross testers.

Further trials to confirm the identified single cross testers need to be done as recommended (Vasal *et al.*, 1992) and (Gama *et al.*, 1995) who also stressed the need to do more than one evaluation to identify good lines and testers in tropical maize germplasm. Single crosses LT52, LT26 and LT99 can be used as testers while further evaluations are

being done to confirm their suitability. There is need to establish heterotic groups of genotypes that were not classified into heterotic groups. Good specific combiners such as LT27 can be used by the national program as possible candidates for release or for use in the development of three way hybrids that can there after be released to farmers for commercial production.

REFERENCES

Allard, R.W. 1960. Principles of plant breeding. Wiley, New York, Inc. pp 263-279.

Altin, G and R. Frey. 1990. Quantitative trait loci mapping in maize yield and its components under different water treatments. *Field Crops Research* **72**: 334-344

AREX. 2004. Crop Assessment and Early Warning Unit Seasonal Report, Harare , Zimbabwe

Banziger, M., P.S. Setimela, D. Hodson and B. Vivek. 2006. Breeding for improved abiotic stress tolerance in maize adapted to Southern Africa, *Agricultural Water Management,* **80**: 212-224

Bänziger, M., P.S. Setimela, D. Hodson and B. Vivek . 2004. Breeding for improved drought tolerance in maize adapted to Southern Africa. Fourth International Crop Science Congress, Brisbane, Australia

Bänziger, M., G.O. Edmeades and H.R. Lafitte . 2002. Physiological mechanisms contributing to the increased N stress tolerance of tropical maize selected for drought tolerance. *Field Crops Research,* **75**:223-233.

Banziger, M., and A.O. Diallo . 2002. Stress tolerant maize for farmers in sub Saharan Africa. In: CIMMYT Maize Research Highlights: 2002.CIMMYT

Banziger, M., Edmeades G.O., D. Beck, and M. Bellon. 2000. Breeding for drought and nitrogen stress tolerance in maize: From theory to practice, D.F.:CIMMYT.

Bänziger, M., G.O. Edmeades and H.R. Lafitte.1999.Selection for drought tolerance increases maize yields over a range of N levels. *Crop Science* **39**: 1035-1040.

Banziger, M., F.J. Betran, and Lafitte, H.R.(1997). Efficiency of high-nitrogen selection environments for improving maize for low-nitrogen target environments. *Crop Sci* **37**:1103-1109.

Banziger, M., and H.R. Latfitte .1997. Efficiency of Secondary Traits for Improving Maize for Low-Nitrogen Target Environments. *Crop Science,* **37** : 1110-1117.

Betran, F.J., D. Beck ., Banziger, M. and G.O. Edmeades. 2003. Genetic analysis of inbred and hybrid grain yield under stress and non stress environments in tropical maize. *Crop Science*, **43**:807-817.

Betran, F.J., J.M. Ribaut, D.Beck and G, D. de Leon. 2003. Genetic diversity, specific combining ability, and heterosis in tropical maize under stress and non stress environments. *Crop Science*, **43**:797-806.

Bindiger, F.R. 2003. Field Screening for Drought tolerance –Principles and Illustrations: In: Nutritional fortification of cereals pp 243-276

Bolanos, J and G.O. Edmeades. 1993. Eight cycles of selection for drought tolerance in lowland tropical maize.II. Responses in grain yield, biomass, and reproductive behaviour. *Field Crops Research*, **31**:233-268

Bolanos, J and G.O. Edmeades. 1996. The importance of anthesis silking interval in breeding for drought tolerance in tropical maize. *Field Crops Research*, **48**:65-80

Byerlee, D and P.W. Heisey. 1997. Evolution of the African maize economy. In: Byerlee D and Eicher C.K. (eds). Africa's emerging maize revolution. Boulder, Colorado; Lynne Rienner Publishers

Ceccarelli, S. 1996. International Course On Applied Plant Breeding: Breeding for sustainable development of marginal environments, IAC, Wageningen.

CIMMYT. 2001.Maize inbred lines released by CIMMYT. A compilation of 454 CIMMYT Maize Lines (CMLs), CML1-CML454. CIMMYT, Mexico.

Comstock, R.E. and H.F. Robinson. 1952. Estimation of average dominance of genes. In:Gowen, J.W. (eds). 1952. Heterosis.

Cooper, M., D.W. Podlich and S. Fukai S .1999. Combining information from multi-environment trials and molecular markers to select adaptive traits for yield improvement of rice in water-limited environments. 'Genetic improvement of rice for water-limited environments'. J O'Toole and B Hardy (eds). pp 13-33.

De Vries J. and G.Toenniessen. 2001. Securing the harvest. CABI Publisher

Doswell, C.R., R.L.Paliwal and R.P.Cantrell .1996. Maize in the Third World. Westview Press. U.S.A.

Duvick, D.N. 1997. Heterosis feeding people and protecting natural resources. Genetics and exploitation of heterosis in crops. *Based on the International Symposium on the genetics and exploitation in crops.* CIMMYT, Mexico. 17-22 August 1999. pp 6-7.

Duvick, D.N. and D. Farnham. 1997. The current status and future prospects for productivity improvements in maize. *Paper Prepared For Illinois World Food and sustainable Agriculture program conference. "Meeting the Demand for Food in the 21st century".*

Duvick, D.N. 1992. Genetic contributions to advances in yield of USA maize. *Maydica* **37**:69

Eberhart, S.A and W.A. Russell. 1966. Stability parameters for comparing cultivars. *Crop Science,* **6**:36-40

Edmeades, G.O., J. Bolaños, S.C. Chapman, H.R. Lafitte and M. Bänziger. 1999. Selection improves tolerance to mid/late season drought in tropical maize populations. I. Gains in biomass, grain yield and harvest index. *Crop Science* **39**, 1306-1315.

Edmeades, G.O., J. Bolanos, M. Banziger, J.M. Ribaut, J.W. White, M.P. Reynolds, and H.R. Lafitte. 1998. Improving crop yields under water deficits in the tropics. In: Chopra, V.L., Singh, R.B and Varma, A (eds). Crop productivity and sustainability-shaping the future. ICSC/IBH, Oxford, UK/New Delhi, India pp 437-451.

Edmeades, G.O., J. Bolanos, M. Banziger, J.M. Ribaut, J.W. White, M.P. Reynolds, and H.R. Lafitte. 1998. Improving crop yields under water deficits in the tropics. In: Chopra, V.L., Singh, R.B and Varma, A (Eds) Crop productivity and sustainability-shaping the future. ICSC/IBH, Oxford, UK/New Delhi, India pp 437-451.

Edmeades, G.O., J. Bolanos, M. Banziger, S.C. Chapman, A.Ortega, H.R. Latiffe, K.S. Fischer and S. Pandey. 1997a. Recurrent selection under managed drought stress improves grain yields in tropical maize. In G.O Edmeades, M, Banziger, H.R Mickelson, and C.B Pena-Valdivia (eds), Developing Drought and Low N-Tolerant Maize. *Proceedings of a Symposium*, March 25-29, 1996, CIMMYT, El Batan, Mexico,415-425. Mexico, D.F.: CIMMYT.

Edmeades, G.O., J. Bolanos and S.C. Chapman. 1997b. Value of secondary traits in selecting for drought tolerance in tropical maize. In G.O Edmeades, M, Banziger, H.R Mickelson, and C.B Pena-Valdivia (eds), Developing Drought and Low N-Tolerant Maize. Proceedings of a Symposium, March 25-29, 1996, CIMMYT, El Batan, Mexico,222-234. Mexico, D.F.: CIMMYT.

Falconer, D.S and T.F.C. Mackay. 1996. Introduction to quantitative genetics. 4th Ed. Longman. Essex. England.

FAOSTAT .2003. Statistical Database of the Food and Agriculture Organization of the United Nations. http://www.fao.org/waicent/portal/statistics_en.asp .

Gardner, C.O., and S.A. Eberhart. 1966. Analysis and the interpretation of the variety cross diallel and related populations. Biometrics **22**: 439-452

Griffing, B, .1956. Concept of general and specific combining ability relation to diallel crossing systems. Division of Plant Industry. C.S.I.R.O. Canberra, A.C.T. *Australian Journal of Biological Science*. **9**, 463-493.

Gutirrez –Gaitam, M.A., H. Corttez- Mendoza, E.N. Wathika, Gardner and L.L. Darrah. 1996. Testcross evaluation of Mexican maize populations. *Crop Science,* **26**: 99-104

Hallauer, A.R. and J.B. Miranda. 1981. Quantitative genetics in maize breeding. Iowa State University Press. Ames. Iowa.

Hallauer, A.R. 1997. Temperate maize and heterosis. In Book of Abstracts: The Genetics and exploitation of heterosis in crops. *An International Symposium*. 17-22 August 1997. Mexico City, Mexico. pp 268-69.

Hallauer, A.R., and J.B. Miranda. 1988. Quantitative genetics in maize breeding. 2nd Edition. Lowa State University Press. Ames Lowa.

Hallauer, A.R. 1975. Relation of gene action and type of tester in maize breeding procedures. *Proc. Annu. Corn Sorghum Res. Conf.* **30**:150-65

Heisey P.W. and G.O. Edmeades. 1999. In 'CIMMYT 1997/98 World Maize Facts and Trends'. pp. 1-36. CIMMYT Mexico D.F..

Jayne S.T. and M. Smale . 2004. Maize In Eastern and Southern Africa: Seeds of success in a historical perspective. In: Haggblade S and Gabre Madhin E. (eds), Success Stories in African Agriculture, IFPRI, Washington D.C.

Lafitte, H.R. and G.O. Edmeades. 1994. Stress tolerance in maize is linked to constitutive changes in ear growth characteristics. Crop Science, **35**:820-826.

Machida, L .1997. Estimates of yield loss in maize production due to drought in Zimbabwe. *Proceedings of Symposium*. March 25-29, 1997 CIMMYT El Batan Mexico pp 75-78.

Malik, S.I., N.M. Minhas and M. Munir .2004. General and Specific combining ability studies in maize diallel crosses. *Journal of Agriculture and Biology* Volume **6**, No 5, pp855-859.

Mashingaidze K .2006. Maize Research and Development. In: Zimbabwe's agricultural revolution revisited. Rukuni M, Tawonezvi P and Eicher C (eds) . University Of Zimbabwe Publication pp 363-377.

Matzinger, D.F. 1953. Comparison of three types of testers for the evaluation of inbred lines of corn. *Agronomy Journal*. **45**: 493-95.

Mechlinger, A.E., W.Schmit and H.H. Geiger. 1988. Comparison of testcrosses from F2 and first backcross populations in maize. *Crop Science*, **28**:743-749

Mickleson, H.R., H. Cordova, K.V. Pixley, and M.S. Bjarnason. 2001. Heterotic Relationships among nine temperate and subtropical maize populations: *Crops Science***41**:1012-1020.

Nass L.L, M. Lima and P.B. Gallo .2000. Combining Ability of Maize Inbred Lines Evaluated In Three Environments In Brazil, *Scientific Agriculture* Volume **57**, No.1 Brasilia.

Olver, R.C.1988. Maize breeding in Zimbabwe: In : H.O. Gevers. 1998. Proceedings of Eleventh South African Maize Breeding Symposium,.pp22-27

Pingali., P.L. and S. Pandey . 2001. Meeting world maize needs: technological opportunities and priorities for the public sector. In: Pingali, P.L (ed).2001. *CIMMYT 1999-2000 World Maize Facts and Trends. Meeting World Maize Needs.*

Pixley, K.V. 1994. Maize Resaerch in sub Saharan Africa. An overview of past impacts and future research highlights, CIMMYT Zimbabwe.

Pixley, K.V. and M.S. Bjarnason. 2002. Stability of grain yield, endosperm modification and protein quality of hybrid and open pollinated quality protein maize cultivars. *Crop Science*, **42**: 1882-1890

Pswarayi, A. 2004. Combining ability and tester identification of CIMMYT early maturing maize (Zea mays. L) germplasm under stress and non-stress conditions. MSC Thesis. University of Zimbabwe. Harare. Zimbabwe.

Pswarayi, A., and B. Vivek. 2004. Combining Ability of CIMMYT's early maturing maize (Zea mays L.) germplasm under stress and non-stress conditions and identification of testers. *Proceedings of the 4th International Congress*. 26th Sept- 1st October 2004.

Simmonds L.P. 1991. Selection for local adaptation in a plant breeding program. TAG Theoretical and Applied Genetics

SAS Institute .2001. SAS system for windows version 8.2. SAS Institute. Cary, NC

Singh B.D. 2003. Plant Breeding: Principles and Methods, Kalyani Publishers, New Dehli, India

Smale M and T.S. Jayne .2004. Maize Breeding In East and Southern Africa, 1900-2000 In: Building on success in African Agriculture : Vision 2020 For Food Agriculture and the Environment.

Sprague, G.F., and L.A. Tatum. 1942. General versus specific combining ability in single crosses of corn. *Journal of American . Soc. Agronomy*. **34**: 923-932.

Srivastava, A., I.S. Singh and M.Z.K. Warsi .2004. Heterosis and combining ability of CIMMYT and NARS Lines. In: *46th Annual Maize Genetic Conference*: 11-14 March, 2004. Mexico.

Tattersfield, J.R. 1982. The role of research in increasing food security. *Zimbabwe Agricultural Journal*, **81**:31-35

Troyer, A.F. 1996. Breeding widely adapted, popular maize hybrids. *Euphytica*, **92**: 163-174.

Vasal, S.K., H. Cordova, S. Pandey, and G. Srinivan. .1986. Tropical maize and heterosis. *In CIMMYT Research Highlights 1986.* Mexico. D.F. CIMMYT.

Vasal, S.K., G. Srinivasan, S. Pandey, D.L. Beck, J. Crossa and C. De Leon.1992. Heterosis and Combining Ability of CIMMYT's tropical late white maize germplasm. *Maydica* **37**:217-223

Vasal, S.K., G. Srinivasan, F.C. Gonzalez., G.C. Han, S. Pandey, D.L. Beck and J. CrossaJ. 1992c. Heterosis and combining ability of CIMMYT's tropical x subtropical maize germplasm. *Crop Science* **32**:1483-1489

Vasal, S.K., H. Cordova, D.L. Beck and G.O. Edmeades. 1997. Choices among breeding procedures and strategies for developing stress tolerant maize germplasm. In: Edmeades G.O., Banziger M, Mickelson, and Pena-Valdivia C.B.(eds). *Developing drought and low N tolerant maize. Proceedings of a symposium* , March 22-29,1996, CIMMYT, El Batan, Mexico.

APPENDICES

Appendix A : SCA Effects for Anthesis Dates Under Optimum Conditions

	TESTER										
LINE	1	2	3	4	5	6	7	8	9	10	MEAN
1	68.0	66.0	67.0	69.3	63.3	67.0	64.7	67.3	66.0	64.7	66.3
2	66.0	67.0	67.0	66.3	67.3	65.7	65.3	64.3	64.0	62.7	65.6
3	65.8	65.0	63.7	66.3	66.3	65.3	67.7	66.7	67.3	67.0	66.1
4	65.8	65.0	62.0	62.3	67.0	67.7	64.0	66.0	67.0	66.3	65.3
5	66.4	66.0	62.3	67.7	68.3	66.0	67.7	63.3	66.7	63.7	65.8
6	60.0	66.0	66.0	65.7	67.7	66.7	65.7	66.7	66.0	66.3	65.7
7	65.3	68.5	68.7	66.0	65.7	63.7	67.8	64.5	69.3	62.7	66.2
8	66.0	65.2	69.0	69.0	66.0	68.0	65.7	64.3	66.7	65.3	66.5
9	67.7	65.7	69.5	68.7	66.0	69.0	68.0	65.8	63.0	67.0	67.0
10	67.5	65.5	68.5	66.0	65.3	67.0	65.0	65.0	66.0	68.0	66.4
MEAN	65.8	66.0	66.4	66.7	66.3	66.6	66.1	65.4	66.2	65.4	66.1
LSD0.05	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3

Appendix B: SCA Effects For Anthesis Dates Under Low N

	TESTER										
LINE	1	2	3	4	5	6	7	8	9	10	MEAN
1	77.3	77.0	81.0	75.0	76.3	75.0	75.0	78.7	72.3	73.7	76.1
2	81.3	81.0	80.3	78.7	78.7	77.7	71.7	79.0	73.3	74.0	77.6
3	80.3	74.0	77.3	73.3	75.0	73.3	77.0	71.0	70.0	70.7	74.2
4	79.0	75.3	75.7	75.0	74.0	74.0	71.7	74.0	71.0	68.7	73.8
5	77.3	79.0	74.0	73.0	71.7	72.0	74.0	74.7	72.0	68.5	73.6
6	66.0	67.0	66.0	67.0	68.0	66.7	67.3	67.0	66.7	66.7	66.8
7	70.0	72.7	76.3	70.3	72.0	71.3	69.3	70.0	67.7	67.7	70.7
8	79.3	80.3	82.3	77.7	80.0	78.0	76.3	81.0	70.7	79.0	78.5
9	75.0	74.0	75.0	73.0	72.3	71.0	68.3	71.3	68.7	68.3	71.7
10	80.0	73.0	80.3	75.7	75.7	73.3	71.0	70.7	71.0	70.3	74.1
MEAN	76.6	75.3	76.8	73.9	74.4	73.2	72.2	73.7	70.3	70.8	73.7
LSD0.05	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3

Appendix C: SCA Effects For Anthesis Dates Under Drought Conditions

	TESTER										
LINE	1	2	3	4	5	6	7	8	9	10	MEAN
1	85.3	84.7	85.7	82.0	83.0	84.7	88.3	86.0	78.7	83.0	84.1
2	86.0	80.0	88.7	79.7	88.3	89.7	94.3	85.0	82.7	83.7	85.8
3	86.3	82.0	85.0	80.3	79.3	79.3	81.0	78.7	80.3	79.3	81.2
4	84.3	81.0	87.7	80.0	81.7	82.7	85.7	81.7	77.7	80.3	82.3
5	84.3	85.7	84.0	79.7	81.3	83.0	84.0	82.3	81.0	80.3	82.6
6	77.5	75.7	76.3	72.0	77.7	76.7	76.8	81.0	71.8	73.5	75.9
7	84.0	82.7	81.3	76.0	78.0	81.0	82.3	80.7	77.7	77.7	80.1
8	87.0	86.7	86.7	82.7	83.3	85.0	89.7	86.0	80.7	82.7	85.1
9	82.8	83.5	85.0	78.3	81.3	81.3	83.0	81.3	78.0	78.3	81.3
10	79.7	81.0	88.3	77.3	82.3	81.3	89.0	82.0	79.3	82.7	82.3
MEAN	83.7	82.3	84.9	78.8	81.6	82.5	85.4	82.5	78.8	80.2	82.1
LSD0.05	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3

Appendix D: SCA Effects For ASI Under Optimum Conditions

	TESTER										
LINE	1	2	3	4	5	6	7	8	9	10	MEAN
1	4.3	3.3	4.0	5.3	5.3	3.3	5.7	4.7	5.0	4.7	4.6
2	3.7	5.0	2.7	5.7	5.0	5.3	2.0	4.7	6.3	5.3	4.6
3	3.7	4.7	2.7	4.0	6.7	2.7	1.7	4.0	3.7	4.0	3.8
4	1.7	1.3	1.7	3.0	1.7	2.0	1.7	2.7	3.7	0.3	2.0
5	5.0	3.0	2.3	6.3	4.7	4.3	4.3	6.0	5.3	1.7	4.3
6	1.3	0.0	0.5	1.0	0.7	1.3	1.0	1.3	1.0	1.0	0.9
7	3.7	2.0	2.7	2.0	2.3	2.7	2.3	3.0	1.3	0.7	2.3
8	4.3	5.7	2.3	4.7	4.5	3.7	5.3	6.0	3.0	0.0	4.0
9	3.3	2.7	2.0	3.0	2.3	1.7	1.7	1.7	1.7	0.8	2.1
10	3.7	6.7	2.0	5.3	5.0	1.4	3.3	4.0	3.7	3.7	3.9
MEAN	3.5	3.4	2.3	4.0	3.8	2.8	2.9	3.8	3.5	2.2	3.2
LSD0.05	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6

Appendix E: SCA Effects For ASI Under Low N Conditions

	TESTER										
LINE	1	2	3	4	5	6	7	8	9	10	MEAN
1	4.0	4.0	2.0	4.7	6.0	4.0	5.3	5.7	4.3	2.3	4.2
2	5.3	5.3	5.0	6.7	5.0	6.0	3.7	7.3	7.3	5.0	5.7
3	3.0	5.3	3.3	4.7	5.0	4.3	3.3	7.7	4.7	3.0	4.4
4	1.0	2.0	1.7	3.3	3.7	1.0	3.3	3.7	2.3	1.0	2.3
5	2.0	2.3	5.3	5.7	3.3	3.3	5.7	4.7	4.0	2.0	3.8
6	1.0	1.3	1.3	2.0	1.7	1.7	1.3	1.3	1.0	1.3	1.4
7	8.0	2.7	1.7	6.0	4.3	1.0	4.7	6.3	3.7	1.0	3.9
8	4.0	2.3	3.0	3.0	3.7	3.0	1.7	4.0	6.3	3.3	3.4
9	4.3	3.0	2.0	6.7	3.7	2.7	5.0	5.3	3.7	2.7	3.9
10	5.0	6.0	2.7	4.0	4.3	5.7	3.7	7.0	2.3	5.0	4.6
MEAN	3.7	3.4	2.9	4.7	3.9	3.2	3.6	5.3	3.9	2.7	3.7
LSD0.05	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6

Appendix F: SCA Effects For ASI Under Drought Conditions

	TESTER										
LINE	1	2	3	4	5	6	7	8	9	10	MEAN
1	4.3	4.3	4.3	2.3	3.7	2.3	2.0	6.0	3.3	2.3	3.5
2	3.7	4.3	10.0	7.0	6.0	9.3	7.7	7.0	4.3	8.0	6.7
3	3.7	4.0	4.0	5.3	6.3	4.3	4.0	3.0	2.7	1.3	3.9
4	3.3	3.0	2.7	4.3	4.3	1.7	4.7	3.7	1.7	1.7	3.1
5	5.0	4.3	3.7	3.3	5.7	5.0	4.0	4.0	4.7	8.7	4.8
6	3.0	2.7	2.7	1.7	1.0	2.3	1.3	2.0	1.8	2.5	2.1
7	4.7	2.0	5.7	1.3	2.0	2.7	2.0	4.3	2.0	1.7	2.8
8	2.0	2.3	2.0	2.7	1.0	3.0	4.0	3.3	2.0	2.3	2.5
9	2.5	5.5	4.3	2.3	2.7	4.3	3.7	4.0	2.0	2.7	3.4
10	6.7	5.3	8.3	5.0	3.7	4.7	3.0	4.0	3.3	7.0	5.1
MEAN	3.9	3.8	4.8	3.5	3.6	4.0	3.6	4.1	2.8	3.8	3.8
LSD0.05	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6

Appendix G: SCA Effects For EPP Under Optimum Conditions

	TESTER										
LINE	1	2	3	4	5	6	7	8	9	10	MEAN
1	1.07	1.25	1.22	1.46	1.30	1.25	1.13	1.13	1.03	1.22	1.21
2	1.27	1.45	1.41	1.06	1.26	1.09	1.22	1.15	1.18	1.57	1.27
3	1.25	1.25	1.15	1.19	1.13	1.02	1.20	1.29	1.11	1.15	1.17
4	1.21	1.19	1.16	1.39	1.07	1.06	0.93	1.18	1.10	1.35	1.16
5	1.20	0.91	1.20	1.43	1.35	1.10	1.18	1.20	1.29	1.09	1.20
6	1.13	1.21	1.08	1.24	1.11	1.37	0.97	1.18	1.24	1.19	1.17
7	1.39	1.63	1.15	1.18	1.10	1.24	1.51	1.26	1.09	1.38	1.29
8	1.01	1.14	1.14	1.11	1.11	1.42	1.07	1.20	1.09	1.14	1.14
9	1.32	1.23	1.06	1.42	1.13	1.26	1.73	1.34	1.16	1.37	1.30
10	1.34	1.16	1.15	1.00	1.16	1.31	1.57	1.37	1.16	1.23	1.25
MEAN	1.22	1.24	1.17	1.25	1.17	1.21	1.25	1.23	1.15	1.27	1.22
LSD0.05	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39

Appendix H: SCA Effects For EPP Under Low N Conditions

	TESTER										
LINE	1	2	3	4	5	6	7	8	9	10	MEAN
1	0.52	0.74	0.72	0.87	0.81	0.62	0.81	0.51	0.61	0.73	0.69
2	0.55	0.67	0.79	0.74	0.77	0.65	0.70	0.57	0.76	0.67	0.69
3	0.77	0.74	0.61	0.82	0.71	1.20	0.61	0.69	0.81	0.82	0.78
4	0.78	0.98	0.76	0.96	0.69	0.68	0.58	0.85	0.80	0.59	0.77
5	0.69	0.77	0.59	0.77	0.77	0.83	0.66	0.61	0.83	0.72	0.72
6	0.70	0.76	0.72	0.61	0.85	0.74	0.77	0.68	0.73	0.70	0.73
7	0.78	0.81	0.46	0.97	0.82	0.79	0.69	0.77	0.81	0.90	0.78
8	0.68	0.71	0.67	0.87	0.81	0.74	0.76	0.50	0.69	0.69	0.71
9	0.83	0.87	0.75	0.80	0.70	0.77	0.78	0.88	0.87	0.70	0.80
10	0.68	0.76	0.70	0.84	0.74	0.87	0.80	0.71	0.81	0.80	0.77
MEAN	0.70	0.78	0.68	0.82	0.77	0.79	0.72	0.68	0.77	0.73	0.74
LSD0.05	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39

Appendix K: Line GCA ranks for measured traits

LINE	GY Rank	EPP Rank	AD Rank	ASI Rank	PH Rank	RL Rank	SL Rank	EH Rank	EPO Rank	ER Rank	Average Rank	Overall Rank
1	4	9	8	7	7	9	6	8	4	4	6.6	8
2	2	7	9	10	10	8	7	10	9	8	8.0	10
3	8	6	5	6	5	1	8	5	7	10	6.1	7
4	10	3	4	2	4	7	5	3	6	7	5.1	5
5	1	8	7	8	6	6	3	7	5	6	5.7	6
6	9	5	1	1	1	10	10	1	1	9	4.8	4
7	6	2	2	3	2	3	2	2	3	2	2.7	1
8	7	10	10	5	8	5	9	9	10	5	7.8	9
9	3	1	3	4	3	4	4	6	8	1	3.7	2
10	5	4	6	9	9	2	1	4	2	3	4.5	3
Mean	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5		

Appendix L: Tester GCA Ranks for measured traits

TESTER	GY Rank	AD Rank	ASI Rank	PH Rank	RL Rank	SL Rank	EH Rank	EPO Rank	EPP Rank	ER Rank	Average Rank	Overall Rank
1	9	9	6	8	1	6	9	8	8	7	7.1	10
2	4	8	5	7	6	2	7	6	4	5	5.4	5
3	1	10	2	9	2	3	10	10	10	2	5.9	8
4	2	3	9	5	8	8	8	9	1	1	5.4	5
5	5	5	8	2	3	10	1	1	6	4	4.5	2
6	3	6	7	10	10	1	3	2	3	8	5.3	4
7	6	4	3	3	9	5	5	5	2	9	5.1	3
8	8	7	10	6	4	7	6	4	9	6	6.7	9
9	10	1	4	1	5	4	2	7	5	3	4.2	1
10	7	2	1	4	7	9	4	3	7	10	5.4	5
Mean	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5		