Declaration

I hereby declare that this dissertation, prepared for the Master of Science degree which was submitted by me to the University of Free State is my original work and has not previously in its entirety or part been submitted to any other University. All sources of materials and financial assistance used for the study have been duly acknowledged. I also agree that the University of the Free State has the sole right to publication of the dissertation.

Signed on the 27th November 2007 at the University of Free State, Bloemfontein, South Africa.

Signature:

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Dedication

To my wife (Faustine), son (Kudakwashe), daughters, Nyengeterai and Nyasha, my late grandmother, mother and father.

Quotation

You can take away the tractors, the fertilizer, the irrigation pipes and the combine.
You can burn down the barn and pull up fences and still be a farmer.
But take away the seed those minute bits of germplasm planted in the field, and
you might as well try growing rocks".
Dick Yost (Oregon Farmer/Stockman), 1984

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List of abbreviations

ACO	Across optimal
AD	Anthesis date:
ART	Agricultural Research Trust
ASI	Anthesis-silking interval
ANOVA	Analysis of variance
CIMMYT	Centro International de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Centre)
CRS	Chiredzi Research Station
DNA	Deoxyribonucleic acid
EPP	Ears per plant
FAOSTAT	Food and Agriculture Organization Statistics
GCA	General combining ability
GD	Genetic distance
GY	Grain yield
HGA	Heterotic group A
HGB	Heterotic group B
HLN	Harare Low Nitrogen
HPH	High parent heterosis
KRS	Kadoma Research Station
LSD	Least significant differences
MAB	Marker assisted back cross
MAS	Marker assisted selection
MPH	Mid parent heterosis
NARS	National Agricultural Research Systems
PIC	Polymorphic information content
QTL	Quantitative trait loci
RARS	Rattray Arnold Research Station
RFLP	Restriction fragment length polymorphism
SEN	Senescence
SCA	Specific combining ability
SX	Single cross
TX	Triple cross

Chapter 1

Introduction

Maize (*Zea mays* L.) is one of the oldest food grains. It belongs to the grass family Poaceae (Gramineae), tribe Maydeae and is the only cultivated species in this genus. It is the most productive food plant with a multiplication ratio of 1: 600 or more per plant bases under optimum conditions (Aldrich *et al*., 1975).

Maize grain today is recognized worldwide as a strategic food and feed crop that provides an enormous amount of protein and energy for humans and livestock. Maize ranks second in cereal production after wheat, with an annual production of about 600 million t (Sasson, 1990; Paliwal, 2000). It is estimated that by the year 2020, demand for maize in developing countries will surpass the demand for both wheat and rice. From 1995 to 2020, global and sub-Saharan Africa consumption was projected to increase by 50% and 93% respectively (CIMMYT, 2001).

From the year 2000, of the 140 million has of maize grown globally, approximately 96 million hectares were in the developing world (CIMMYT, 2001). In many of the developing countries, such as Guatemala, Mexico, Kenya, Zambia and Zimbabwe, maize is the basic staple food, with a per capita consumption average of 100 kilograms per year, supplying 40% of the total calorie needs (Sasson, 1990).

Drought is one of the important constraints to crop production even during the rainy season on soils in subtropical and mid altitude environments due to erratic rainfall distribution (Lal *et al*., 1982), affecting agricultural production on about 60% of the land area in the tropics (Sanchez *et al.*, 1977). Drought reduces maize yields by about 15% annually in the lowland tropics and subtropics, amounting to an estimated 16 million t of grain loss (Edmeades *et al.,* 1992).

Supplementary irrigation could potentially improve maize production in drought prone areas. However the majority of smallholder farmers cannot access irrigation either because of their geographical location or cannot afford infrastructure development costs. Only about 5% of the cropped area in developing countries is irrigated (FAOSTAT, 2003).

Nitrogen deficiency is almost universal in the tropics except on recently cleared land (Sanchez *et al.,* 1977), and is one of the most important abiotic factors limiting maize yields in the tropics (Lafitte and Banziger, 1997). This means that the nitrogen requirement of the crop must be met by the addition of organic or inorganic fertilizers. The non-availability of fertilizers and high prices contribute to constraints limiting maize production in most developing countries. In spite of maize yield potential of above 10 ton/ha, fertilizer consumption on crop land averages 25kg/ha and seems to have decreased over the past 10 years (FAOSTAT, 2003) as farmers have faced increased input cost and decreasing production price (Banziger *et al*., 2004).

There are few early maturing maize varieties available from commercial seed houses. Not much information is available on varieties that combine early maturity, drought and low nitrogen tolerance. This may be because commercial breeders target commercial farmers who prefer high yielding intermediate to late maturing varieties.

While intermediate to late maturing maize varieties are ideal and suitable for commercial production because of their high yield potential, maize in the tropics is continually exposed to different forms of drought and nitrogen stress. This may be partly due to global climatic changes, partly due to displacement of maize to more difficult production environments by high value crops, and partly due to declining soil organic matter reducing soil fertility and water holding capacity (Banziger and Cooper, 2001).

Efforts to improve maize productivity focusing on producing high yielding, high input varieties, improving crop management and soil fertility through several organic and inorganic amendment options, largely benefits average smallholder and commercial farmers but not the resource poor farmers.

In semi-arid communal areas of Zimbabwe, crop residue is harvested, stored and used as supplementary livestock feed, before the pastures regenerate at the beginning of summer. Animals in communal areas free range in fields during winter. This results in little plant residues left to ameliorate the soil and consequently soil fertility declines with each successive planting in communal settings. The soils are inherently infertile, deficient in nitrogen, phosphorus and sulphur in particular and have a low potential to sustain agricultural production under continuous cultivation (Mapfumo and Giller, 2001).

Smallholder farmers often use cattle manure to replenish soil fertility in semi arid communal areas of Zimbabwe. However a large proportion of communal farmers do not own cattle. They have no control of livestock feeding on crop residue in their fields during the winter period resulting in further decline of soil fertility in fields. During the rainy season, they loose prime planting time working in richer families' fields in order to meet immediate requirements such as food and school fees for children and sometimes in return for ploughing their fields later in the season. They have no resources to purchase seed and fertilizers.

The International Maize and Wheat improvement Centre (CIMMYT) started to improve maize for drought tolerance in the 1970s. Progenies of experimental maize were evaluated under three carefully managed water supply levels (1) flowering drought stress, (2) grain filling drought stress and (3) well watered conditions (Banziger *et al*., 2004). Selection was for an index that sought to maintain constant anthesis date and grain yield under well water conditions, increase grain yield stem and leaf extension under drought and decrease anthesis-silkig interval (ASI), leaf senescence and canopy temperature under drought (Bolanos and Edmeades, 1993). Selection gains under drought were due to increased partitioning of dry matter to the growing ear, but biomass production and likely water uptake did not change (Bolanos and Edmeades, 1993; Edmeades *et al.* 1992).

Most assessments on progress of CIMMYT's drought maize populations were conducted in environments where the populations were selected and it was hypothesized that selection gains may be limited to particular drought conditions in the selection environment (Banziger *et al*., 2004). According to Banziger *et al.* (2004), Byrne *et al*. (1995) demonstrated greater yield stability of one drought tolerant selected population compared to its conventionally selected counter part across international testing locations. Improvements under drought were associated with selection gains across a wide range of nitrogen supply levels (Banziger *et al*., 2000) indicating that the screening approach using managed drought environments may have wide merits (Banziger *et al*., 2004).

It was indicated that early maturing maize varieties are important for resources poor farmers, for the following reasons: (a) they provide an early harvest, bridging the hunger gap before the main harvest period, (b) in areas where two cropping seasons occur, they provide additional early harvest for subsequent cropping for the main season (Pswarayi and Vivek, 2007), (c) they enable multiple planting dates over an extended period of time as a measure to cope with the uncertainty of the rainfall patterns, for example mid season droughts, and early termination of the rainfall season in southern African countries (Rohrbach, 1998) and (d) the flexibility with planting dates, enable farmers relying on borrowed draught power to plant later in the season.

In an effort to improve maize yields at household level in marginalized areas with minimum input requirements, it was important to develop early maturing and drought tolerant varieties that could tolerate low soil nitrogen found in the tropical and subtropical regions. The main objective of this study was to assess the relative importance of general combining ability (GCA) and specific combining ability (SCA) of CIMMYT's early maize lines and single cross hybrids to drought stress and low soil nitrogen stress for the mid altitude environments.

Specific objectives were (1) to study the heterotic relationship of CIMMYT's early maturing maize germplasm and combining ability for grain yield, under drought and low soil nitrogen as well as identify lines and single crosses hybrids with good GCA and SCA (2) classify the maize inbred lines and single cross hybrids into different heterotic groups (3) assess the relative importance of a potential CIMMYT early maturing maize tester and (4) where possible identify a potential heterotic group B early maturing tester.

Chapter 2

Review of literature

2.1 Maize production and uses

FAO forecasted world production of coarse grains in 2006 at about 976 million t, down 1.5% from 2005 (FAO Food Outlook, 2006). Maize accounted for about 70% (approximately 692.2 million t) of the total. The main factor for smaller crop plantings was reduced incentive in maize and high production cost relative to expected returns and adverse weather (FAO Food Outlook, 2006).

In the tropics, maize is grown in 66 countries and is of major economic significance in 61 of those countries (Paliwal, 2000). In southern Africa, maize is grown on over 12 million ha (FAOSTAT, 2003). Maize is one of the most productive species of food plants. It is a C4 plant with a high rate of photosynthetic activity. Its multiplication ratio on per plant basis is 1:600 to 1000 (Aldrich *et al*., 1975), and has the highest potential carbohydrate production per unit area.

In developing countries maize is generally used as food, while in the developed world, it is used widely as a major source of carbohydrate in animal feed and as industrial raw materials for wet and dry milling (Paliwal, 2000). Apart from a strong demand for starches and sweeteners, there has been exponential growth in maize-based ethanol production, fuelled by rapid increases in world energy and petrol prices (FAO Food Outlook, 2006).

The average yield of maize in the tropics is 1.8 t/ha, against the global average of 4.2 t/ha (CIMMYT, 1994). According to Larsson (2005) a survey of sub-Saharan Africa revealed that over the period 2000-2002 both average maize production and yields for smallholder farmers were generally low with an overall mean of 1.3 t/ha.

2.2 The importance of early maturing maize varieties

In southern Africa, in efforts to cope with rainfall risk, many small-scale farmers purposefully pursue multiple planting dates over extended periods of time in order to assure that at least part of the crop is successful (Rorhrbach, 1998). According to Pswarayi and Vivek (2007) farmers grow early maturing maize varieties because such varieties provide an early harvest to bridge the hungry period before harvest of a full season crop, and this is especially important in areas where two growing seasons occur in a year. Farmers can produce an early maturing crop during the secondary, short season, enabling the planting of a full season maize crop or other crops in the following main season.

Early maturing varieties offer flexibility in planting dates which enables (1) multiple planting in a season to spread the risk of loosing a single crop to mid season droughts (2) late planting during delayed onset of rainfall and (3) avoidance of known terminal drought during the cropping season (Pswarayi and Vivek, 2007). Early maturing varieties are ideal for off-season plantings in drying riverbeds and are also suitable for intercropping as they provide less competition for moisture, light and nutrients than the late maturing varieties (CIMMYT, 2000).

Using maize maturity to maintain grain yield in response to late season drought, in trials conducted in two locations over two seasons, Larson and Clegg (1999) found that use of well adapted early maturing hybrids could improve yield stability. They also found that an early maturing hybrid, Pioneer 3737, produced yield comparable to those of late maturing hybrids in all instances. Their results indicated that well adapted early maturing hybrids could produce yields comparable or better than late maturing hybrids in areas where late season water stress was prevalent.

Kamara *et al*. (2006) evaluated three maize varieties that had been identified either as drought tolerant or as able to escape drought. The drought tolerant maize was evaluated on farmers' fields for two years. Farmers selected extra early maturing because they provided food security during the period of food scarcity in August /September and emphasis was on earliness of crop maturity rather than on yield.

2.3 Effects of drought stress on maize production

Low water holding capacity of soil, erratic rainfall distribution, shallow effective rooting depths, high losses by runoff and evaporation lead to wide spread occurrence of drought stress in subtropical environments (Lal *et al.,* 1982). In lowland tropics and subtropics, drought reduces maize yields by about 15% annually, amounting to an estimated 16 million t of grain (Edmeades *et al.*, 1992).

Drought affects maize at different stages of development starting from crop establishment up to grain filling. Grain yield is affected to some degree at almost all growth stages; however the crop is more susceptible during flowering (Banziger *et al*., 2000). Studies on the timing of drought stress have indicated that flowering is the most sensitive stage for yield determination in maize, and losses in grain yield and kernels per plant can exceed 50% when drought coincides with this period (Grant *et al.*, 1989). It is common for drought imposed at flowering to lengthen the anthesis-silking interval (ASI) (Bolanos and Edmeades, 1993).

This is usually caused by a delay in silk emergence relative to emergence of the anthers, the latter being little affected by drought (Westgate and Boyer, 1986). Delayed silk emergence may be due to reduced rate of silk elongation, a process that is strongly affected by water status (Westgate and Boyer, 1986). Extreme sensitivity seems confined to the period -2 to 22 days after silking, with a peak at seven days. Almost complete barrenness can occur if maize plants are stressed in the interval just before tassel emergence to the beginning of grain fill (Grant *et al*., 1989).

Banziger *et al.* (2000) reported that drought can affect maize production by decreasing plant population during the seedling stage, by decreasing leaf area development and photosynthesis rate during the pre-flowering period, by decreasing ear and kernel set during the two weeks bracketing flowering, and by decreasing photosynthesis and inducing early senescence during grain filling. Additional reduction in production may come from increased energy and nutrient consumption of drought adaptive responses, such as increased root growth under drought.

While irrigation could relieve smallholder farmers from the harsh effects of drought, land under irrigation in sub-Saharan Africa still constitutes a small fraction (7%) of cultivated land (Larsson, 2005).

2.4 Effects of low soil nitrogen on maize yields

Maize has a strong positive response to nitrogen (N) supply, and inadequate N is second only to drought as a constraint to tropical maize production (Lafitte, 2000). Nitrogen stress reduces photosynthesis by reducing leaf area development and accelerating leaf senescence. The pattern of nitrogen stress is usually similar across locations. At the beginning of the season and especially with fertilizer applied, N supply usually exceeds the N demand by the crop. As the season progresses N is used, leading to N depletion in the soil. Consequently N becomes scarce and N stress develops. The usual scenario is that N stress becomes increasingly severe over time (Banziger and Lafitte, 1997).

Depending on the timing of N stress in the growing plant parts, different yield determining factors are affected. When there is ample nitrogen available, N stress may develop during grain filling only, affecting kernel weight. If stress develops during flowering stage, kernel abortion increases. Nitrogen stress before flowering reduces leaf area development, photosynthetic rate and number of potential kernel ovules. Severe N stress delays both shedding of pollen shed and emerging of silks, but the delay in silking is relatively more, such that anthesis-silking interval (ASI) becomes greater (Banziger *et al*., 2000).

Nitrogen requirements for the maize crop can be met by addition of organic or inorganic fertilizer. However the non-availability and high price of fertilizers contribute to constraints, limiting maize productivity in most developing countries as the majority smallholder farmers lack resources for purchasing yield-improving inputs. In spite of the maize yield potential above 10 t/ha, fertilizer application on crops averages 25 kg/ha and seems to have decreased over the past 10 years (FAOSTAT, 2003) as farmers have faced increasing input costs and decreasing production prices (Banziger *et al.,* 2004).

In a 2000-2002 survey of sub Saharan Africa, Larsson (2005) reported that 53% of smallholder farmers did not apply fertilizer at all during the 2002 season and most of those who did, used very small quantities averaging 14 kg/ha. These quantities are low compared to what commercial farmers apply (300-400 kg/ha). At micro level, fertility and water availability varied greatly within farmers' fields (Banziger *et al.*, 2000).

2.5 Breeding strategies for developing drought and low N tolerant varieties

According to Banziger *et al.* (2000), breeding methodologies in the tropics were strongly influenced by maize breeding in temperate areas. In temperate environments maize is grown under relatively stress free conditions, and farm yields are comparable to yields obtained from experiment stations. On the contrary in tropical environments maize is frequently stressed and on farm yields fall far below those obtained on breeding stations. This means that selection under high yielding conditions may not be the best way to increase yields in farmers' fields.

In developing countries, farmers in high yielding, high input areas are attractive targets for the private sector rather than the average, often resource poor farmers. As a result, commercial breeders often ignore abiotic stress tolerance. Public sector is influenced by the same view although their responsibility and target environments include areas not served by the private sector (Banziger *et al*., 2000).

Heritability and genetic variance for grain yield usually decreases under abiotic stress as yield levels fall. Difference between entries is non-significant and the expected selection gain is less than under conditions where yields are high. Because of the high genotype x environment interactions involved, stress experiments often produce rankings that differ significantly from one experiment to another, making it difficult to identify the best germplasm (Banziger *et al.*, 2000).

Using a selection approach based on three types of environments described as: recommended agronomic management high rainfall condition, low N stress and managed drought stress, Banziger *et al*. (2004) produced 41 CIMMYT hybrids and compared their performance with

42 released and pre-leased hybrids from private seed companies in several environments across east and southern Africa. Hybrids from the CIMMYT stress breeding programme showed consistent advantage over commercial checks and hybrids from private companies at all yield levels. Eberhart-Russell stability analysis estimated 40% yield advantage at the one tonne level, which decreased to 2.5% at 10 t level. Those results suggested that simultaneous selection for tolerance and resistance to abiotic and biotic stress while monitoring performance under high potential conditions could result in significant progress for target environments where combination of stresses occur at lower yield level.

Physiology of maize shows that certain plant characteristics that are less relevant under non-stressed conditions become important for yield under drought and N stress. The most apparent example is the ability of a genotype to produce grain-bearing ears under drought stress at flowering. This characteristic can only be observed under drought conditions. This requires managing both drought and low N tolerance stresses. In the case of drought, this is achieved by conducting experiments partly or entirely during dry seasons and managing the stress through irrigation. In the case of low N, this is achieved by carrying out experiments in fields that are depleted of nitrogen. The objective of such experiments is to measure the genotypic drought tolerance and or the genotypic low N tolerance (Banziger *et al*., 2000).

In a study to determine effects of drought screening methodology on genetic variance and covariance in Pool 16 DT maize populations, Badu-Apraku *et al*. (2004) found narrow based heritability estimates of 73% for grain yield. Although the induced stress appeared to be too severe to properly elicit the true differences among families, they found sufficient genetic variance to warrant continued selection for drought tolerance among the white early maturing populations.

In a similar study, Zaidi *et al.* (2004) examined the performance of hybrid progenies of drought–tolerant populations (DTP) in stressed (drought and low-N) and unstressed environments. They compared a set of high yielding normal single cross hybrids developed using inbred lines improved with main emphasis on yield *per se* under optimal conditions with DTPc9S_3 top-crosses across environments. They found that performance of normal hybrids was slightly higher than DTP top-crosses under optimal conditions.

However, normal hybrids performed poorly with an average yield of 3.3-4.8% under drought and 34.8-36.2% under low N. Hybrid progenies from DTP yielded up to 31.8-42.4% under drought and 48.9-63.6% under low-N compared to yields without stress. Estimation of gains with selection for mid season drought in DTPs over selection for improved yields under optimal input conditions were 89.6% for drought and 39.3% for low N. They attributed the improved performance of DTP hybrids across environments to improvement in secondary traits such as reduced anthesis-silking interval (ASI), increased ears per plant, delayed senescence and relatively high leaf chlorophyll during late grain filling.

In Ghana, Sallah *et al.* (2002) assessed nine early maturing maize composites including drought tolerant selections under stressed and non-stressed conditions. Effects due to environment x genotype were highly significant (P<0.01) for grain yield, 50% (ASI), plant height, lodging, ears per plant and ear ratings for both drought stressed and unstressed conditions. Average yield in stressed environments ranged from 2.21 to 3.12 t/ha while in favourable environments it was 4.17 to 5.96 t/ha. Two drought tolerant selections out yielded the improved check and the local landrace in stressed environments. In non-stressed environments, grain yield was similar (average 5.85 t/ha) for the two elite varieties and the improved check.

Grain yield in stressed environments was positively correlated (r=0.71, P<0.01) with yield in the non-stressed environments. Estimates of Eberhart and Russell (1966) stability parameters for coefficient of regression across environments were b=1.04 for improved varieties and b=0.65 for the local varieties. The deviation of 0.13 and 0.22 for improved and landrace varieties respectively indicated that improved maize varieties were more stable than the local landrace varieties. The positive association of grain yield in stressed environments suggested that a variety that was outstanding in the stressed environment was also high yielding in the optimal environment and hence the methodology for improving populations and varieties enhanced productivity.

In a study to determine stability of drought tolerant maize in Ethiopia, Seboksa *et al.* (2001) evaluated 19 promising maize genotypes at six locations for three years. Combined ANOVA showed highly significant ($P<0.01$) genotype, genotype x environment and genotype x year effects on grain yield. Genotype DTP-1 C6's regression coefficient was close to one and this small deviation from the regression was fairly stable across environments. It had a mean yield above the grand mean and was considered having potential for future use in drought prone areas in Ethiopia.

Omoigui *et al.* (2006) assessed the genetic gain after three cycles of full sib recurrent selection applied on a low N pool type maize population. The population was derived from intermating of germplasm from CIMMYT in order to improve tolerance to low soil N. The three cycles of full sib recurrent selection for low N tolerance resulted in genetic gain of 2.3% and 1.9% grain yield at low N and high N respectively. The selection also increased the stay green ability and kernel weight with a corresponding gain of 17.7% and 4.7% respectively. The observed gains compared favourably with the expected genetic gains and it was concluded that full sib recurrent selection was a useful procedure in population improvement for improved performance of low soil N tolerance.

Ribaut and Ragot (2007) presented results of marker-assisted backcross (MABC) selection experiments aimed at improving grain yield under drought conditions in tropical maize and also compared the method with alternative marker assisted (MAS) strategies. Introgression of alleles at five target regions involved in the expression of yield components and flowering traits increased grain and reduced the silking anthesis interval under water-limited conditions. Eighty-five percent of the recurrent parent's genotype at the non target loci was recovered in only four generations of MABC by screening large segregating populations for three and four generations. Selected MABC derived B2F3 were crossed with two testers and evaluated under different water regimes. The mean grain yields of MABC hybrids were consistently higher than that of control hybrids under severe water stress conditions. Under those conditions the best MABC derived hybrids yielded 50% more than control hybrids. No differences were observed between MABC and control hybrids under mild stress conditions, confirming that the genetic regulation for drought tolerance is dependent on the stress intensity.

2.6. Combining ability

Combining ability of inbred lines is the ultimate factor determining future usefulness of the lines for hybrids (Hallauer and Miranda, 1988). The concept was refined by Sprague and Tatum (1942) to produce two expressions, general combining ability and specific combining ability. They called the additive portion of genotypic variance general combining ability (GCA), determined by mean hybrid performance of a determined line. The non-additive portion was the specific combining ability (SCA), a measure for cases where some hybrid combinations are better, or worse, than expected based on mean performance of the lines evaluated. They defined SCA as those instances in which certain hybrid combinations are either better or poorer than would be expected on the average performance of the parent inbred lines included in the crosses. Specific combining ability is used to indicate the value of superior genotype combinations.

General combining ability was also defined as the average performance of a line in a hybrid combination, when expressed as a deviation from the overall mean of all its crosses (Falconer, 1989). These deviations can be positive or negative. A positive deviation can be favourable or unfavourable, depending on the trait under consideration. Positive deviation for yield is desirable as this indicates high yielding potential. On the contrary, positive high values on ear rots and foliar disease ratings would not be desirable. Negative GCA values on anthesis date (AD) are more desirable for selection of early maturing combinations.

General combining ability tests are used for preliminary screening of lines from a large number of lines in a breeding programme. Lines with poor GCA are discarded. GCA estimates can also be used in genetic studies to identify the type of gene action governing traits of interest. A high GCA estimate is indicative of additive gene action (Hallauer and Miranda, 1988).

Any particular cross has an expected value, which is the sum of the general combining abilities of its two parental lines. The cross may deviate from the expected value to a greater or lesser extent and this deviation is called the specific combining ability (SCA) of the two lines in combination (Falconer, 1989). SCA is used to indicate the value of superior genotype combinations. The SCA measurement represents the final stage in the selection of inbred lines as it identifies specific inbred combinations to use in hybrid formation (Hallauer and Miranda, 1988).

Specific combining ability estimates are also used in genetic studies to identify the type of gene action governing the traits of interest. A high SCA measure indicates non-additive gene action. In addition, SCA estimates can be used to determine heterotic relationships among different genotypes. As an example, if a line, A, gives a large positive SCA estimate for yield, when crossed to line B, but a large negative SCA estimate, when crossed to line C, line A is in the same heterotic group with line C but different group with line B. Lines from different heterotic groups which give high positive SCA estimates are said to be complementary to each other (Hallauer and Miranda, 1988). General combining ability and specific combining ability estimates are dependent on the particular set of materials (inbred lines, populations or varieties) included in the test, and therefore any new germplasm introduced in a breeding programme have to be tested for GCA and SCA (Hallauer and Miranda, 1988).

Previous investigations have shown that both GCA and SCA can interact with environments (Matzinger *et al.*, 1959; Pixley and Bjarnason, 1993). Using tropical maize, Betran *et al.* (2003a) observed significant interaction for combining ability under low and high N. The type of gene action appeared to be different under drought than low N, with additive effects being more important under drought and dominance effects more important under low N.

Betran *et al.* (2003b) carried out a comprehensive study on genetic diversity, specific combining ability and heterosis in tropical maize under stress and non-stress environments. Their objectives were to estimate heterosis and specific combining ability for grain yield under stressed and non-stress environments, and determine genetic diversity using restriction fragment length polymorphism (RFLP) within a set of tropical lines. They also determined genetic distance (GD) to classify the lines according to their GD, correlation between the GD and hybrid performance, heterosis and SCA. Seventeen inbred lines were crossed in a diallel. The inbreds and the F1 hybrids were evaluated in 12 stress and non-stress environments. The expression of heterosis was greater under drought and smaller under low N environments than under non-stressed environments.

A set of DNA markers identifying 81 loci were used to finger print the 17 lines. The level of genetic diversity was high, with 4.65 alleles/locus and polymorphic information content (PIC) values ranging from 0.11 to 0.82. Genomic regions with quantitative trait loci (QTL) for drought tolerance previously identified showed lower genetic diversity. Genetic distance based on RFLP marker data classified inbred lines in accordance to their pedigree.

Positive correlation was found between GD and F1 performance, SCA, mid parent heterosis (MPH) and high parent heterosis (HPH). Specific combining ability had the strongest correlation with GD. Environment significantly affected the correlation between F1s, SCA, MPH and HPH while lower values of GD were revealed in the more stressed environments.

2.7 Testers and combining ability

Usually it is relatively simple to develop a large number of inbred lines that are agronomically satisfactory as lines *per se*. The primary problem is to have adequate testing of the lines to determine performance in hybrid combinations (Hallauer *et al.*, 1988). The most complete information for hybrid performance is obtained in a single cross diallel because this procedure gives information of general and specific combining ability (Sprague and Tatum, 1942). The single cross diallel was not, however practical in the study because of large the number of crosses generated from only a few lines. According to Hallauer and Miranda (1988), the use of a common tester to evaluate lines for general combining ability was introduced by Davis in 1927 and Jenkins and Brunson in 1932. Any of the following materials can be used as testers: inbred lines, single cross hybrids or heterogeneous materials. Following the introduction of the top cross procedure by Davis in 1927, Johnson and Hayes, in 1936, also reported that inbred lines giving high yields in top crosses were more likely to produce better single crosses (Hallauer and Miranda, 1988).

The use of testers in maize breeding has one of the following objectives: (1) evaluation of combining ability of inbred lines in a hybrid breeding programme, or (2) evaluation of breeding values of genotypes for population improvement (Hallauer and Miranda, 1988). In each instance, the choice is essentially to find a tester that provides the best discrimination among genotypes according to the purpose for selection. Matzinger (1953) defined a desirable tester as one that combines the greatest simplicity in use with maximum information on performance to be expected from tested lines when used in other combinations or grown in other environments. Hallauer (1975) pointed out that in general a suitable tester should include simplicity in use, provide information that correctly classifies the relative merit of lines and maximize genetic gain. Testers are used for identifying (selecting) superior genotypes to use in breeding programmes and for the determination of heterotic relationships among genotypes.

2.8 Heterosis

When inbred lines are crossed, the progeny show an increase in those characters that previously suffered a reduction from inbreeding. This is complementary to the phenomenon of inbreeding depression and its opposite, hybrid vigour or heterosis (Falconer, 1989). Heterosis may be defined as the superiority of an F1 hybrid over both of its parents in terms of yield or other characteristics (Singh, 2005). The amount of heterosis is the difference between the crossbred and the inbred means (Falconer, 1989). Generally heterosis is viewed as an increase in vigour, size, growth rate or yield. However in some cases the hybrid may be inferior to the weaker parents. Falconer (1989) gave the formulation of conditions necessary for heterosis of quantitatively inherited traits. He derived an expression for mid-parent (average of parents) heterosis (H) that considers the joint effects of all loci that differed in the cross of two particular lines or populations as $H = \sum dy^2$; d includes the effect of dominance; and therefore heterosis depends on the occurrence of dominance and y^2 is the square of the difference in allele frequency between the lines or populations and determines the amount of heterosis expressed in the cross.

2.9 Heterotic patterns

Heterotic patterns are very critical for maximizing the expression of hetorosis in hybrids. However, they have not been well established and improved in a systematic manner by the majority of maize improvement programmes in the tropics (Paliwal, 2000). In studies to determine the combining ability and heterotic patterns of tropical maize (*Zea mays* L.) developed at CIMMYT, using four line testers Vasal *et al*. (1992a) identified and formed two divergent tropical heterotic groups (THGA and THGB). Lines showing negative SCA with Tester 1 “Pop 21” (Tuxpeno-1) and positive SCA with Tester 3 “Pop 25” (Blanco Cristalino) were classified under Tropical Heterotic Group “A”. Those showing positive SCA with Tester 1 and negative with Tester 3 were classified under Tropical Heterotic Group “B”.

In a similar study in the same year using subtropical CIMMYT maize lines, Vasal *et al*. (1992b), identified and formed two divergent subtropical heterotic groups (STHGA and STHGB). Lines that had negative SCA with Tester 2 (Pop 44) and positive SCA with Tester 4 (Pop 34) were classified under Subtropical Heterotic Group “A” and those showing positive SCA with Tester 2 and negative with Tester 4 were classified under Subtropical Heterotic Group “B”. The hypothesis was that positive SCA effects between inbred lines generally indicate that lines are in opposite heterotic groups and lines in the same heterotic group tended to exhibit negative SCA effects when crossed.

Stojakovic *et al*. (2000) using lines originating from local populations found some lines with desirable traits such yield, early maturing, lodging resistance and grain quality. They also found domestic lines differing in the heterotic potential for grain when crossed with inbred B73 (BSSS germplasm type) and Mo17 (Lancaster germplasm type). They concluded that lines that combined better with Mo17 than B73 belonged to the BSSS heterotic group.

Based on results from CIMMYT-Zimbabwe's regional trials conducted over several years, single cross testers CML312/CML442 (group A) and CML395/CML444 (group B) have proved useful in hybrid formation for subtropical and mid altitude environments and are currently in wide use. These single crosses are intermediate and late maturing respectively (Pswarayi and Vivek, 2007). In a study to identify early maturing testers, they concluded that a single cross L7/L8 was a potential new tester for group A, because inbred L7 and L8 belonged to the heterotic group A. Both inbreds had good GCA effects for grain yield, and the hybrid L7/L8 had good yields: 9.8 ton/ha (optimal), 3.4 t/ha (low nitrogen) and 2.1 t/ha (drought). This potential tester showed earliness in maturity (65 days to anthesis) compared to the existing type A testers CML312/CML442 (72 days to anthesis). L7/L8 was renamed to CML505/CML509

Chapter 3

Evaluation of CIMMYT elite early maturing maize lines for GCA and SCA under nitrogen, drought stress and optimal conditions

3.1 Introduction

According to Hallauer and Miranda (1988), early generation testing was suggested by Jenkins (1935) and Sprague (1946). First selfed (S_0) plants were crossed to testers. Combining ability and general performance of the progeny was determined. This allowed the poorest performing genotypes to be discarded so as to concentrate efforts on promising families in the S_1 and subsequent S_2 generation. General combining ability studies have been used as pointers to potentially useful germplasm in most breeding programmes (Vasal *et al*., 1992a, Pixley and Bjarnason, 1993; Singh, 2005).

CIMMYT continues to face new challenges such as new diseases, drought and declining soil fertility. Such challenges require a systematic introduction of new traits into existing germplasm. Maintaining large numbers of inbred lines with no information on their potential usefulness can result in unnecessary large inventories. A combination of visual selection for desired traits and simultaneous yield evaluation is practiced at CIMMYT as new traits are introduced to existing germplasm.

CIMMYT-Zimbabwe works with two major heterotic groups A (N3, Tuxpeno, Kitali and Reid) type and B (SC, ETO Blanco, Ecuador and Lancaster) type (Mickelson *et al.,* 2001) as aid to orderly maintenance of important germplasm. This helps in reducing the tendency of making blind crosses, which may be difficult to manage in trials. This helps in reducing the tendency of making blind crosses, which may be difficult to manage in trials. Information generated from general and specific combining ability analysis is used for identifying promising combinations and respective heterotic groups.

3.2 Material and methods

Sixteen S_3 maize inbred lines (Appendix 3.1) were crossed to three (single cross) testers, CML312/CML442 and CML505/CML509 (heterotic group A) and CML395/CML444 (heterotic group B) in either an isolation block or by hand pollination using a North Carolina mating design II (Comstock and Robinson, 1948), in Muzarabani-Zimbabwe during the 2005 winter season. The maize inbred lines used in the experiment were developed by CIMMYT Harare, using pedigree selection methods. Seed from 48 crosses were harvested and used to generate six sets of an experimental trial. Twenty-four additional crosses and varieties were included in the trial as controls. As a result, the evaluation trial consisted of 72 entries. The experimental design was alpha (0,1) lattice (Patterson and Williams, 1976) with eight plots per incomplete block. The trials were randomised using the computer software Fieldbook (Banziger and Vivek, 2007).

3.3 Evaluation of trials

Trials were evaluated during the summer of 2006 at the following five sites: Harare, ART Farm, Rattray Arnold Research station and Kadoma in Zimbabwe. The drought trial was evaluated at Chiredzi Research station in winter of the same year (Table 3.1).

Table 3. 1 Location of trial sites in Zimbabwe

Site	Harare Site 1& 2	Kadoma Site 3	Chiredzi Site 4	RARS Site 5	Art Farm Site 6
Latitude	17.80° S.	18.32° S	21.03° S	17.67° S	17.71° S
Longitude	31.05° E.	30.90° E.	31.57° E	31.17° E	30.06° E.
Altitude in masl	1468	1309	392	1452	1536
Natural Region	IIA	IIIA	V	IIB	IIA
Environment	Low N	Optimal	Drought	Optimal	Optimal
Planting period	Summer	Summer	Winter	Summer	Summer
Rainfall/irrigation (mm)	610	801	170	803	980
Fertilizer applied in kg/ha	400 SSP 0 AN	400 NPK 400 AN	400 NPK 400 AN	400 NPK 400 AN	400 NPK 400 AN

3.4 Unstressed field trials

The trial was planted in Zimbabwe during the 2006 summer season at the following locations: ART Farm, Rattray Arnold Research Station and Kadoma. ART farm falls under natural region IIA, which is recommended for large-scale maize production. Rattray Arnold Research Station is in natural region IIB, recommended for tobacco production. Soils in these areas were derived from green stone and sediments of the gold belts. They are deep dark reddish brown kailionitc clays with stable granular structure that provides good aeration and water penetration. A combination of fertile soil and favourable climate makes the regions suitable for intensive production (Vincent and Thomas, 1961). Kadoma is situated in region IIIA. The rainfall in this region is unreliable. Short season and drought tolerant grain crops are recommended to ensure the best use of erratic rainfall. All summer trials were subjected to rain fed conditions. Irrigation was applied to establish the crop. The plot sizes at ART Farm and Rattray Arnold were two 4m rows with 0.75m between rows and 0.25m within row spacing, while plot sizes at Kadoma were one 4m row with 0.75m between rows 0.25m within row spacing.

3.4.1 Crop management

The land was prepared by ploughing, followed by basal maize fert [N (7%; v/v): P_2O_5 (14%; v/v) K_2O (7%; v/v)] fertilizer application at 400 kg/ha. The fertilizer was incorporated into the soil by disking before planting. Furadan 10 G (carbofuran) insecticide was applied at 20 kg/ha in planting holes to control soil pests. Two seeds per planting station were hand planted in all rows. Regent 200 SC (Fipronil) was applied at 500 ml/ha in planting holes to control termites (*Microtermes spp.*) before covering. Fields were kept free from weeds by applying a combination of Dual 960 EC and Gesaprim 500WP pre-emergence herbicides and hand weeding using hoes. The application rates for dual and gesaprim were 1.3 l/ha and 3.0 l/ha respectively. Maize seedlings were thinned to one plant per station giving a plant density of 53 000 plants per hectare at three weeks after planting. Nitrogen fertilizer was applied as ammonium nitrate (34.5% N) at 400 kg/ha soon after thinning. Thionex 1% (Endosulfan) granules were used to control stalk borers (*Busseola fusca*) at a rate of 3.0 kg/ha.

3.5 Nitrogen stressed trials

Two trials were planted on different dates at CIMMYT-Harare (region IIA) in managed low soil nitrogen blocks during the same season. The low nitrogen (Low N) fields had been depleted of nitrogen by growing unfertilized, non-leguminous crops for several seasons, removing crop biomass after each season. Nitrogen fertilization in these trials was designed so that yields under managed N stress averaged 20-35% of those of well-fertilized maize crop at the site (Vivek *et al.,* 2005). According to soil analysis performed by the Soil Chemistry Section, Department of AREX Zimbabwe, the recommended fertilizer requirements were 400 kg/ha (NPK) basal and 400kg/ha (AN) top dressing.

The land was ploughed and disked to loosen the soil. No basal maize fertilizer was applied. Instead, single super phosphate (SSP, 19% P_2O_5) was applied at 400 kg/ha at planting. Planting, irrigation, thinning, pests and weeds control were similar to unstressed trials. No nitrogen fertilizer was applied in either experiment.

3.6 Drought stressed trial

One trial was planted under managed drought stress conditions at Chiredzi Research Station during the 2006 winter season. Irrigation was applied at the beginning of the season to establish good plant stands. Afterwards drought stress intensity was controlled by withdrawing irrigation during flowering and grain filling stages, according to Banziger *et al*. (2000). Chiredzi Research Station situated in region V, was chosen because of the warm winter temperatures and is rain free during this period. The soils are black clay and granitic sands. Ploughing, disking and incorporation of compound maize fert (NPK) (400 kg/ha) were done similarly to unstressed trials. The trial was planted in one 4m row plots with 0.75m between rows and 0.25m within row spacing and was replicated twice. Planting and soil pests control was also similar to unstressed trials (i.e. Regent and Furadan were applied accordingly at planting).

Fifty millimetres of irrigation water was applied at planting. A combination of Dual 960 EC and Gesaprim 500WP were applied as pre-emergence herbicides at 1.3 l/ha and 3.0 l/ha respectively. Twenty millimetres of irrigation were applied at seven days after planting to assist emergence. The third irrigation, 50 millimetres were applied at three weeks after planting to allow thinning of seedlings to one plant per station and the first top dressing fertilizer application of ammonium nitrate (34.5 % N) at 200 kg/ha. The second top dressing of 200 kg/ha ammonium nitrate was applied two days after the last irrigation (16 days from the previous application). This gave a total of 170 mm of irrigation applied in four cycles and 138 kg/ha of N fertilizer applied in two doses. The period from planting to the last irrigation was 44 days. Weeding was also carried out using hoes to keep the crop free of weed infestation. Endosulfan granules were used to control stalk borers (*Chilo spp.*).

3.7 Data collection and descriptions (adopted from Vivek *et al.*, 2005)

Data were collected in trials during both summer and winter seasons in all plots at all sites. During the growth period, disease severity scores were carried out for the following traits: northern leaf blight (*Exserohilum turcicum*), common rust (*Puccinia sorghi*), and gray leaf spot (*Cercospora zeae maydis)* on a 1-5 rating scale. During the same period, male and female flowering dates were taken. Plant and ear height, were taken when all the internodes had elongated fully. The number of plants showing root lodging and stem lodging, and ears with open tips were counted just before harvest.

Harvested plants and ears were counted at harvest in all plots at all sites. Grain texture and number of rotten ears due ear rot diseases, *Fusarium moniliforme, Fusarium graminiarum*, and Diplodia *(Stenocarpella spp)* were recorded during harvesting. Field weighing was carried out at harvest at all sites except at Rattray Arnold. This was followed by grain weight and moisture recording after drying and shelling at all sites.

Anthesis date (AD): Measured as number of days after planting when 50% of the plants shed pollen.

Anthesis-silking interval (ASI): Determined by (1) measuring the number of days after planting when 50% of the plants shed pollen (anthesis date, AD) and show silks (silking date, SD) respectively, and (2) calculating ASI = SD – AD.

Common rust (PS): Score of the severity for common rust (*Puccinia sorghi)* symptoms rated on a scale from 1 (=clean, no infection) to 5 (= severely diseased).

Plant height (PH): Measured as height between the based of a plant to the insertion of the first tassel branch of the same plant.

Ear height (EH): Measured as height between the based of a plant to the insertion of the top ear of the same plant.

Ear rot (ER): Percentage of rotten ears.

Ears per plant (EPP): Counted as number of ears with at least one fully developed grain divided by the number of harvested plants.

Grain yield (GY): Shelled grain weight per plot adjusted to 12.5% grain moisture and converted to tons per hectare.

Grain moisture (MOI): Percent water content of grain as measured at harvest.

Grain texture (GTX): rated on a scale from 1 (=flint) to 5 (=dent).

Grey leaf spot (GLS): Score of grey leaf spot (*Cercospora zeae maydis)* symptoms rated on a scale from 1 (=clean, no infection) to 5 (=severely diseased).

Northern leaf blight (ET): Score of the severity of northern leaf blight (*Exserohilum turcicum)* symptoms rated on a scale from 1 (=clean, no infection) to 5 (=severely diseased)

Root lodging (RL): Measured as a percentage of plants that show root lodging, i.e. those stems that are inclining by more than 45%.

Stem lodging (SL): Measured as a percentage of plants that show stem lodging, i.e. those stems that are broken below the ear.

Senescence (SEN): Leaf senescence severity score on scale of 1-10, taken during grain filling by estimating the % of dead leaf area and dividing by 10 (1= 10% dead leaf area

3.7. 1 Data analysis

Data from individual sites were subjected to an analysis of variance (ANOVA), according to alpha (0,1) lattice design (Patterson and Williams, 1976) using Fieldbook software (Banziger and Vivek, 2007). The programme computed entry, site and across site means, mean square errors and least significant differences (LSD) for all measured traits. It was necessary to analyze data for all the entries included in the experiment in order to compare the general performance of CIMMYT early maturing hybrids with existing hybrids. The programme grouped results into mega environments and ranked the hybrids according to performance by site.

The GLM procedure of SAS (SAS, 1999) was used to compute analysis of variance (ANOVA) of crosses (entries), line and tester for individual site and across sites for all measured traits. The procedure prepared mean square errors for sites, mean square for site x line, mean square site x tester and mean square site x line x tester for the second SAS analysis step. The programme computed general combining ability (GCA) effects and specific combining ability (SCA) effects for line and tester experiments of individual sites and across sites. The programme also calculated the standard errors for each site and across sites. In the procedure, additional entries were excluded from the analysis. The output from the procedure showed the general tendencies of line GCA and SCA for all measured traits because it pooled the data across sites.

The objective was to evaluate GCA and SCA under low nitrogen and drought stressed and unstressed conditions. Line x tester analysis for adjusted yield, anthesis dates (AD) and plant heights were performed using AGROBASE Generation II software. The programme computed ANOVA for entries, GCA for lines and testers and SCA for line x tester of selected traits for individual sites. The programme calculated LSD for entries, line and tester GCA and SCA, the proportional contribution GCA and SCA to entry mean squares. In addition the programme calculated broad and narrow sense heritability. Across site analysis was performed to see the general performance of hybrids on selected traits across environments.

The mathematical model of the combining ability analysis was: $Y_{ijk} = \mu + l_i + t_j + (l x\ t)_{ij} + e_{ijk}$.
Where: Y_{ijk} is the k^{th} observation on i x j^{th} progeny,
μ is the general mean,
l_i is the effects of the i^{th} line,
t_j is the effects j^{th} tester,
$(l \text{ x } t)_{ij}$ is the interaction effect of the cross between the i^{th} line and j^{th} tester
and e_{ijk} is the error term associated with each observation.

3.8 Results

3.8.1 Yield

Across site analysis of variance showed highly significant mean squares ($P<0.01$) for sites, entries and site x entry interaction (Tables 3.2). Average yield per entry across sites ranged from 6.2 to 9.1 t/ha. When yield was ranked based on across site performance 70% of the top 10 hybrids were obtained from crosses involving heterotic group A tester (CML312/CML444). Two crosses were also obtained from crosses involving CML505/CML509 (Appendix 3.2). Table 3.3 shows the top 10-grain yielding hybrids ranked according to performance across optimal conditions compared under stressed conditions. One cross involving CML505/CML509 is also among the top 10 hybrids.

There were significant differences ($P<0.05$) between entries, GCA for lines, and testers at Harare low N1. The second low nitrogen (low N2) trial did not show differences among entries, lines, testers and line x tester interactions. Table 3.4 shows mean square values for yield at different sites. The proportional contribution of lines to total sum of square was 36.6% against 55.9 % for line x tester contribution. Broad sense heritability was 33.6% and narrow sense heritability was 19.7%. Grain yield at low N1 was from 0.7 t/ha to 2.4 t/ha. The best performing hybrids were entries 44, 8, 5, 45 and 18 and the poorest were entries 24, 40, 46, 33 and 32 (Appendix 3.3).

Under drought stress (Chiredzi), line GCA was significant ($P<0.05$) and tester GCA was significant ($P<0.01$) (Table 3.4). GCA and SCA contribution to variability were 42.8% and 39.6% respectively. Broad sense heritability was 27.6% while narrow sense heritability was 32.0%. Grain yield ranged from 0.3 to 1.4 t/ha. The best performing hybrids under drought were entries 7, 5, 15, 28 and 18 while the worst performances were from entries 32, 40, 13, 29 and 46 (Appendix 3.3).

Under optimum conditions (Kadoma, Rattary Arnold and ART Farm), entries were significantly different ($P<0.05$). Line GCA was significant ($P<0.05$) at Kadoma, highly significant ($P<0.01$) at Rattray Arnold and not significant at ART Farm. Tester GCA was highly significant (P<0.01) at Kadoma and Rattray Arnold and significant (P<0.05) at ART Farm.

Average GCA: SCA contributions for Kadoma and Rattrary Arnold were 42.0%: 37.5% respectively. Average broad sense heritability and narrow sense heritability were 30.1% and 32.6% respectively. Grain yield at Kadoma 3 ranged from 5.1 to 10.2 t/ha. At Rattary Arnold, yield ranged from 4.7 to 10.3 t/ha, while that of ART Farm was from 6.3 to 11.1 t/ha (Appendix 3.3).

Table 3. 2 Mean squares for grain yield, anthesis dates and plant heights

Source	DF	Grain yield		Anthesis date		Plant height	
Site	5	1002.80	**	13828.06	**	206499.83	**
Blocks in loc	6	14.38	**	13.00	**	1579.83	**
Entry	47	1.80	**	76.92	**	1636.87	**
Site x entry	235	1.46	**	7.53	**	226.33	ns
Block	1	0.11	ns	6.67	ns	119.17	ns
Error	281	0.83		4.09		235.15	

** Significant at P<0.01
ns Not Significant

Table 3. 3 Performance of the top 10 hybrids based on optimal conditions in different locations

		Stressed Environments							Optimal Environments				
Entry	Hybrid	HLN		CRS	Across stress				KRS	RARS	ART	ACO.	
		GY t/ha	GY t/ha	GY t/ha	GY t/ha	ASI dys	EPP No	Sen 1-10	GY t/ha	GY t/ha	GY t/ha	GY t/ha	AD dys
17	F//CML395/CML444	1.1	1.8	0.4	1.1	8.6	0.4	2.2	6.3	10.3	11.1	9.2	69
44	O//CML395/CML444	2.4	1.7	0.5	1.5	10.5	0.4	2.0	10.2	8.1	8.2	8.8	69
43	O//CML312/CML442	1.1	1.5	0.4	1.2	15.1	0.2	2.0	8.2	8.5	9.7	8.8	71
2	A//CML395/CML444	1.5	1.7	0.5	1.4	2.9	0.5	2.4	6.1	9.0	11.1	8.7	72
35	L//CML395/CML444	0.9	2.8	1.0	1.5	8.5	0.5	2.2	7.0	9.0	10.0	8.7	71
33	K//CML505/CML509	0.7	1.4	0.7	1.0	4.5	0.7	2.9	7.2	9.5	9.2	8.6	66
11	D//CML395/CML444	1.4	2.0	0.7	1.2	4.5	0.5	2.1	9.4	8.3	7.5	8.4	72
40	N//CML312/CML442	0.3	1.4	0.3	1.1	17.1	0.2	2.7	8.4	8.3	8.4	8.4	70
10	D//CML312/CML442	0.9	1.4	0.9	1.0	8.1	0.7	2.2	7.4	8.2	9.3	8.3	70
4	B//CML312/CML442	0.8	1.2	1.1	1.2	4.1	0.8	2.2	9.0	6.9	8.5	8.1	68
Mean		1.3	1.6	0.8		0.6	0.6	2.5	7.1	7.2	8.2	7.3	
LSD (p<0.05)		0.7	0.5	0.4			0.3	0.9	1.8	1.8	1.8	1.3	

Table 3. 4 Grain yield mean square values for the line and tester trials at different locations

Source	DF	HLN1 Site 1	HLN2 Site 2	KRS Site 3	CRS Site 4	RARS Site 5	ART Site 6
ENTRY	47	0.44*	0.18ns	2.98*	0.15ns	3.13*	2.51*
LINE (GCA)	15	0.51*	0.10ns	3.94*	0.21*	4.09**	1.69ns
TESTER (GCA)	2	0.77*	0.23ns	13.43**	0.63**	16.76**	7.65**
LINE*TESTER (SCA)	30	0.39*	0.22ns	1.80ns	0.10ns	1.76ns	2.57ns
Error	47	0.22	0.14	1.68	0.08	1.59	1.54

** Significant at P<0.01
* Significant at P<0.05
ns Not Significant

3.8.2 Anthesis dates

Anthesis dates were significantly different (P<0.05) at sites 1, 2 and 3 and highly significantly different (P< 0.01) at sites 4, 5 and 6 for entries (Table 3.5). Line x tester interaction was significant (P<0.05) at site 5. Line GCA contribution to entry sum of square was 35.5 and SCA was 41.7% under low nitrogen. GCA:SCA was 26.7%:7.7% under drought conditions. Average GCA for optimum sites was 31.5 and SCA was 20.6%. Narrow sense heritability was 36.2% under low N and 89% under drought. Average narrow sense heritability at optimal sites was 76.9%

Across site analysis of variance revealed highly significant values (P<0.01) for sites, entries, site x entry interaction (Table 3.2). The drought site had the highest number of days to flowering with an overall mean of 95 days. Site 4 had the lowest number of days to flowering (average 63 days). Desired hybrids for this study would be those with a low number of days to flowering. All 10 of the best hybrids for the trait were obtained from lines crossed to CML505/CML509 (Table 3.6). Details for specific site are presented in Appendix 3.3.

Table 3. 5 Mean square values for flowering dates at different sites

Source	DF	HLN1	HLN2	KRS	CRS	RARS	ART Farm
ENTRY	47	10.28*	16.55*	7.02*	39.62**	26.01**	15.12**
LINE (GCA)	15	11.75*	13.78ns	8.62*	32.62**	27.97**	9.87**
TESTER (GCA)	2	52.79**	159.78**	57.17**	614.34**	265.04**	234.14**
LINE*TESTER (SCA)	30	6.71ns	8.38ns	2.88ns	4.80ns	9.09*	3.15ns
Error	47	4.61	7.36	2.97	0.08	4.09	2.33

** Significant at P<0.01
* Significant at P< 0.05
ns Not Significant

Table 3. 6 Ten hybrids showing the earliest anthesis dates (days) across locations

Entry	Hybrid	HLN1	HLN2	KRS	CRS	RARS	ART	AC Sites
48	P//CML505/CML509	65.5	69.0	60.5	88.5	63.0	68.5	69.2
27	I//CML505/CML509	69.5	67.5	60.0	90.0	63.0	69.0	69.8
6	B//CML505/CML509	67.5	69.5	61.0	89.5	66.0	67.5	70.2
30	J//CML505/CML509	66.5	74.0	62.5	92.5	57.5	68.0	70.2
18	F//CML505/CML509	67.5	71.0	62.0	89.0	63.5	70.5	70.6
15	E//CML505/CML509	67.0	69.5	62.5	91.5	62.5	72.0	70.8
21	G//CML505/CML509	64.5	71.0	60.5	92.0	65.0	72.0	70.8
9	C//CML505/CML509	70.0	71.5	61.0	94.5	63.0	70.5	71.8
33	K//CML505/CML509	67.5	74.0	62.0	90.5	64.0	72.5	71.8
45	O//CML505/CML509	69.5	70.0	62.5	95.0	65.0	69.5	71.9
Overall Mean		69.9	73.6	63.7	97.7	68.1	73.3	74.4
LSD (p<0.05)		3.1	3.9	2.5	2.6	2.9	2.2	1.6

3.8.3 Plant heights

Mean squares for entries were significant (P<0.05) at site 5 and 6. Line GCA was significant (P<0.05) under drought conditions. Tester GCA was highly significant (P<0.01) at all sites (Table 3.7). GCA contribution under low N was 18.54% and SCA contribution was 47.96 %. Under drought conditions, GCA accounted for 46.61% while SCA accounted for 27.57% of variability. Narrow sense heritability was lowest (26.43%) under low N condition and highest (57.23%) at the rain fed site (3). The tallest plants were observed at ART Farm where the average was 2.52m and the shortest plants were observed under low N. The aim is to reduce the plant height. Table 3.8 presents the top 10 entries and details are presented in Appendix 6. Across site ANOVA (Table 3.2 and 3.9) showed highly significant differences (P<0.01) between sites and no significant site x entry interactions were detected.

Table 3. 7 Mean square values for plant height at different locations

Source	DF	HLN1	HLN2	KRS	CRS	RARS	ART
ENTRY	47	549.5ns	252.5ns	450.0ns	217.5ns	870.5*	428.6*
LINE (GCA)	15	319.2ns	188.3ns	351.6ns	317.7*	511.4ns	417.8ns
TESTER (GCA)	2	4326.0**	1688.3**	5964.3**	1319.8**	11534.6**	3470.2**
LINE*TESTER (SCA)	30	412.8ns	188.8ns	131.6ns	94.0ns	339.1ns	231.2ns
Error	47	350.8	169.9	240.1	112.4	347.6	187.7

** Significant at P<0.01

* Significant at P< 0.05

ns Not Significant

Table 3. 8 Ten hybrids with the lowest plant heights (in cm) across locations

Entry	Hybrid	HLN1	HLN2	KRS	CRS	RARS	ART	AC Sites
48	P//CML505/CML509	105	170	215	138	180	211	169
24	H//CML505/CML509	150	135	215	148	188	232	171
30	J//CML505/CML509	130	150	213	145	180	247	176
27	I//CML505/CML509	160	155	210	140	183	268	178
45	O//CML505/CML509	133	150	225	150	185	251	180
9	C//CML505/CML509	143	170	220	143	190	233	180
36	L//CML505/CML509	118	165	225	148	203	239	182
39	M//CML505/CML509	115	170	230	153	188	229	184
42	N//CML505/CML509	123	158	230	155	183	235	184
6	B//CML505/CML509	155	163	225	148	200	231	184
Mean		138	170	240	159	210	252	197.7
LSD (p<0.05)		26.6	18.5	22.0	15.1	26.5	19.5	12.32

Appendix 3.2 shows across site ANOVA for additional traits. Sites were highly significant (P<0.01) for ASI, EPP and SEN. Anthesis silking interval and ears per plant were highly significant P<0.01 among entries. Genotype x environment (G x E) interaction was significant (P<0.01) for ears per plant.

3.8.4 General combining ability (GCA) effects

Line GCA effects for grain yield were significant (P<0.05) under low N1, drought and optimum site 3 and highly significant (P<0.01) at site 5. Testers were significantly different (P<0.05) under low N1 and highly significant (P<0.01) under all optimum sites (Table 3.2). GCA value above 1.45 was observed in line 15 at Kadoma and in line 11 at Rattray Arnold.

The lowest GCA effects of -1.2 were observed in line 10 at Rattray Arnold (Table 3.9). The highest average across site GCA value of 0.56 was obtained from line 15. CML395/CML444 had positive GCA in site 1, 2, 3, 5 and 6 and negative GCA in the drought site. CML505/CML509 had positive GCA under drought only (Table 3.10).

There were significant differences (P<0.05) in general combining ability effects for flowering dates at sites 1 and 3, and highly significant differences (P<0.01) at sites 4, 5 and 6 (Table 3.5). Line 15 had the lowest ASI GCA value of -0.9 day (data not presented). Line GCA was highly significant (P<0.01) for plant heights at the drought site and significant (P<0.05) at one optimal site. Line 15 appeared among the top 4 lines with negative PH GCA values. CML505/CM509 had the best negative GCA values for AD ASI and PH (data not presented).

Table 3. 9 General combining ability effects for yield of lines at different sites

Line	HLN1	HLN2	KRS	CRS	RARS	ART	AC Sites
1	0.19	-0.09	-0.65	-0.15	0.01	0.74	0.01
2	0.05	0.07	0.65	0.40	-0.79	-0.75	-0.06
3	0.26	0.07	0.64	0.26	0.23	-0.37	0.18
4	0.03	-0.01	0.73	0.06	0.79	-0.14	0.25
5	0.40	0.02	-0.82	-0.06	0.25	0.72	0.08
6	0.01	0.26	-1.23	0.07	1.11	0.69	0.15
7	-0.02	-0.22	0.72	0.05	-0.09	-0.35	0.02
8	-0.30	0.12	-0.11	-0.16	-1.64	-0.30	-0.40
9	-0.01	-0.02	-0.71	0.05	-0.06	0.22	-0.09
10	0.18	-0.05	-1.18	0.11	-1.20	0.03	-0.35
11	-0.32	-0.05	0.49	-0.25	1.50	0.01	0.23
12	-0.34	0.24	0.09	0.21	-0.12	0.46	0.09
13	0.33	-0.15	0.81	-0.07	-0.74	-0.31	-0.02
14	-0.53	-0.12	-0.53	-0.23	0.30	-0.60	-0.29
15	0.50	-0.03	1.46	-0.18	0.92	0.70	0.56
16	-0.25	0.06	0.34	-0.01	-0.11	-0.75	-0.12
Mean	0.00	0.00	0.00	0.00	0.00	0.00	
LSD (P<0.05)	0.54	0.43	1.51	0.33	1.46	1.44	

Table 3. 10 General combining ability effects for yield of testers at different sites

Tester	HLN1	HLN2	KRS	CRS	RARS	ART	AC Sites
CML312/CML442	0.83	-0.08	0.32	0.01	0.06	0.16	0.21
CML395/CML444	0.65	0.09	0.43	-0.14	0.69	0.39	0.35
CML505/CML509	-1.48	-0.01	-0.75	0.14	-0.74	-0.55	-0.56
Mean	0.00	0.00	0.00	0.00	0.00	0.00	
LSD (P<0.05)	0.42	0.19	0.65	0.14	0.63	0.62	

3.8.5 Specific combining ability effects

Specific combing ability for yield was significant (P<0.05) at the low nitrogen site only. Significant differences (P<0.05) for anthesis dates were observed at Rattray Arnold only. There were no differences on specific combining ability effects for plant heights.

3.9 Heterotic grouping

Lines were assigned into groups using yield SCA averages across sites with CML505/CML509 (Group A) and CML395/CML444) (Group B). Five lines were assigned into heterotic group A and five lines were assigned into group B. Three lines were classified as AB, two of which were more inclined into group B than into group A. CML505/CML509 assigned five lines in a similar way with CML312/CML442 (Table 3.12). Three lines gave negative SCA values with CML505/CML509 and CML395/CML444. Of the three lines 9 and 10 had positive SCA values (0.42 and 0.48 respectively) with CML312/CML442.

Table 3. 11 Heterotic group classification based on SCA with CML505/CML509 and CML395/CML444

Line	CML312/CML442 (HGA)	CML395/CML444 (HGB)	CML505/509 (HGA)	Heterotic Group Classification
1	0.04	0.08	-0.12	A
2	0.18	-0.20	0.01	B
3	-0.04	-0.10	0.14	B
4	-0.11	0.27	-0.16	A
5	-0.19	0.13	0.05	AB
6	-0.06	0.36	-0.31	A
7	-0.13	0.03	0.09	AB
8	0.00	0.23	-0.21	A
9	0.42	-0.13	-0.29	None
10	0.48	-0.30	-0.18	None
11	-0.04	-0.45	0.47	B
12	-0.27	0.27	-0.01	A
13	0.03	-0.12	0.09	B
14	0.18	-0.13	-0.06	None
15	-0.13	-0.09	0.21	B
16	-0.33	0.07	0.28	AB

3.10 Discussion

Grain yield obtained at most sites compared well to those obtained in results of the 2005 early to intermediate maturing (EIHYB05) regional trials coordinated by CIMMYT. There are exceptions to the results obtained in the second low nitrogen site, which, however, needs further investigations. Across site analysis of variance showed highly significant differences between sites, entry x site (G x E) interaction for yield, anthesis date and ears per plant. This was expected, considering the extreme differences of the growing conditions the trials were subjected to. This shows that different environments affected the relative performance of various hybrids. Beck *et al*. (1990) Mickelson *et al.,* 2001 Betran *et al.,* 2003b Banziger *et al* reported similar observations.

General and specific combining ability under optimum conditions accounted for 79.5% of entry sum of square in more or less equal proportions. The same could be said for the trial under drought conditions suggesting that both additive and dominance gene action were important for yield improvement. Under low nitrogen conditions dominance gene action was predominant over additive gene action. It was, however, noted that general combining ability changed in different environments, as was also reported by Pixley and Bjarnason (1993). The most notable change among testers was that CML312/CML442 had negative GCA under low N and CML395/CML444 had negative GCA under drought conditions. The two testers had positive GCA in all other sites. CML 505/509 had positive GCA under drought but negative in all other sites.

General combining ability information from the trial could be used to identify potential lines for improvement. For the low N conditions lines 15, 5, 13 and 3 were promising because they had comparable good positive GCA in this environment. Although the general combining ability values were relatively low, lines 2 and 3 and 12 could be selected as potential candidates for drought improvement because they had higher GCA values in that environment. CML505/CML509 proved to be a potential candidate for drought breeding because the tester had positive GCA under drought. Six out of the best ten hybrids under drought were obtained with this tester. On the one hand the ten earliest hybrids were obtained from crosses with CML505/CML509. The same could be said for the hybrids with the shorter stature. Line 15, [[COMPE2/P43SR//COMPE2]F#-20-1-1-B-1-BB-6-BB-2-1-BB/[SW1SR/COMPE1-W###S2#]-126-2-1-B-5-2-BB-1-B]-B-2-B proved superior to all of the lines included in the trial, because it combined well with all three testers. All three hybrid combinations with line 15 were in the top ten grain yielding hybrids across sites. The line was assigned into heterotic group B, which means that a line with good general combining ability in the same group (B) should be identified to form a group B early to intermediate single cross tester.

SCA was not so different that lines could be distinguished objectively. However the lines were separated into heterotic groups based on their SCA average performance with CML505/CML509 (heterotic group A tester) and CML395/444 (heterotic group B tester). Three lines were assigned to heterotic group AB because they produced positive GCA with both testers. Two of the three lines were more inclined to group B. Lines 9, 10, and 14 had negative SCA with both testers, and could be rejected because they did not improve yield in either combination. This is in agreement with Vasal *et al.* (1992a&b). However, lines 9 and 10 had the highest positive SCA values with CML312/CML442 of 0.42 and 0.48 respectively. These specific combining ability values were in the top three obtained in the trial across sites. Heterotic group B, line 11 had the best specific combining ability of 0.47 with CML505/CML509. The hybrid combination (line 11 x CML505/CML509) was ranked number 6 across optimal sites. CML505/CML509 grouped six lines in the same group with CML312/CML442 supporting earlier conclusions by Pswarayi and Vivek (2007) and Ndhlela (2007). The tester is early maturing as observed from its all cross combinations, which had the lowest number of flowering days when compared to CML312/442 and CML395/CML444.

The majority (70%) of the top 10-grain yielding hybrid combinations across sites were obtained from lines crossed to heterotic group B tester. This demonstrates the reliability and importance of CIMMYT's heterotic grouping. When the ranking was based on performance across optimal sites, 50% of the top 10 hybrids were crossed to heterotic group B testers. Of the five remaining hybrids, four were crosses involving CML312/CML442 and one was a cross involving CML505/CML509. This was expected, as CML312/CML442 and CML395/CML444 are intermediate to late in maturing respectively. This gives both testers an edge over early maturing CML505/CML509 when optimum conditions prevail.

Heritability for yield was low across all environments and this seems normal with maize. Heritability for anthesis dates and plant height were high, suggesting that selection for improvement was possible. Given the high number of flowering dates obtained from the trial there is need to improve this trait as a drought escape strategy. The best hybrid combination from this trial could also be included in CIMMYT early to intermediate (EIHYB) regional trials for adaptation evaluations in other environments with a view of reaching resource poor farmers

Chapter 4

The evaluation of early maturing maize hybrids under drought, nitrogen stressed and optimal conditions

4.1 Introduction

In 1997, CIMMYT initiated a programme aimed at improving maize for drought prone mid altitudes of southern Africa. The programme was product orientated, hence open pollinated populations were developed while simultaneously addressing several high priority constraints in the region, such a major leaf and ear rot diseases and low nitrogen (Banziger *et al*., 2004). This gave rise to the introduction of very early maturing germplasm. Several lines, single crosses (SX) and triple crosses (TX) were developed in pursuit for early maturing combinations.

These efforts resulted in an increased volume of seed inventories. With this background it was necessary to identify potentially useful single crosses for further improvement and forming of hybrids that could be of use to resource poor farmers, and discard poor performers.

4.2 Material and methods

4.2.1 Hybrid formation

Seventy-one single cross maize hybrids and seven triple cross hybrids (Appendix 4.1) were crossed to three testers, CML312/CML442, CML395/CML444 and CML505/CML509 using the North Carolina mating design II (Comstock and Robison, 1948) in the 2005 winter season at Muzarabani. Seeds were harvested from 234 crosses and used to generate six evaluation trials. Six additional crosses were included in the evaluation trials, bringing the total number of entries to 240 in the experiment. The experimental design was alpha (0,1) lattice (Patterson and Williams, 1976) with 12 plots per incomplete block. The randomization was done using the computer software Fieldbook (Banziger and Vivek, 2007). With the exception of the hybrid material, the trial layout and management was the same as described in Chapter 3. However the materials referred to as lines in this chapter were single crosses. Because of the line x tester procedure used in the analysis, the term may be used interchangeably with the term "single cross" when necessary. Site allocation was different for this trial as indicated in Table 4.1.

Table 4. 1 Location of trial sites in Zimbabwe

Site	**ART Farm** Site 1	**Harare** Site 2	**Chiredzi** Site 3	**Kadoma** Site 4	**RARS** Site 6
Latitude	17.71^o S	17.80^o S.	21.03^o S	18.32^o S	17.67^o S
Longitude	30.06^o E.	31.05^o E.	31.57^o E	30.90^o E.	31.17^o E
Altitude in masl	1536	1468	392	1309	1452
Natural Region	IIA	IIA	V	IIIA	IIB
Environment	Optimal	Low N	Drought	Optimal	Optimal
Planting period	Summer	Summer	Winter	Summer	Summer
Rainfall/irrigation (mm)	980	610	170	801	803
Fertilizer applied in kg/ha	400 NPK 400 AN	400 SSP 0 AN	400 NPK 400 AN	400 NPK 400 AN	400 NPK 400 AN

4.2.2 Data analysis

Data from individual sites were analysed according to alpha (0,1) lattice design (Patterson and Williams, 1976) using the computer software Fieldbook (Banziger and Vivek, 2007). The GLM procedure of SAS (SAS, 1999) was used to compute analysis of variance (ANOVA), for crosses entries, GCA and SCA for lines and testers for individual sites and across sites for all measured traits. Ear per plant (EPP) and senescence (SEN) values were obtained from the SAS output. Pooled across site SCA values for heterotic group classification were also obtained from SAS output.

AGROBASE Generation II software (Agrobase, 2007) was used to perform a line x tester analysis for adjusted grain yield (GY), anthesis dates (AD), anthesis silking interval (ASI) and plant height (PH) for individual sites. This procedure was important for comparing GCA and SCA under unstressed, low nitrogen and drought stressed conditions. The programme computed ANOVA for entries, GCA for lines and testers and SCA for line x tester of GY, AD, ASI, and PH for individual sites. It calculated LSD for entries, line and tester GCA and SCA, and the proportional contribution of GCA and SCA to entry mean squares. It also calculated broad and narrow sense heritability. Across site analysis was performed to evaluate the general performance of hybrids on selected traits (GY, AD and PH) across environments.

4.3 Results

4.3.1 Yield

Across site analysis of variance revealed significant differences between sites and entries. Site x entry interaction was significant (P<0.01) (Table 4.2). Grain yield ranked according to performance across all sites revealed that 65% of the top 20 hybrids were obtained from crosses involving heterotic group A testers. Three of the crosses involved the early maturing tester (CML505/509) (Appendix 4.2). When grain yield was ranked according to performance across optimal sites, CML312/CML442 and CML395/CML444 each had a 50% share of the top 20 hybrids (Table 4.3).

Table 4. 2 Across site mean squares for grain yield, anthesis dates and plant heights

Source	DF	Grain Yield	Anthesis Date	Plant Height
Site	4	8021.78**	65720.79**	74667.98**
Blocks in loc	5	2.41ns	35.86**	2401.59**
Entry	212	3.51**	77.97**	1391.07**
Site x entry	848	2.50**	7.25**	303.91**
Block	1	1.79ns	132.38**	7269.59**
Error	1059	2.03	4.83	240.79

** Significant at P<0.01

ns Not Significant

Table 4. 3 Performance of the top 20 grain yielding hybrids in different environments

Entry	Hybrid	Stressed Environments						Optimal Environments				
		HLN	CRS	Across stresses				ART	KRS	RARS	ACO	
		GY t/ha	GY t/ha	GY t/ha	ASI dys	EPP No	Sen 1-10	GY t/ha	GY t/ha	GY t/ha	GY t/ha	AD dys
217	BP//CML312/CML442	1.6	0.6	1.1	3.5	0.8	2.3	12.4	8.2	6.3	9.0	68.8
20	G//CML395/CML444	1.1	0.8	0.9	0.0	0.7	2.4	11.7	8.9	6.2	8.9	67.2
142	AV//CML312/CML442	1.3	0.9	1.1	11.5	0.3	2.5	12.7	8.3	5.5	8.8	71.2
152	AX//CML395/CML444	1.2	1.0	1.1	6.5	0.3	2.2	10.4	10.3	5.7	8.8	68.2
197	BJ//CML395/CML444	1.3	1.1	1.2	20.5	0.3	2.8	13.1	7.1	5.6	8.6	71.3
166	BC//CML312/CML442	1.2	1.2	1.2	10.5	0.4	2.4	11.6	8.2	5.1	8.3	70.2
17	F//CML395/CML444	1.1	0.6	0.9	6.0	0.7	2.6	11.3	7.2	6.2	8.2	68.2
143	AV//CML395/CML444	1.2	1.0	1.1	10.0	0.4	2.9	9.5	8.0	7.0	8.2	72.0
209	BM//CML395/CML444	1.2	1.0	1.1	12.0	0.6	2.8	11.7	8.0	5.0	8.2	70.7
215	BO//CML395/CML444	1.5	1.4	1.4	3.5	0.7	2.4	10.2	8.5	5.9	8.2	69.8
25	I//CML312/CML442	1.6	0.8	1.2	2.5	0.8	2.6	11.0	7.4	5.7	8.1	66.0
83	AB//CML395/CML444	0.9	0.3	0.6	5.0	0.7	2.4	9.8	8.4	5.8	8.0	68.3
106	AJ//CML312/CML442	1.9	0.8	1.3	7.0	0.5	2.8	9.9	7.9	6.1	8.0	67.0
145	AW//CML312/CML442	1.9	1.3	1.6	7.5	0.3	2.4	10.8	7.8	5.3	8.0	70.2
151	AX//CML312/CML442	1.9	1.0	1.4	6.0	0.6	2.4	9.6	9.7	4.6	8.0	66.5
164	BB//CML395/CML444	1.6	1.2	1.4	18.5	0.3	2.5	10.5	7.9	5.7	8.0	69.7
181	BE//CML312/CML442	1.2	0.8	1.0	6.5	0.6	2.2	9.6	8.7	5.6	8.0	69.7
187	BG//CML312/CML442	1.0	0.7	0.9	8.0	0.7	2.7	11.1	7.3	5.7	8.0	69.8
214	BO//CML312/CML442	1.4	0.4	0.9	7.5	0.6	2.8	11.0	7.4	5.6	8.0	68.3
218	BP//CML395/CML444	2.2	0.5	1.3	10.0	0.5	2.5	9.8	6.8	7.0	7.9	71.8
Mean		1.36	0.84		7.4	0.63	2.6	9.10	6.26	5.15		
LSD (p<0.05)		0.83	0.49		7.8	0.33	0.7	2.63	2.33	1.27		

Under low nitrogen conditions (Harare), entries showed significant differences (P<0.05) for yield. Line GCA was significant (P<0.05) (Table 4.4). GCA and SCA contributions to entry mean squares were 40.4% and 58.9% respectively. Broad sense heritability was 16.1% and narrow sense heritability was 9.7%. Mean grain yield ranged from 0.6 t/ha to 3.2 t/ha. The top 10-grain yielding hybrids under low N conditions were entries 46, 161, 168, 162, 24, 81, 7, 28, 36 and 44 (Appendix 4.2).

Under drought conditions (Chiredzi) entries differed significantly (P<0.01). General combining ability of lines and testers was significant (P<0.01) (Table 4.4). GCA and SCA contribution to entry sum of squares was 47.4% and 46.5% respectively. Broad sense heritability was 25.7%. Narrow sense heritability was 22.9%. Grain yield ranged from 0.3

t/ha to 1.98 t/ha. The best yielding entries were 126, 162, 192, 204, 129, 194, 21, 157, 108 and 79 (Appendix 4.2).

Optimal site 1 (ART Farm) showed no significant difference between entries. At Kadoma and Rattray Arnold, hybrids were significantly different at P<0.05 and P<0.01 respectively. Line GCA was significant (P<0.05) at Kadoma and Rattray Arnold. Tester GCA was significant (P<0.05) at ART farm and highly significant (P<0.01) at Kadoma and Rattray Arnold (Table 4.4). Average GCA and SCA contribution to variability at the three sites were 32.4% and 54.4% respectively. Narrow sense heritability was 13.8% at Kadoma and 28.0% at Rattray Arnold.

Table 4. 4 Grain yield mean square values at different sites

Source	DF	ART Farm	HLN	CRS	KRS	RARS
ENTRY	212	3.66ns	0.49*	0.21**	3.86*	1.32**
LINE (GCA)	70	3.94ns	0.60*	0.30**	3.85*	1.15*
TESTER (GCA)	2	14.20*	0.358ns	1.36**	43.42**	35.87**
LINE*TESTER (SCA)	140	3.37ns	0.43ns	0.15ns	3.30ns	0.92ns
Error	212	3.57	0.35	0.13	2.80	0.82

* Significant at P< 0.05
** Significant at P<0.01
ns Not Significant

4.3.2 Anthesis dates (AD)

Across site analysis of variance revealed highly significant differences (P<0.01) between sites and entries and significant site x entry interaction (Table 4.2). At individual site level, hybrids showed highly significant differences (P<0.01) at all sites. Line and tester mean squares were highly significant (P<0.01). Line x tester interaction was significant (P<0.05) at ART farm only (Table 4.5). The average GCA contribution across all sites was 48.6%. SCA average contribution was 17.9%. Narrow sense heritability average was 74.1%.

The drought site had the highest number of days to flowering with an overall mean of 98 days. The rain fed site (Kadoma) had the lowest number of days to flowering (average 64 days). Twenty entries with the lowest number of days to flowering are presented in Table 4.6. Ninety-five percent of the hybrids in this category were CML505/CML509 cross combinations. Appendix 4.2 presents means across sites.

Table 4. 5 Mean square values for anthesis dates (AD) under different environments

Source	DF	ART Farm	HLN	CRS	KRS	RARS
ENTRY	212	17.87**	22.31**	48.11**	7.68**	10.99**
LINE (GCA)	70	28.15**	33.68**	82.61**	9.68**	14.21**
TESTER (GCA)	2	701.88**	872.59**	1283.57**	248.32**	444.76**
LINE*TESTER (SCA)	140	2.96*	4.48ns	13.20ns	3.25ns	3.18ns
Error	212	2.32	3.81	12.904	2.92	2.81

* Significant at P< 0.05
** Significant at P<0.01
ns Not Significant

Table 4. 6 Anthesis dates (days) of the top 20 hybrids in different environments

Entry	Hybrid	ART	HLN	CRS	KRS	RARS	AC Sites
117	AM //CML505/CML509	68	65	85	60	64	68.8
91	AD //CML505/CML509	68	69	87	60	59	69.0
70	W // CML505/CML509	65	67	87	58	67	69.1
82	AA //CML505/CML509	66	67	85	61	65	69.1
46	O // CML505/CML509	66	68	85	60	65	69.2
40	M // CML505/CML509	67	67	85	61	65	69.3
162	AZ //CML505/CML509	67	64	87	61	67	69.3
37	L // CML505/CML509	66	67	88	60	65	69.4
34	K // CML505/CML509	68	68	88	58	65	69.6
112	AK //CML505/CML509	64	69	90	60	64	69.6
79	Z // CML505/CML509	66	68	90	59	65	69.7
43	N // CML505/CML509	67	69	89	59	65	69.8
64	U // CML505/CML509	66	69	89	61	62	69.8
68	W // CML312/CML442	68	68	89	59	64	69.8
73	X // CML505/CML509	67	69	86	62	64	69.9
120	AN //CML505/CML509	70	70	88	58	63	69.9
126	AP //CML505/CML509	67	67	88	61	65	69.9
153	AX //CML505/CML509	69	68	91	58	62	69.9
3	A // CML505/CML509	67	69	89	60	63	70.1
88	AC //CML505/CML509	66	69	93	61	61	70.1
Mean		72	73	95	63	66	74
LSD (P<0.05)		2.1	2.7	5.0	2.4	2.3	1.9

4.3.3 Plant heights

Hybrids showed highly significant differences ($P<0.01$) in plant height at four sites excluding the drought site. Line GCA was significant at the same four sites. Tester GCA was highly significant ($P<0.01$) at all sites. Line x tester interaction was significant ($P<0.05$) under low nitrogen conditions only (Table 4.7). The average contribution of GCA and SCA to entry sum of squares was 44.6% and 34.3% respectively. Narrow sense heritability average was 42.7%. Across site ANOVA (Table 4.2) showed highly significant differences ($P<0.01$) between sites and entries and significant site x entry interaction. Short plants were observed under drought conditions and tall plants under optimum conditions. Table 4.7 shows selected entries based on average plant height across all sites.

Table 4. 7 Mean square values for plant heights under different environments

Source	DF	ART Farm	HLN	CRS	KRS	RARS
ENTRY	212	616.8**	420.2**	211.0ns	485.9**	872.9**
LINE (GCA)	70	861.5**	657.4**	237.3ns	567.6**	1103.3**
TESTER (GCA)	2	24781.3**	5512.7**	2525.9**	13388.7**	18510.1**
LINE*TESTER (SCA)	140	149.2ns	228.8*	164.8ns	260.7ns	505.7ns
Error	212	133.4	170.0	191.3	235.6	506.9

* Significant at $P< 0.05$
** Significant at $P<0.01$
ns Not Significant

Table 4. 8 Plant height (in cm) of the top 20 hybrids in different environments

Entry	Hybrid	ART	HLN	CRS	KRS	RARS	AC Sites
63	U//CML505/CML509	217	148	140	195	180	176
222	BQ//CML505/CML509	220	148	135	210	180	178
60	T//CML505/CML509	242	143	133	183	198	179
39	M//CML505/CML509	218	133	145	220	188	181
42	N//CML505/CML509	223	135	150	205	190	181
4	B//CML312/CML442	247	145	145	213	160	182
99	AG//CML505/CML509	235	153	110	203	210	182
87	AC//CML505/CML509	230	163	118	205	198	183
84	AB//CML505/CML509	210	163	143	215	185	183
66	V//CML505/CML509	218	158	148	208	185	183
117	AM//CML505/CML509	227	163	145	205	180	184
36	L//CML505/CML509	218	175	138	208	183	184
57	S//CML505/CML509	224	155	140	198	205	184
72	X//CML505/CML509	224	150	143	195	210	184
69	W//CML505/CML509	221	163	135	210	195	185
162	AZ//CML505/CML509	227	155	135	205	203	185
48	P//CML505/CML509	222	165	153	203	185	185
160	AZ//CML312/CML442	234	143	130	220	203	186
6	B//CML505/CML509	217	163	150	200	203	186
88	AD//CML312/CML442	225	173	128	213	198	187
Mean		250	175	147	231	217	204
LSD (P<0.05)		16.1	18.2	19.3	21.4	31.4	13.6

Appendix 4.2 show across site ANOVA for line x tester for the following additional selected traits ASI, EPP, SEN. Sites were significant (P<0.05) for ASI and highly significant (P<0.01) for EPP and SEN. Genotype x environment interaction was significant (P<0.01) for ASI, and SEN.

4.4 General combining ability

Line GCA for yield was significant (P<0.5) at Harare, Kadoma and Rattray Arnold and highly significant (P<0.01) at Chiredzi. Tester GCA was significant (P<0.01) at Chiredzi Kadoma and Rattray Arnold and significant (P<0.05) at ART farm (Table 4.4). The top 20 and bottom 20 combiners ranked according to the type of environment are presented in Table 4.9. General combing ability for the testers is presented in Table 4.10.

Table 4. 9 GCA for GY of the top 20 and bottom 20 single crosses under stress and optimal environments

Low N		Drought		Across site		Across Optimal	
Single cross	GCA	Single cross	GCA	Single cross	GCA	Single cross	GCA
54	1.06	8	0.56	51	1.01	51	1.63
16	0.95	23	0.55	37	0.67	7	1.12
56	0.9	24	0.5	55	0.66	55	1.04
35	0.57	27	0.44	7	0.64	37	0.91
55	0.55	32	0.43	8	0.63	17	0.82
30	0.52	39	0.38	6	0.50	49	0.78
49	0.45	31	0.36	17	0.48	8	0.73
42	0.45	13	0.36	49	0.47	6	0.71
27	0.45	37	0.35	36	0.40	44	0.64
8	0.41	9	0.33	42	0.38	36	0.62
4	0.39	40	0.32	9	0.31	45	0.54
10	0.39	6	0.31	3	0.27	5	0.51
38	0.3	25	0.31	45	0.27	42	0.50
17	0.29	7	0.29	44	0.27	67	0.43
73	0.28	35	0.26	64	0.26	9	0.43
15	0.28	28	0.26	25	0.23	65	0.42
37	0.26	4	0.25	5	0.20	26	0.40
36	0.26	3	0.23	65	0.20	64	0.38
23	0.24	10	0.17	67	0.20	34	0.38
45	0.23	2	0.17	26	0.20	3	0.35
20	-0.28	19	-0.14	53	-0.27	21	-0.40
46	-0.29	5	-0.15	12	-0.28	75	-0.41
29	-0.3	63	-0.18	14	-0.28	30	-0.42
74	-0.3	72	-0.22	43	-0.29	62	-0.42
5	-0.36	70	-0.25	33	-0.29	33	-0.43
65	-0.36	47	-0.27	54	-0.30	43	-0.43
19	-0.4	56	-0.29	13	-0.30	68	-0.46
76	-0.42	74	-0.29	68	-0.33	12	-0.52
59	-0.42	17	-0.33	21	-0.34	78	-0.52
28	-0.43	76	-0.37	78	-0.34	76	-0.53
14	-0.44	55	-0.38	62	-0.36	19	-0.53
7	-0.46	49	-0.46	70	-0.38	20	-0.53
63	-0.48	44	-0.46	20	-0.40	10	-0.54
21	-0.48	66	-0.47	19	-0.43	13	-0.55
47	-0.48	45	-0.49	24	-0.46	47	-0.68
32	-0.49	67	-0.52	76	-0.47	74	-0.82
40	-0.54	48	-0.52	23	-0.52	54	-0.85
22	-0.54	46	-0.55	47	-0.56	24	-0.93
62	-0.54	59	-0.57	74	-0.61	59	-1.06
70	-0.64	53	-0.62	59	-0.83	23	-1.12
LSD (P<0.05)	0.68		0.40				

Table 4. 10 Yield general combining ability of testers under different environments

Tester	ART Farm	HLN	CRS	KRS	RARS	AC Sites	AC Optimal
CML312/CML442	0.12	0.02	0.01	0.35	0.14	0.13	0.20
CML395/CML444	0.24	-0.06	-0.10	0.29	0.42	0.16	0.32
CML505/CML509	-0.36	0.03	0.09	-0.64	0.56	-0.06	-0.15
LSD (P<0.05)	0.44	0.14	0.08	0.39	0.21		

4.5 Specific combining ability and heterotic groups

Specific combing ability of lines and testers were significant (P<0.05) under low nitrogen conditions. The best specific combing ability values (above 0.5) obtained with CML505/CML509 were with single crosses 11, 22, 23, 38, 39 and 62. Thirty-four single crosses were assigned into group B and 21 were assigned into group A. Five single crosses were assigned into AB and 11 were not classified. (Table 4.11).

Table 4. 11 Heterotic group classification of single crosses based on SCA with CML505/CML509 and CML395/CML444

SX	CML312/CML442 (HGA)	CML395/CML444 (HGB)	CML505/CML509 (HGA)	Heterotic Group Classification
1	-0.30	0.13	0.16	AB
2	-0.25	-0.04	0.28	B
3	0.28	-0.40	0.11	B
4	0.56	-0.32	-0.25	None
5	-0.03	0.04	-0.01	A
6	-0.25	0.23	0.05	A
7	-0.07	0.55	-0.46	A
8	-0.27	-0.09	0.36	B
9	0.50	-0.41	-0.15	None
10	0.31	-0.19	-0.13	None
11	-0.48	-0.22	0.69	B
12	0.63	-0.96	0.26	B
13	0.25	-0.30	0.09	B
14	0.08	-0.15	0.06	B
15	-0.09	-0.13	0.22	B
16	0.10	-0.29	0.16	B
17	0.51	-0.41	-0.14	B
18	0.24	0.31	-0.55	A
19	-0.03	-0.22	0.24	B
20	0.45	-0.08	-0.38	None
21	-0.56	0.51	0.08	A
22	-0.37	-0.20	0.56	B
23	-0.02	-0.50	0.52	B
24	-0.34	0.30	0.03	A

SX	CML312/CML442 (HGA)	CML395/CML444 (HGB)	CML505/CML509 (HGA)	Heterotic Group Classification
25	-0.10	0.06	0.04	AB
26	0.37	-0.15	-0.22	None
27	-0.25	0.08	0.17	B
28	-0.52	0.31	0.21	AB
29	0.06	-0.27	0.20	B
30	-0.36	-0.12	0.47	B
31	-0.20	-0.23	0.43	B
32	-0.10	-0.15	0.26	B
33	-0.88	0.46	0.41	AB
34	-0.34	-0.09	0.42	B
35	-0.18	0.01	0.17	B
36	0.47	-0.46	-0.04	None
37	-0.38	0.36	0.06	A
38	-0.50	-0.16	0.66	B
39	-0.63	0.07	0.56	B
40	-0.24	0.38	-0.10	A
41	0.07	-0.18	0.11	B
42	-0.06	0.08	-0.02	A
43	0.18	-0.30	0.11	B
44	-0.04	-0.44	0.46	B
45	-0.40	0.02	0.37	B
46	-0.16	-0.03	0.18	B
47	-0.36	0.08	0.28	B
48	0.74	0.09	-0.81	A
49	0.55	-0.35	-0.19	None
51	0.20	0.39	-0.59	A
53	0.51	0.49	-1.00	A
54	-0.33	-0.03	0.36	B
55	-0.44	0.22	0.21	AB
56	0.64	-1.09	0.45	B
59	-0.15	1.39	-1.12	A
61	0.41	-0.28	-0.13	None
62	0.34	-0.93	0.59	B
63	0.58	-0.16	-0.42	None
64	0.23	-0.09	-0.14	None
65	-0.34	0.01	0.32	B
66	-0.51	1.02	-0.53	A
67	-0.38	0.03	0.34	B
68	-0.42	0.83	-0.42	A
70	0.08	0.52	-0.60	A
71	0.50	-0.24	-0.20	None
72	0.07	0.67	-0.75	A
73	0.42	0.41	-0.79	A
74	0.60	0.43	-0.99	A
75	-0.17	0.46	-0.24	A
76	0.54	-0.60	0.05	B
78	-0.10	0.41	-0.31	A

4.6 Discussion

Dominant gene action was predominant over additive gene action under low nitrogen conditions for yield, as indicated by the GCA and SCA contribution of 40.4% and 58.9% to hybrid sum of squares respectively. This means that although additive gene action was important, dominant gene action was more important. This also means that environment only contributed 0.7% to the hybrid performance. Heritability for yield was 9.7%, suggesting that selecting for yield *per se,* may not be effective under low nitrogen conditions. Banziger *et al.* (2000) stated that heritability and genetic variance decreases under abiotic stress as yield levels fall.

Under drought conditions, GCA and SCA contributions suggested that both additive and dominant gene action were important for hybrid performance. Singh (2005) stated that heritability for yield generally ranges between 10 – 50%. Narrow sense heritability of 22.9% was within reasonable limits for possible improvement.

This scenario suggests that selecting for both low nitrogen and drought tolerance traits may not be straight forward. This is especially so, since maize has become highly domesticated over the years. Banziger *et al.* (2000) recommended simultaneous selection for secondary traits after result from CIMMYT researchers estimated selection gains of 20% through use of secondary traits. Anthesis dates (AD), anthesis silking interval (ASI), ears per plant (EPP), plant height (PH) and leaf senescence (Sen) were some of the recommended traits. Selection for earliness, aimed at ensuring that the selected cultivars are sufficiently early maturing to complete their cycle within a given season, was recommended as a drought escape strategy. It was observed from the results that CML505/CML509 conferred earliness to most hybrids involved in the study. At the same time results on flowering dates indicated that the germplasm was very early compared to the previous set. The information was made available for use in further selection for improvement.

ASI aimed at improving nicking, especially under drought conditions, and 4-8 days were ideal. Data from the nitrogen site was analysed and matched with the hybrids in a table containing grain yield, anthesis dates and plant heights. The ability to produce ears and kernels under stress is an important yield contributor. According to Banziger *et al.* (2000), stress inducing 0.3-0.7 ears per plant within the entire trial was intense enough to enable selection. Results obtained from Fieldbook analysis of the drought site were matched to the performance (Appendix 3.3). Several of hybrids were within the selectable region.

According to Westgate and Boyer (1986) selection for reduced growth of stems and tassels may reduce competition for assimilates at flowering by decreasing kernel abortion. Plant height results were presented in the results and the best plants for the trait were selected. Based on Fieldbook and SAS analysis, results on leaf senescence were not significant. It was decided that the information on leaf senescence would be of little value in pointing to potential useful lines in this trial.

The optimum sites showed that GCA contribution to hybrids was 32.4% and SCA was 54.5% suggesting that dominant gene action was more important for hybrid performance. Heritability under rain fed conditions was 13.8% and 28% at Rattray Arnold. It remains, however, important to select materials under conditions that simulate as far as possible conditions that prevail in resource poor farmers' field inline with CIMMYT's low nitrogen, drought and early maturing selection efforts.

The best general combiners across optimal sites were heterotic group A single crosses 51, 7, 55, 37, and heterotic group B single cross 17. These produced GCA values above 0.8 and could be useful where better conditions prevail. Where low nitrogen conditions are major limiting factors, heterotic group B single crosses 54, 16, 56 could be used to form hybrids with heterotic A early maturing tester. Single cross 8, 23 and 24 were ranked the best under severe drought of less than 170mm rain per year/season? The best specific combining ability values obtained with CML505/CML509 were with single crosses 11, 22, 23, 38, 39 and 62. These single cross combinations could be considered for wide adaptation testing in drought prone environments. Thirty-four single crosses were assigned to group B and 21 were assigned to group A. Five single crosses were assigned to AB and 11 could not be assigned to either group because they gave negative SCA with both testers.

The top 10 grain yielding hybrids under low N conditions were entries 46, 161, 168, 162, 24, 81, 7, 28, 36 and 44, and under drought the top 10 entries were 126, 162, 192, 204, 129, 194, 21, 157, 108 and 79. Results of anthesis silking interval (ASI), ears per plant (EPP) and senescence from the drought site were matched with other results in Appendix 4.2. The highest and lowest number of ears per plant was 1.0 and 0.2 respectively

Sixty five percent of the top 20 grain yielding hybrids across site was obtained from single crosses crossed with heterotic group A testers (either CML312/CML442 or CML505/CML509). When yield results were ranked according to optimal sites CML395/CML444 and CML312/CML442 shared 50% each, of the cross combinations in the top 20 category. This was expected because both testers have a yield advantage over the early maturing CML505/CML509.

Yields obtained from ART farm were very high and could not be used to detect differences in hybrid performances. Yields obtained from other sites were reasonable, considering the earliness of the materials studied as expressed by AD and bearing in mind the reduced yield associated with earliness.

Chapter 5

General recommendations and conclusions

The International Maize and Wheat improvement Centre (CIMMYT) in collaboration with the National Agricultural Research Systems (NARS) routinely conduct regional trials with the objective of evaluating and selecting high yielding, stable genotypes in a wide range of environments (Vivek *et al*., 2001). The selected genotypes are further incorporated into public and private breeding programmes to broaden the maize germplasm for wide adaptation (Setimela *et al*., 2007).

In most breeding programmes, variety testing and selection is done under high potential areas. Genotypes selected under these conditions usually perform poorly under poor conditions in contrast to genotypes selected under both conditions (Banziger *et al.,* 2006). Selections performed under low potential and high potential areas enable breeders to select for traits that will improve yield for both low potential and high potential environments (Banziger *et al.,* 2006).

Among the first set of lines, we found a superior line that combined well with all the testers. [[COMPE2/P43SR//COMPE2]F#-20-1-1-B-1-BB-6-BB-2-1-BB/[SW1SR/COMPE1-W###S2#]-126-2-1-B-5-2-BB-1-B]-B-2-B (line15) had a good combination of desired characters such as yield, anthesis dates and plant height. All its crosses with the three testers were among the best ten hybrids in the trial. The line had the best GCA values across most environments The line also had good yielding potential under low N conditions. The cross between line 15 and CML395/CML444 produced yield (2.37 t/ha) 82 % above average under severe nitrogen depleted conditions. When crossed with CML505/CML509 it also produced (1.9 t/ha) 47% above average under the same conditions. The same line crossed with CML505/CML509 produced 18% yield above average under severe drought. It was also interesting to note that entry 45, the hybrid between line 15 and CML505/CML509 yielded 7.15 t/ha in 63 days to flowering at Kadoma and 7.79 t/ha in 65 days at Rattray Arnold. The same cross produced plant heights of 2.25m and 1.85m at Kadoma and Rattray Arnold respectively, thus combining good yield, low nitrogen and drought tolerance, earliness and short stature. Line 11 had the best specific combining ability with CML505/CML509. The cross combination was ranked number 6 across optimal sites.

The lines were separated into heterotic groups based on their SCA average performance with CML505CML509 (heterotic group A tester) and CML395/444 (heterotic group B tester). Some lines were assigned to heterotic group AB, because they produced positive SCA with both testers. These still require further studies to elicit more information on their heterotic behaviour. Lines that had negative SCA with both testers could be rejected because they did not improve yield in either combinations.

However, we noted that some lines and single crosses marked for rejection had positive SCA values with CML312/CML442. CML505/CML509 grouped six lines in the same group with CML312/CML442 among the first set of lines, supporting earlier conclusions by Pswarayi and Vivek (2007) and Ndhlela (2007) that the line may be a potential early group A tester. The earliness of the tester was evidenced by the hybrid combinations, which had the lowest number of flowering days as indicated in the results. The results of the heterotic grouping could also be an important aid to future hybrid combinations and backcross breeding schemes.

Heritability for yield was low across all environments and this seems normal with maize. Heritability for anthesis dates and plant height were high and reasonable, suggesting that selection for improvement was possible. The number of flowering dates obtained from the trial suggests that the lines are early to intermediate and could be improved. The best hybrid combination from this trial could also be included in CIMMYT early to intermediate hybrid (EIHYB) regional trials for adaptation evaluations in other environments with a view to reach the resource poor farmers.

Among single crosses, the best general combiners across optimal sites were heterotic group A single crosses 51, 7, 55, 37, and heterotic group B single cross 17. These produced GCA values above 0.8 and could be useful where better conditions prevail. Where low nitrogen conditions is a major limiting factor, heterotic group B single crosses 54, 16, 56 could be used to form hybrids with heterotic A early maturing tester. Single cross 8, 23 and 24 were ranked the best under severe drought of 170mm. The best specific combinations with CML505/CML509 were obtained with heterotic group B single crosses 11, 22, 23, 38, 39 and 62. Thirty-four single crosses were assigned to group B and 21 to group A. Five single crosses were assigned into AB and 11 were not assigned to either group.

The top 10 grain yielding hybrids under low N conditions were entries 46, 161, 168, 162, 24, 81, 7, 28, 36 and 44, and under severe drought 126, 162, 192, 204, 129, 194, 21, 157, 108 and 79. Results of anthesis silking interval (ASI), ears per plant (EPP) and senescence from the drought site were matched with other results in Appendix 4.3. The highest and lowest number of ears per plant was 1.0 and 0.2 respectively

Sixty five percent of the top 20 grain yielding hybrids across site was obtained from single crosses with heterotic group A testers (either CML312/CML442 or CML505/CML509). When yield results were ranked according to optimal sites CML395/CML444 and CML312/CML442 shared 50% each, of the cross combinations in the top 20 category. This was expected because both testers have a yield advantage over the early maturing CML505/CML509.

Yields obtained from ART farm were very high and could not be used to detect differences in hybrid performances. Yields obtained from other sites were reasonable, considering the earliness of the materials studied as expressed by AD. The information obtained should assist CIMMYT breeders in making informed recommendations to collaborators. There were some impressive low nitrogen tolerant hybrids, which produced yields above 1.8 t/ha under very severe low N conditions. This is within the regional average. Hybrids with average yield across sites above 6.5 t/ha could be produced for low potential areas. I believe these would improve yields in resource poor farmers' fields. The challenge is to convince private seed companies and distribution agencies of the importance of drought and low nitrogen tolerance and early maturing maize for low potential areas.

Chapter 6

Summary

Since the initiation of a product oriented breeding programme aimed at improving maize for drought prone mid altitudes of southern Africa, CIMMYT developed several inbred lines and single cross hybrids using pedigree selection methods, with emphasis on earliness, drought and low nitrogen stress tolerance. This resulted in increased volumes of seed inventories.

Sixteen inbred lines and 71 single cross hybrids were crossed to three (single cross) testers, CML312/CML442 and CML505/CML509 (heterotic group A) and CML395/CML444 (heterotic group B) and evaluated as two separate experiments for general and specific combining ability in contrasting environments (optimal, managed drought and nitrogen stressed). The objective was to asses the relative importance of general combining ability (GCA) and specific combining ability (SCA) in identifying promising early maturing maize lines, single crosses and testers that could tolerate drought and nitrogen stress conditions, thus simulating prevailing conditions in most resource poor farmers' fields in the mid altitude environments of southern Africa.

The first experiment consisted of 48 experimental crosses and 24 additional crosses. Six trails were planted in a lattice (Alpha 0,1) with eight plots per incomplete block. The second experiment consisted of 213 experimental crosses and additional 27 double crosses and synthetics. Five trials were planted in a lattice (Alpha 0,1) with 12 plots per incomplete block. Trials were planted under optimal conditions at ART farm, Rattray Arnold and Kadoma, nitrogen stressed conditions at Harare and drought stressed conditions at Chiredzi in Zimbabwe in 2006.

Data was collected on grain yield (GY), anthesis dates (AD), anthesis silking interval (ASI), plant heights (PH), ears per plant (EPP), and leaf senescence (SEN). Data was analysed first according to Lattice (alpha 0.01) design using computer software Fieldbook, for the general performances of all crosses for all traits. Line x tester analysis for general combining ability

and specific combining ability was performed using SAS and AGROBASE II computer software.

The first experiment identified heterotic group B line 15 as superior with a GCA value of 0.56. The line had a SCA value of 0.21 with early maturing (heterotic group A tester) CML505/CML509. The hybrid had grain yield of 7.9t/ha and 1.3t/ha across optimal and stress environments respectively and was early maturing (69 days) (silking anthesis days).

In the second set of materials heterotic group A single crosses 51, 37, 55, and 7 had good general combining ability above 0.64. Heterotic group B single crosses 11, 38, 39 and 22 had good specific combing ability with CML505/CML509. The hybrid combinations ranged between 6.1-7.4 t/ha across optimal environments and 0.8-1.4 t/ha across stressed environments. These hybrids were very early (AD 64-66 days), could be evaluated in wide environments for GCA with heterotic group A lines and single crosses in order to identify an early maturing group B tester. CML505/CML509 classified the early maturing lines and single crosses into heterotic groups better than CML312/CML442.

Opsomming

Sedert die begin van produk georiënteerde teelprogramme wat gemik is op die verbetering van mielies vir die droogte geneigde mid-hoogte areas van suidelike Afrika, het CIMMYT verskeie ingeteelde lyne en basters ontwikkel met stamboomteling, met klem op vroegheid, droogte en lae stikstof toleransie. Dit het gelei tot meer saadbronne.

Sestien ingeteelde lyne en 71 enkelkruis basters is gekruis met drie (enkelkruis) toetsers, CML312/CML442 en CML505/CML509 (heterotiese groep A) en CML395/CML444 (heterotiese groep B) en is geëvalueer in twee verskillende eksperimente vir algemene en spesifieke kombineervermoë in kontrasterende omgewings (optimaal, en beheerde droogte en stikstof gestremde toestaande). Die doel was om die relatiewe belangrikheid van algemene (GCA) en spesifieke (SCA) kombineervermoë te bepaal om sodoende goeie potensiële vroeë lyne, enkelkruise en toetsers te identifiseer wat tolerant is vir droogte en lae stikstof toestande, deur dus die toestande in meeste hulpbron arm boere se lande te simuleer in die mid-hoogte omgewings van Suidelike Afrika.

Die eerste eksperiment het bestaan uit 48 eksperimentele kruisings en 24 addisionele kruisings. Vyf proewe is geplant in 'n alfa tralie met 12 persele per onvolledige blok. Die proewe is geplant onder optimale toestande by ART plaas, Rattray Arnold en Kadoma, stikstof gestremde proewe by Harare en droogte gestremde toestande by Chiredzi in Zimbabwe in 2006.

Data is ingesamel op graanopbrengs (GY), antese datum (AD), antese baard interval (ASI), plant hoogte (PH), koppe per plant (EPP), en blaar verdroging (SEN). Data is geanaliseer met die alfa tralie ontwerp met die Fieldbook sagteware; vir algemene evaluering van alle kruisings vir alle eienskappe. Lyn x toetser analise vir algemene en spesifieke kombineervermoë is gedoen met SAS en AGROBASE II sagteware.

Die eerste eksperiment het heterotiese groep B lyn 15 as die beste uitgewys met 'n GCA waarde van 0.56. Die lyn het 'n SCA waarde van 0.21 gehad met vroeë ryp (heterotiese

groep A toetser) CML505/CML509. Die baster het ‘n graanopbrengs van 7.9t/ha en 1.3t/ha onder optimale en stremmingstoestande afsondelik gehad, en was vroeg ryp (69 dae tot baard antese).

In die tweede stel material het heterotiese groep A enkelkruise 51, 37, 55, en 7 goeie algemene kombineervermoë gehad bo 0.64. Heterotiese groep B enkelkruise 11, 38, 39 en 22 het goeie spesifieke kombineervermoë gehad met CML505/CML509. Die baster kombinasies het gewissel tussen 6.1-7.4t/ha oor optimale omgewings, en 0.8-1.4t/ha oor gestremde omgewings. Hierdie basters was baie vroeg (AD 64-66 dae), en kan oor verskillende omgewings geëvalueer word vir GCA met heterotiese groep A lyne en enkelkuisings om ‘n vroeg-ryp groep B toetser te identifiseer. CML505/CML509 het die vroeg-ryp lyne en enkelkruise in beter in heterotiese groepe verdeel as CML312/CML442.

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Appendices

Appendix 3. 1 Experiment 1 lines

Line	Code	Pedigree
1	A	[CML440/[TEWDSR-DrtTolSynS1#-8-XX-1-B*4/CML390]-B-6-2-B-3-#-1-B//[[[NAW5867/P30SR]-111-2/[NAW5867/P30SR]-25-1]-9-2-3-B-2-B/CML388]-B-35-2-B-1-#-1-BB]-10-B
2	B	[CML440/[COMPE2/P43SR//COMPE2]F#-20-1-1-B-1-BB-6-BB-2-B//ZM303c1-32-3-B-1-1-B]-4-B
3	C	[CML440/[COMPE2/P43SR//COMPE2]F#-20-1-1-B-1-BB-6-BB-2-B//ZM303c1-260-3-B-3-1-B]-3-B
4	D	[CML440/[COMPE2/P43SR//COMPE2]F#-20-1-1-B-1-BB-6-BB-2-B//ZM303c1-260-3-B-3-1-B]-2-B
5	E	[CML440/[[[NAW5867/P49SR//NAW5867]-43-1/[NAW/P49//NAW]-12-7]-4-1-1-B-1-B/CML390]-B-14-1-B-3-#-B//ZM303c1-32-3-B-1-1-B]-3-B
6	F	[CML440/[[[NAW5867/P49SR//NAW5867]-43-1/[NAW/P49//NAW]-12-7]-4-1-1-B-1-B/CML390]-B-14-1-B-3-#-B//ZM303c1-32-3-B-1-1-B]-1-B
7	G	[CML440/[[[NAW5867/P30SR]-111-2/[NAW5867/P30SR]-25-1]-9-2-3-B-2-B/CML388]-B-35-2-B-1-#-1//ZM303c1-32-3-B-1-1-B]-1-B
8	H	[CML440/[[[K64R/G16SR]-39-1/[K64R/G16SR]-20-2]-5-1-2-B*4/CML390]-B-38-1-B-7-#-B//[[[NAW5867/P30SR]-111-2/[NAW5867/P30SR]-25-1]-9-2-3-B-2-B/CML388]-B-35-2-B-1-#-1-BB]-3-B
9	I	[[[[NAW5867/P30SR]-40-1/[NAW5867/P30SR]-114-2]-16-2-2-B-2-B/CML395-6]-B-20-1-B-3-#-B/NC346-BB//[[[NAW5867/P30SR]-111-2/[NAW5867/P30SR]-25-1]-9-2-3-B-2-B/CML388]-B-35-2-B-1-#-1-BB]-4-B
10	J	[[[K64R/P30SR]-82-2/[K64R/P30SR]-87-4]-7-3-4-B-2-B-4-B*4-#/NC346-BB//[89[G27/TEWTSRPool]#-278-2-X-B/[COMPE2/P43SR//COMPE2]F#-20-1-1]-B-31-1-B-2-#-3-BB]-5-B
11	K	[P100C6-26-1-4-##1-4-2-B/P300C4S3B-27-5-##1-3-3-B//P100C6-61-1-4-##1-3-1-B/P300C4S3B-27-5-##1-3-4-B]-B-1-2
12	L	[CML488/[COMPE2/P43SR//COMPE2]F#-20-1-1-B-1-BB-6-BB-2-B]-B-5-B
13	M	[[[[K64R/G16SR]-39-1/[K64R/G16SR]-20-2]-5-1-2-B*4/CML390]-B-38-1-B-2-#-1/[[SW1SR/COMPE1-W]-61-2-1-B/89[32/DRSTEW]#-107-2-3-X-1]-B-14-1-B-1-#-1]-B-5-4
14	N	[[[[K64R/G16SR]-39-1/[K64R/G16SR]-20-2]-5-1-2-B*4/CML390]-B-38-1-B-2-#-1/[[SW1SR/COMPE1-W]-61-2-1-B/89[32/DRSTEW]#-107-2-3-X-1]-B-14-1-B-1-#-1]-B-5-1
15	O	[[COMPE2/P43SR//COMPE2]F#-20-1-1-B-1-BB-6-BB-2-1-BB/[SW1SR/COMPE1-W###S2#]-126-2-1-B-5-2-BB-1-B]-B-2-B
16	P	Syn01E2-64-2

Appendix 3. 2 Across site mean square values for line x tester analysis of selected traits in experiment 1

Source	DF	Yield	AD	ASI	PH	EPP	SEN
Site	5	1002.8**	13811.2**	433.1**	206499.8**	3.2**	617.6**
Entry	47	1.8**	79.7**	9.8**	1636.9**	0.0**	0.7ns
Line	15	2.6**	78.4**	13.9*	1268.9**	0.1**	1.2*
Tester	2	9.5**	1165.3**	26.2ns	24181.3**	0.3**	4.0*
Line x Tester	30	0.9ns	7.9*	6.7ns	317.9ns	0.0ns	0.3ns
Entry x Site	235	1.5**	7.0**	6.4ns	226.3ns	0.0**	0.7ns
Line x Site	75	1.7**	5.2ns	7.0ns	167.4ns	0.0**	0.7ns
Tester x Site	10	5.8**	43.4**	25.5**	824.4*	0.1**	1.7ns
Line x Tester x Site	150	1.0ns	5.4ns	4.8ns	215.9ns	0.0ns	0.6ns
Error	281	0.8	4.3	4.7	262.8	0.0	0.4

** Significant at P<0.01

* Significant at P< 0.05

ns Not Significant

Appendix 3. 3 Performance of experiment 1 hybrids in different environments

		Stressed Environments							Optimal Environments					
Entry	**Hybrid**	**Harare L N**		**CRS**	**Across stresses**				**KRS**	**RARS**	**ART**	**Across Optimal**		
		GY (t/ha)	GY (t/ha)	GY (t/ha)	GY (t/ha)	ASI (days)	EPP (No)	SEN (1-10)	GY (t/ha)	GY (t/ha)	GY (t/ha)	GY (t/ha)	AD (days)	PH (cm)
1	A//CML312/CML442	0.8	1.5	0.6	1.1	11.4	0.4	2.9	7.9	7.7	7.6	7.7	72	199
2	A//CML395/CML444	1.5	1.7	0.5	1.4	2.9	0.5	2.4	6.1	9.0	11.1	8.7	72	216
3	A//CML505/CML509	1.6	1.2	0.8	1.3	3.0	0.8	3.2	5.3	5.1	8.2	6.2	69	185
4	B//CML312/CML442	0.8	1.2	1.1	1.2	4.1	0.8	2.2	9.0	6.9	8.5	8.1	68	196
5	B//CML395/CML444	2.2	1.6	1.4	1.5	3.4	0.9	1.1	7.1	6.4	7.3	6.9	69	198
6	B//CML505/CML509	1.1	2.0	1.1	1.3	3.2	1.0	2.6	7.0	6.0	6.6	6.5	65	184
7	C//CML312/CML442	1.2	1.2	1.4	1.3	5.5	0.7	2.4	7.9	7.0	8.1	7.7	67	191

		Stressed Environments							**Optimal Environments**					
Entry	**Hybrid**	**Harare L N**		**CRS**	**Across stresses**				**KRS**	**RARS**	**ART**	**Across Optimal**		
		GY (t/ha)	GY (t/ha)	GY (t/ha)	GY (t/ha)	ASI (days)	EPP (No)	SEN (1-10)	GY (t/ha)	GY (t/ha)	GY (t/ha)	GY (t/ha)	AD (days)	PH (cm)
8	C//CML395/CML444	2.3	1.5	0.7	1.1	7.9	0.6	3.3	8.3	7.2	8.8	8.1	70	201
9	C//CML505/CML509	1.2	2.1	1.0	1.5	4.2	0.8	2.9	6.9	8.1	6.7	7.2	65	180
10	D//CML312/CML442	0.9	1.4	0.9	1.0	8.1	0.7	2.2	7.4	8.2	9.3	8.3	70	201
11	D//CML395/CML444	1.4	2.0	0.7	1.2	4.5	0.5	2.1	9.4	8.3	7.5	8.4	72	214
12	D//CML505/CML509	1.7	1.3	0.9	1.3	7.4	0.7	3.5	6.6	7.6	7.3	7.2	67	186
13	E//CML312/CML442	1.8	1.4	0.4	1.3	8.0	0.5	2.8	5.6	7.0	9.6	7.4	69	191
14	E//CML395/CML444	1.8	2.1	0.6	1.3	8.9	0.5	2.0	7.1	9.0	8.2	8.1	69	206
15	E//CML505/CML509	1.5	1.2	1.2	0.8	4.1	0.9	2.1	6.0	6.4	8.9	7.1	65	190
16	F//CML312/CML442	1.0	1.9	1.0	1.4	6.6	0.7	2.7	5.6	7.5	9.2	7.4	69	211
17	F//CML395/CML444	1.1	1.8	0.4	1.1	8.6	0.4	2.2	6.3	10.3	11.1	9.2	69	207
18	F//CML505/CML509	1.8	1.7	1.1	1.1	2.5	0.7	2.7	5.5	6.9	6.4	6.3	65	195
19	G//CML312/CML442	1.0	1.1	0.9	1.5	4.9	0.6	3.0	8.5	8.5	6.3	7.8	69	204
20	G//CML395/CML444	1.3	1.4	0.8	1.1	6.5	0.6	2.5	6.9	7.3	9.5	7.9	68	207
21	G//CML505/CML509	1.6	1.5	0.9	1.3	3.6	0.8	3.1	8.0	5.6	7.8	7.1	66	184
22	H//CML312/CML442	1.4	1.8	0.6	1.4	7.9	0.6	3.1	6.7	5.8	8.0	6.8	68	194
23	H//CML395/CML444	1.3	1.7	0.8	0.7	4.3	0.5	2.9	8.7	6.2	8.3	7.7	70	204
24	H//CML505/CML509	0.3	1.6	0.6	0.9	5.7	0.8	2.8	5.5	4.7	7.4	5.9	66	171
25	I//CML312/CML442	1.6	1.6	1.0	1.2	3.2	0.9	3.3	7.4	6.5	9.4	7.8	67	197
26	I//CML395/CML444	1.0	1.8	0.6	1.6	4.9	0.6	2.6	6.6	7.4	7.8	7.3	68	203
27	I//CML505/CML509	1.2	1.3	0.9	1.2	2.9	0.9	2.6	5.0	7.6	8.1	6.9	64	178
28	J//CML312/CML442	1.8	1.4	1.2	1.2	2.2	0.8	2.3	7.1	6.4	8.6	7.4	67	199
29	J//CML395/CML444	1.6	1.4	0.4	1.2	5.5	0.5	2.3	5.1	6.9	8.5	6.8	69	201
30	J//CML505/CML509	1.1	1.6	1.1	1.3	2.5	0.9	2.2	5.4	4.7	7.6	5.9	62	176
31	K//CML312/CML442	1.5	2.0	0.7	0.7	8.5	0.5	2.1	7.4	8.2	7.7	7.8	69	202
32	K//CML395/CML444	0.8	1.1	0.3	1.1	7.1	0.4	2.1	8.1	8.4	7.7	8.1	70	215
33	K//CML505/CML509	0.7	1.4	0.7	1.0	4.5	0.7	2.9	7.2	9.5	9.2	8.6	66	192
34	L//CML312/CML442	1.0	1.4	1.1	1.0	2.5	0.7	2.4	7.2	6.1	9.1	7.5	69	201

Entry	Hybrid	Stressed Environments							Optimal Environments					
		Harare L N		CRS	Across stresses				KRS	RARS	ART	Across Optimal		
		GY (t/ha)	GY (t/ha)	GY (t/ha)	GY (t/ha)	ASI (days)	EPP (No)	SEN (1-10)	GY (t/ha)	GY (t/ha)	GY (t/ha)	GY (t/ha)	AD (days)	PH (cm)
35	L//CML395/CML444	0.9	2.8	1.0	1.5	8.5	0.5	2.2	7.0	9.0	10.0	8.7	71	217
36	L//CML505/CML509	1.0	1.8	0.9	1.4	0.7	0.6	2.6	7.2	6.1	6.9	6.7	67	182
37	M//CML312/CML442	1.5	1.5	0.7	0.7	2.0	0.6	2.2	7.2	6.2	8.1	7.2	70	194
38	M//CML395/CML444	1.7	1.4	0.6	0.8	4.0	0.6	1.7	9.3	7.5	6.9	7.9	73	190
39	M//CML505/CML509	1.7	1.3	0.8	1.7	0.7	0.7	1.8	7.1	5.7	8.6	7.1	66	184
40	N//CML312/CML442	0.3	1.4	0.3	1.1	17.1	0.2	2.7	8.4	8.3	8.4	8.4	70	185
41	N//CML395/CML444	1.0	1.7	0.5	1.4	5.8	0.5	1.5	5.7	8.1	8.1	7.3	73	196
42	N//CML505/CML509	1.0	1.2	0.9	1.3	2.9	0.6	2.7	5.4	5.3	6.3	5.7	68	184
43	O//CML312/CML442	1.1	1.5	0.4	1.2	15.1	0.2	2.0	8.2	8.5	9.7	8.8	71	201
44	O//CML395/CML444	2.4	1.7	0.5	1.5	10.5	0.4	2.0	10.2	8.1	8.2	8.8	69	211
45	O//CML505/CML509	1.9	1.4	0.9	1.3	5.5	0.7	2.8	7.2	7.8	8.8	7.9	65	180
46	P//CML312/CML442	0.5	1.1	0.4	1.3	11.3	0.5	2.6	6.6	7.4	8.1	7.4	67	187
47	P//CML395/CML444	0.9	1.1	0.5	1.1	11.2	0.4	3.2	7.8	7.4	7.4	7.5	69	193
48	P//CML505/CML509	1.8	2.2	1.1	1.5	11.4	0.4	2.9	5.7	6.5	7.0	6.4	64	170
	Mean	1.30	1.55	0.79		0.58	0.62	2.5	7.06	7.21	8.2	7.32		197.7
	LSD (p<0.05)	0.67	0.53	0.40			0.27	0.9	1.84	1.79	1.76	1.28		12.3

Appendix 3. 4 Experiment 1 specific combining ability effects in different environments

Line	Line	Tester	HLN1	HLN2	Kadoma	Chiredzi	RARS	ART Farm
1	A	CML312/CML442	-0.32	0.33	1.13	-0.02	0.40	-1.52
1	A	CML395/CML444	0.06	0.25	-0.74	0.02	1.04	1.74
1	A	CML505/CML509	0.26	-0.59	-0.39	0.00	-1.44	-0.23
2	B	CML312/CML442	-0.40	-0.61	0.97	-0.09	0.40	0.85
2	B	CML395/CML444	0.71	-0.21	-1.00	0.32	-0.69	0.42
2	B	CML505/CML509	-0.30	0.82	0.04	-0.23	0.29	-1.28
3	C	CML312/CML442	-0.20	-0.61	-0.16	0.33	-0.46	0.06
3	C	CML395/CML444	0.55	-0.33	0.20	-0.18	-0.10	0.56
3	C	CML505/CML509	-0.36	0.95	-0.03	-0.15	1.43	-0.62
4	D	CML312/CML442	-0.29	-0.17	-0.71	0.31	0.11	0.87
4	D	CML395/CML444	-0.05	0.68	1.14	0.30	-0.42	-0.68
4	D	CML505/CML509	0.33	-0.51	-0.43	-0.06	0.31	-0.19
5	E	CML312/CML442	0.28	-0.16	-0.98	-0.33	-0.51	0.55
5	E	CML395/CML444	-0.04	0.87	0.48	0.01	0.84	-1.08
5	E	CML505/CML509	-0.23	-0.72	0.50	0.33	-0.33	0.53
6	F	CML312/CML442	-0.10	0.38	-0.52	0.13	-0.76	0.12
6	F	CML395/CML444	-0.38	-0.16	0.07	-0.28	1.35	1.85
6	F	CML505/CML509	0.49	-0.22	0.45	0.15	0.58	-1.97
7	G	CML312/CML442	-0.15	-0.31	0.39	0.01	1.27	-1.72
7	G	CML395/CML444	-0.13	-0.02	-1.36	0.09	-0.49	1.26
7	G	CML505/CML509	0.28	0.33	0.96	-0.10	-0.77	0.46
8	H	CML312/CML442	0.55	0.40	-0.60	-0.07	0.19	-0.09
8	H	CML395/CML444	0.16	-0.21	1.29	0.27	-0.02	0.04
8	H	CML505/CML509	-0.70	-0.20	-0.69	0.20	-0.16	0.06
9	I	CML312/CML442	0.49	0.20	0.71	0.16	-0.73	0.80
9	I	CML395/CML444	-0.40	0.32	-0.15	-0.09	-0.48	-1.03
9	I	CML505/CML509	-0.09	-0.52	-0.56	-0.07	1.21	0.22
10	J	CML312/CML442	0.44	0.04	0.90	0.27	0.37	0.18
10	J	CML395/CML444	-0.07	-0.31	-1.19	-0.33	0.19	-0.10

Line	Line	Tester	HLN1	HLN2	Kadoma	Chiredzi	RARS	ART Farm
10	J	CML505/CML509	-0.37	0.27	0.28	0.06	-0.56	-0.07
11	K	CML312/CML442	0.64	1.21	-0.51	0.14	-0.53	-0.69
11	K	CML395/CML444	-0.38	-0.94	0.14	-0.10	-0.99	-0.88
11	K	CML505/CML509	-0.27	-0.27	0.37	-0.04	1.52	1.56
12	L	CML312/CML442	0.22	-0.62	-0.26	0.11	-1.03	0.24
12	L	CML395/CML444	-0.20	0.62	-0.57	0.11	1.24	0.96
12	L	CML505/CML509	-0.02	0.00	0.83	-0.22	-0.20	-1.20
13	M	CML312/CML442	0.03	0.30	-0.95	0.00	-0.30	0.10
13	M	CML395/CML444	-0.07	-0.15	1.00	0.04	0.38	-1.40
13	M	CML505/CML509	0.03	-0.15	-0.05	-0.05	-0.07	1.30
14	N	CML312/CML442	-0.27	0.03	1.60	-0.25	1.03	0.67
14	N	CML395/CML444	0.08	0.33	-1.22	0.10	0.14	0.08
14	N	CML505/CML509	0.19	-0.36	-0.37	0.15	-1.17	-0.76
15	O	CML312/CML442	-0.52	0.13	-0.60	-0.18	0.29	0.67
15	O	CML395/CML444	0.43	0.16	1.22	-0.01	-0.69	-1.10
15	O	CML505/CML509	0.09	-0.29	-0.62	0.18	0.40	0.43
16	P	CML312/CML442	-0.41	-0.55	-0.40	-0.24	0.28	0.45
16	P	CML395/CML444	-0.28	-0.92	0.69	-0.01	-0.41	-0.50
16	P	CML505/CML509	0.68	1.47	-0.29	0.25	0.13	0.04
Mean			0.00	0.00	0.00	0.00	0.00	0.00
LSD (p<0.05)			0.73	0.58	2.03	0.44	1.97	1.94

Appendix 4. 1 Experiment 2 single crosses

SX & TX	Code	Pedigree
1	A	[CML197/N3//FR808]-X-8-2B-2-1-BB/[CML197/N3//FR808]-X-17-1-3-5-1-BB
2	B	[CML197/N3//FR808]-X-8-2B-2-1-BB/ZEWAc1F2-219-4-3-B-1-BB
3	C	[CML197/N3//FR808]-X-8-4-2-1-B-1-BB/ZEWAc1F2-164-3-3-B-1-BB
4	D	[CML197/N3//FR808]-X-8-4-2-1-B-1-BB/ZEWAc1F2-300-2-2-B-1-BB
5	E	[CML197/N3//FR808]-X-8-4-2-1-B-1-BB/ZEWAc1F2-80-1-1-B-1-BB
6	F	ZEWAc1F2-13-3-2-B-1-BB/[CML197/N3//FR808]-X-17-1-3-5-1-BB
7	G	ZEWAc1F2-13-3-2-B-1-BB/[CML197/N3//FR808]-X-8-2B-2-1-BB
8	H	ZEWAc1F2-13-3-2-B-1-BB/[CML197/N3//FR808]-X-8-4-2-1-B-1-BB
9	I	ZEWAc1F2-13-3-2-B-1-BB/ZEWAc1F2-312-7-1-B-1-BB
10	J	ZEWAc1F2-134-4-1-B-1-BB/ZEWAc1F2-312-7-1-B-1-BB
11	K	ZEWAc1F2-151-6-1-B-1-B/ZEWAc1F2-13-3-2-B-1-BB
12	L	ZEWAc1F2-151-6-1-B-1-B/ZEWAc1F2-300-2-2-B-1-BB
13	M	ZEWAc1F2-151-6-1-B-1-B/ZEWAc1F2-312-7-1-B-1-BB
14	N	ZEWAc1F2-151-6-1-B-1-B/ZEWAc1F2-80-1-1-B-1-BB
15	O	ZEWAc1F2-151-6-1-B-1-B/ZEWAc1F2-84-2-2-B-2-B
16	P	ZEWAc1F2-164-3-3-B-1-BB/ZEWAc1F2-134-4-1-B-1-BB
17	Q	ZEWAc1F2-219-4-3-B-1-BB/[CML197/N3//FR808]-X-17-1-3-5-1-BB
18	R	ZEWAc1F2-219-4-3-B-1-BB/[CML197/N3//FR808]-X-8-4-2-1-B-1-BB
19	S	ZEWAc1F2-300-2-2-B-1-BB/[CML197/N3//FR808]-X-8-2B-2-1-BB
20	T	ZEWAc1F2-300-2-2-B-1-BB/ZEWAc1F2-134-4-1-B-1-BB
21	U	ZEWAc1F2-300-2-2-B-1-BB/ZEWAc1F2-84-2-2-B-2-B
22	V	ZEWAc1F2-312-7-1-B-1-BB/ZEWAc1F2-80-1-1-B-1-BB
23	W	ZEWAc1F2-312-7-1-B-1-BB/ZEWAc1F2-83-6-1-B-1-BB
24	X	ZEWAc1F2-312-7-1-B-1-BB/ZEWAc1F2-84-2-2-B-2-B
25	Y	ZEWAc1F2-80-1-1-B-1-BB/ZEWAc1F2-13-3-2-B-1-BB
26	Z	ZEWAc1F2-83-6-1-B-1-BB/[CML197/N3//FR808]-X-8-4-2-1-B-1-BB
27	AA	ZEWAc1F2-83-6-1-B-1-BB/ZEWAc1F2-164-3-3-B-1-BB
28	AB	ZEWAc1F2-84-2-2-B-2-B/[CML197/N3//FR808]-X-8-4-2-1-B-1-BB
29	AC	ZEWAc1F2-84-2-2-B-2-B/ZEWAc1F2-13-3-2-B-1-BB
30	AD	ZEWAc1F2-84-2-2-B-2-B/ZEWAc1F2-134-4-1-B-1-BB
31	AE	ZEWAc1F2-84-2-2-B-2-B/ZEWAc1F2-164-3-3-B-1-BB
32	AF	ZEWBc1F2-149-1-1-B-1-BB/ZEWBc1F2-158-1-2-B-1-B

SX & TX	Code	Pedigree
33	AG	ZEWBc1F2-158-1-2-B-1-B/ZEWBc1F2-316-5-1-B-2-B
34	AG	ZEWBc1F2-158-1-2-B-1-B/ZEWBc1F2-79-3-1-B-1-BB
35	AI	ZEWBc1F2-216-2-2-B-2-BB/[SC/CML204//FR812]-X-30-2-3-2-1-BB
36	AJ	ZEWBc1F2-216-2-2-B-2-BB/ZEWBc1F2-158-1-2-B-1-B
37	AK	ZEWBc1F2-316-5-1-B-2-B/[SC/CML204//FR812]-X-30-2-3-2-1-BB
38	AL	[SC/CML204//FR812]-X-30-2-3-2-1-BB/ZEWBc1F2-104-1-1-B-3-B
39	AM	ZM303c1-243-3-B-1-1-BB/ZM303c1-33-2-B-2-2-BB
40	AN	ZM303c1-260-3-B-3-1-BB/ZM303c1-243-3-B-1-1-BB
41	AO	ZM303c1-260-3-B-3-1-BB/ZM303c1-32-3-B-1-2-BB
42	AP	ZM303c1-32-3-B-1-2-BB/ZM303c1-243-3-B-1-1-BB
43	AQ	ZM303c1-32-3-B-1-2-BB/ZM303c1-33-2-B-2-2-BB
44	AR	[NAW5867/P49SR(S2#)//NAW5867]F#-48-2-2-B-1-1-BB-B/[[[NAW5867/P49SR//NAW5867]-43-1/[NAW/P49//NAW]-12-7]-4-1-1-B-1-B/CML390]-B-14-1-B-3-#-B
45	AS	CML488/SW89300-1P5S2-5-##1-6-3-BB
46	AT	[[[K64R/G16SR]-39-1/[K64R/G16SR]-20-2]-5-1-2-B*4/CML390]-B-38-1-B-7-#-B/[SW1SR/COMPE1-W###S2#]-126-2-1-B-5-2-BB-1-B
47	AU	[TEWDSR-DrtTolSynS1#-8-XX-1-B*4/CML390]-B-6-1-B-2-#-1/[[[NAW5867/P49SR//NAW5867]-43-1/[NAW/P49//NAW]-12-7]-4-1-1-B-1-B/CML390]-B-14-1-B-3-#-B
48	AV	CML488/P300C5S1B-33-4-5-##1-6-1-B
49	AW	[NAW5867/P49SR(S2#)//NAW5867]F#-48-2-1-B-2-B-7-BB-1-B/[[[NAW5867/P49SR//NAW5867]-43-1/[NAW/P49//NAW]-12-7]-4-1-1-B-1-B/CML390]-B-14-1-B-3-#-B
50		[[[K64R/G16SR]-39-1/[K64R/G16SR]-20-2]-5-1-2-B*4/CML390]-B-38-1-B-7-#-B/CML395
51	AX	SW89300-1P5S2-5-##1-6-5-B/[TIWD-EarlySelSynS1#-2-XX-2-B/[SW1SR/COMPE1-W]-126-2-1-B]-B-11-4-B-2-#
52		[89[G27/TEWTSRPool]#-278-2-X-B/[COMPE2/P43SR//COMPE2]F#-20-1-1]-B-32-2-B-4-#-1-B/CML488
53	AY	[Ent52:92SEW1-2/[DMRESR-W]EarlySel-#L-2-1-B/CML386]-B-22-1-B-4-#-1/[TEWDSR-DrtTolSynS1#-8-XX-1-B*4/CML390]-B-6-2-B-3-#-1
54	AZ	P300C5S1B-33-4-5-##1-6-1-B/[NAW5867/P49SR(S2#)//NAW5867]F#-48-2-1-B-2-B-7-BB-1-B-#-B
55	BB	[TEWDSR-DrtTolSynS1#-8-XX-1-B*4/CML390]-B-6-1-B-2-#-1-B/[NAW5867/P49SR(S2#)//NAW5867]F#-48-2-1-B-2-B-7-BB-1-B-#-B
56	BC	CML488/[[[NAW5867/P30SR]-40-1/[NAW5867/P30SR]-114-2]-16-2-2-B-2-B/CML395-6]-B-20-1-B-3-#-B
57		COMPE20/CML445
58		[[NAW5867/P30-SR//NAW5867]-84-1/[NAW/P30//NAW]-3-1]-6-2-2-1-3-B-3-B/CML395
59	BD	CML312/[COMPE2/P43SR//COMPE2]F#-20-1-1-B-1-BB-6-BB-2-B
60		[[[NAW5867/P49SR//NAW5867]-43-1/[NAW/P49//NAW]-12-7]-4-1-1-B-1-B/CML390]-B-14-1-B-3-#-

SX & TX	Code	Pedigree
		B/CML488
61	BE	SW89300-1P5S2-5-##1-6-3-BB/[[[K64R/G16SR]-39-1/[K64R/G16SR]-20-2]-5-1-2-B*4/CML390]-B-38-1-B-7-#-B
62	BF	[89[G27/TEWTSRPool]#-278-2-X-B/[COMPE2/P43SR//COMPE2]F#-20-1-1]-B-31-1-B-3-#-1-B/SW89300-1P3S2-1-##1-7-1-B
63	BG	[[[NAW5867/P49SR//NAW5867]-43-1/[NAW/P49//NAW]-12-7]-4-1-1-B-1-B/CML390]-B-14-1-B-3-#-B/[[[NAW5867/P30SR]-43-2/[NAW5867/P30SR]-114-1]-9-3-3-B-1-B/CML395-1]-B-13-1-B-4-#-4-B
64	BH	SW89300-1P3S2-1-##1-7-1-B/[TIWD-EarlySelSynS1#-2-XX-2-B/[SW1SR/COMPE1-W]-126-2-1-B]-B-11-4-B-2-#-1-B
65	BI	[Ent67:92SEW1-17/[DMRESR-W]EarlySel-#I-3-3-B/CML391]-B-31-B-3-#-2-B/[TIWD-EarlySelSynS1#-2-XX-2-B/[SW1SR/COMPE1-W]-126-2-1-B]-B-11-4-B-2-#-1-B
66	BJ	[TEWDSR-DrtTolSynS1#-8-XX-1-B*4/CML390]-B-6-2-B-4-#-B/SW89300-1P5S2-5-##1-6-3-BB
67	BK	[Ent67:92SEW1-17/[DMRESR-W]EarlySel-#I-3-3-B/CML391]-B-31-B-3-#-2-B/SW89300-1P5S2-5-##1-6-3-BB
68	BL	[89[G27/TEWTSRPool]#-278-2-X-B/[COMPE2/P43SR//COMPE2]F#-20-1-1]-B-31-1-B-3-#-1-B/[[[K64R/G16SR]-39-1/[K64R/G16SR]-20-2]-5-1-2-B*4/CML390]-B-38-1-B-7-#-B
69		[[[K64R/G16SR]-39-1/[K64R/G16SR]-20-2]-5-1-2-B*4/CML390]-B-38-1-B-7-#-B/ZEWAc1F2
70	BM	[TEWDSR-DrtTolSynS1#-8-XX-1-B*4/CML390]-B-6-1-B-2-#-1-B/SW89300-1P3S2-1-##1-7-1-B
71	BN	[TEWDSR-DrtTolSynS1#-8-XX-1-B*4/CML390]-B-6-2-B-4-#-B/[TIWD-EarlySelSynS1#-2-XX-2-B/[SW1SR/COMPE1-W]-126-2-1-B]-B-11-4-B-2-#-1-B
72	BO	[89[G27/TEWTSRPool]#-278-2-X-B/[COMPE2/P43SR//COMPE2]F#-20-1-1]-B-32-2-B-4-#-1-B/[[[K64R/G16SR]-39-1/[K64R/G16SR]-20-2]-5-1-2-B*4/CML390]-B-38-1-B-7-#-B
73	BP	[TIWD-EarlySelSynS1#-2-XX-2-B/[SW1SR/COMPE1-W]-126-2-1-B]-B-11-4-B-2-#-1-B/[[[K64R/G16SR]-39-1/[K64R/G16SR]-20-2]-5-1-2-B*4/CML390]-B-38-1-B-7-#-B
74	BQ	[Ent320:92SEW2-77/[DMRESR-W]EarlySel-#I-2-4-B/CML390]-B-13-2-B-4-#-1-B/[Ent67:92SEW1-17/[DMRESR-W]EarlySel-#I-3-3-B/CML391]-B-31-B-3-#-2-B
75	BR	[89[G27/TEWTSRPool]#-278-2-X-B/[COMPE2/P43SR//COMPE2]F#-20-1-1]-B-32-2-B-4-#-1-B/[TEWDSR-DrtTolSynS1#-8-XX-1-B*4/CML390]-B-6-2-B-4-#-B
76	BS	[Ent320:92SEW2-77/[DMRESR-W]EarlySel-#I-2-4-B/CML390]-B-13-2-B-4-#-1-B/[[[NAW5867/P30SR]-43-2/[NAW5867/P30SR]-114-1]-9-3-3-B-1-B/CML395-1]-B-13-1-B-4-#-4-B
77		[89[G27/TEWTSRPool]#-278-2-X-B/[COMPE2/P43SR//COMPE2]F#-20-1-1]-B-32-2-B-7-#-1-B/ZEWAc1F2
78	BT	ZEWBc1F2/[Ent320:92SEW2-77/[DMRESR-W]EarlySel-#I-2-4-B/CML390]-B-13-2-B-4-#-1-B

Appendix 4. 2 Across sites mean square values for line x tester analysis of selected traits in experiment 2

Source	DF	Yield	AD	ASI	PH	EPP	SEN
Site	4	7748.1**	65381.8**	4347.0*	746577.2**	66.3**	2079.3**
Entry	212	3.9**	73.6**	9.7ns	1392.2**	0.1ns	0.5**
Line	70	3.5*	123.3**	11.6ns	2047.2**	0.1ns	0.6**
Tester	2	78.1**	2951.2**	73.5*	56305.9**	0.3ns	16.6**
Line x Tester	848	2.4ns	8.6**	10.8**	303.9ns	0.1ns	0.4**
Entry x Site	280	2.6ns	11.6**	14.4**	345.2*	0.1ns	0.6**
Line x Site	8	23.7**	165.6**	99.3**	2115.8**	0.3ns	4.7**
Tester x Site	140	3.0*	7.7*	7.9ns	280.2ns	0.1ns	0.2ns
Line x Tester x Site	560	2.0ns	4.9ns	7.7ns	257.3ns	0.1ns	0.3ns
Error	1059	2.2	5.0	7.9	257.6	0.1	0.2

** Significant at P<0.01

* Significant at P< 0.05

ns Not Significant

Appendix 4. 3 Performance of experiment 2 hybrids across environments

Entry	Hybrid	Stressed Environments						Optimal Environments					Across Sites	
		HLN	CRS	Across stresses				ART	KRS	RARS	ACO			
		GY	GY	GY	ASI	EPP	Sen	GY	GY	GY	GY	AD	PH	GY
		t/ha	t/ha	t/ha	dys	No	1-10	t/ha	t/ha	t/ha	t/ha	dys	cm	t/ha
1	A//CML312/CML442	0.8	0.7	0.8	6.5	0.6	2.2	8.8	5.1	6.6	6.8	67.8	208	5.8
2	A//CML395/CML444	1.6	1.0	1.3	10.0	0.3	2.4	8.1	6.7	5.5	6.8	70.2	211	5.6
3	A//CML505/CML509	1.9	0.5	1.2	9.5	0.8	2.2	6.8	4.8	4.7	5.4	63.8	198	4.8
4	B//CML312/CML442	1.3	1.3	1.3	7.0	0.6	2.4	9.6	4.3	5.3	6.4	66.7	182	5.3
5	B//CML395/CML444	1.4	1.0	1.2	4.5	0.7	2.6	9.4	6.9	6.1	7.5	68.5	200	6.2
6	B//CML505/CML509	1.5	0.7	1.1	3.0	0.8	2.6	10.8	5.6	3.8	6.7	64.3	186	5.3

		Stressed Environments						Optimal Environments					Across Sites	
Entry	**Hybrid**	**HLN**	**CRS**	**Across stresses**				**ART**	**KRS**	**RARS**	**ACO**			
		GY t/ha	GY t/ha	GY t/ha	ASI dys	EPP No	Sen 1-10	GY t/ha	GY t/ha	GY t/ha	GY t/ha	AD dys	PH cm	GY t/ha
7	C//CML312/CML442	2.5	0.3	1.4	7.0	0.7	1.9	8.4	7.7	4.8	7.0	66.8	215	5.9
8	C//CML395/CML444	0.8	0.6	0.7	25.0	0.2	2.2	7.7	7.8	5.9	7.1	68.0	210	5.7
9	C//CML505/CML509	1.3	1.2	1.3	1.5	0.9	2.7	7.2	4.5	5.4	5.7	67.2	204	5.1
10	D//CML312/CML442	2.0	0.4	1.2	6.5	0.6	2.9	9.1	7.3	4.7	7.0	67.5	196	5.8
11	D//CML395/CML444	1.8	0.5	1.2	0.5	0.8	2.4	7.7	5.9	4.8	6.1	67.7	199	5.2
12	D//CML505/CML509	1.0	1.3	1.1	3.5	0.7	3.0	7.4	7.0	5.5	6.7	64.5	189	5.5
13	E//CML312/CML442	1.5	0.8	1.2	9.5	0.8	2.1	8.8	7.3	5.3	7.1	66.7	208	5.8
14	E//CML395/CML444	0.8	1.0	0.9	12.0	0.5	2.3	10.3	7.0	5.5	7.6	68.2	202	6.0
15	E//CML505/CML509	0.9	1.1	1.0	4.5	0.4	2.4	9.9	5.9	4.8	6.9	65.2	188	5.4
16	F//CML312/CML442	1.7	0.9	1.3	5.5	1.0	2.4	8.4	6.7	4.7	6.6	68.3	212	5.5
17	F//CML395/CML444	1.1	0.6	0.9	6.0	0.7	2.6	11.3	7.2	6.2	8.2	68.2	217	6.6
18	F//CML505/CML509	1.7	1.3	1.5	5.0	0.8	2.8	7.0	7.2	5.8	6.7	65.8	199	5.7
19	G//CML312/CML442	1.0	0.9	0.9	3.5	0.7	2.5	8.5	8.3	6.5	7.8	67.5	213	6.4
20	G//CML395/CML444	1.1	0.8	0.9	0.0	0.7	2.4	11.7	8.9	6.2	8.9	67.2	212	7.0
21	G//CML505/CML509	0.8	1.5	1.2	2.0	0.8	2.3	8.8	5.8	4.8	6.5	66.3	190	5.2
22	H//CML312/CML442	0.9	1.1	1.0	6.0	0.8	2.3	8.1	6.6	5.6	6.7	67.0	207	5.6
23	H//CML395/CML444	1.4	1.1	1.2	5.5	0.7	2.8	10.8	5.8	5.9	7.5	67.5	208	6.2
24	H//CML505/CML509	2.8	0.7	1.8	3.5	0.9	2.8	8.0	7.8	4.1	6.6	64.7	203	5.6
25	I//CML312/CML442	1.6	0.8	1.2	2.5	0.8	2.6	11.0	7.4	5.7	8.1	66.0	206	6.6
26	I//CML395/CML444	1.5	0.8	1.1	6.0	0.5	2.7	7.0	8.3	6.3	7.2	66.8	219	6.0
27	I//CML505/CML509	0.6	0.7	0.7	4.0	0.8	3.2	10.1	6.3	4.3	6.9	64.3	198	5.3
28	J//CML312/CML442	2.4	0.9	1.7	3.5	0.7	2.3	7.1	6.2	5.2	6.2	65.2	189	5.5
29	J//CML395/CML444	1.2	1.1	1.2	7.5	0.7	2.1	8.9	6.5	4.1	6.5	67.0	197	5.1
30	J//CML505/CML509	1.3	1.2	1.2	7.5	0.7	2.9	7.8	5.8	4.8	6.1	64.0	187	5.0
31	K//CML312/CML442	1.7	0.9	1.3	2.5	0.8	2.6	7.7	5.5	5.6	6.2	65.3	199	5.4
32	K//CML395/CML444	1.1	0.4	0.8	9.5	0.6	2.4	9.3	6.1	5.7	7.0	65.8	201	5.7
33	K//CML505/CML509	2.1	0.7	1.4	3.0	0.9	2.6	9.5	6.8	5.2	7.1	63.8	189	6.0
34	L//CML312/CML442	1.5	0.9	1.2	6.5	0.7	2.5	8.2	8.8	5.7	7.6	66.3	193	6.2

		Stressed Environments						Optimal Environments					Across Sites	
Entry	Hybrid	HLN	CRS	Across stresses				ART	KRS	RARS	ACO			
		GY t/ha	GY t/ha	GY t/ha	ASI dys	EPP No	Sen 1-10	GY t/ha	GY t/ha	GY t/ha	GY t/ha	AD dys	PH cm	GY t/ha
35	L//CML395/CML444	0.9	0.5	0.7	12.5	0.4	2.5	7.0	5.4	6.1	6.2	66.0	190	5.2
36	L//CML505/CML509	2.4	0.8	1.6	3.0	1.0	2.6	8.0	5.7	3.7	5.8	63.8	184	4.9
37	M//CML312/CML442	1.3	1.1	1.2	5.5	0.8	2.7	9.0	5.9	5.2	6.7	64.7	192	5.5
38	M//CML395/CML444	0.9	1.1	1.0	6.5	0.9	2.7	7.9	6.0	5.5	6.5	64.5	197	5.4
39	M//CML505/CML509	1.2	0.5	0.8	3.5	0.8	2.6	7.6	5.6	5.1	6.1	64.7	181	5.1
40	N//CML312/CML442	0.8	1.4	1.1	9.0	0.7	2.4	8.5	6.5	5.4	6.8	65.7	203	5.6
41	N//CML395/CML444	1.0	0.7	0.9	10.0	0.6	1.9	8.7	7.5	4.5	6.9	66.3	203	5.4
42	N//CML505/CML509	1.1	1.4	1.2	4.0	0.8	2.2	6.5	5.7	5.7	6.0	63.7	181	5.2
43	O//CML312/CML442	0.7	0.3	0.5	16.0	0.5	2.9	9.9	5.6	5.5	7.0	65.7	199	5.6
44	O//CML395/CML444	2.3	1.0	1.7	3.5	0.9	2.4	9.1	5.1	5.2	6.5	65.8	203	5.6
45	O//CML505/CML509	1.3	0.5	0.9	5.5	0.8	2.5	8.7	6.6	4.5	6.6	64.2	192	5.3
46	P//CML312/CML442	3.2	0.6	1.9	4.5	0.7	2.4	6.7	8.6	5.3	6.8	66.0	193	5.9
47	P//CML395/CML444	1.8	0.7	1.2	4.0	0.7	2.1	9.2	6.4	4.5	6.7	67.8	199	5.4
48	P//CML505/CML509	1.6	0.5	1.1	2.5	0.6	2.7	10.7	3.7	3.9	6.1	65.5	185	5.0
49	Q//CML312/CML442	1.4	0.3	0.9	13.5	0.5	2.8	11.5	6.0	5.9	7.8	67.8	210	6.3
50	Q//CML395/CML444	1.3	0.3	0.8	14.0	0.2	2.5	9.4	7.1	6.8	7.7	69.7	208	6.3
51	Q//CML505/CML509	1.6	0.5	1.1	5.5	0.7	2.3	9.4	6.6	4.2	6.7	66.0	196	5.4
52	R//CML312/CML442	1.5	0.9	1.2	5.5	0.8	2.7	9.8	6.1	5.3	7.1	67.0	201	5.8
53	R//CML395/CML444	1.5	0.3	0.9	7.5	0.4	2.3	7.8	6.9	6.0	6.9	67.8	215	5.9
54	R//CML505/CML509	1.6	0.6	1.1	8.5	0.5	2.6	7.4	4.0	4.2	5.2	64.8	192	4.4
55	S//CML312/CML442	0.9	0.2	0.5	10.0	0.7	2.5	9.0	5.1	5.7	6.6	68.3	202	5.4
56	S//CML395/CML444	1.2	0.7	1.0	5.5	0.7	2.6	8.6	6.6	4.0	6.4	68.7	201	5.1
57	S//CML505/CML509	1.0	1.0	1.0	4.5	0.7	2.8	9.4	6.1	4.5	6.6	64.2	184	5.2
58	T//CML312/CML442	1.4	0.5	1.0	8.0	0.6	2.7	8.7	7.0	5.5	7.0	66.7	203	5.8
59	T//CML395/CML444	1.0	0.6	0.8	7.0	0.7	2.5	7.8	7.6	5.7	7.0	66.8	196	5.7
60	T//CML505/CML509	1.1	0.4	0.8	5.5	0.7	2.8	7.1	4.9	5.1	5.7	65.0	179	4.8
61	U//CML312/CML442	0.7	0.2	0.5	5.5	0.5	2.1	7.1	7.6	4.1	6.3	68.5	188	4.9
62	U//CML395/CML444	1.4	1.1	1.2	10.0	0.4	2.3	10.0	6.5	5.9	7.5	68.5	202	6.1

		Stressed Environments						Optimal Environments					Across Sites	
Entry	**Hybrid**	**HLN**	**CRS**	**Across stresses**				**ART**	**KRS**	**RARS**	**ACO**			
		GY t/ha	GY t/ha	GY t/ha	ASI dys	EPP No	Sen 1-10	GY t/ha	GY t/ha	GY t/ha	GY t/ha	AD dys	PH cm	GY t/ha
63	U//CML505/CML509	1.1	0.4	0.8	3.5	0.8	2.9	8.9	5.1	3.9	6.0	63.5	176	4.8
64	V//CML312/CML442	1.1	0.6	0.8	10.5	0.7	2.4	7.2	7.0	5.2	6.5	65.7	197	5.3
65	V//CML395/CML444	0.8	0.9	0.8	18.0	0.5	2.5	8.1	6.1	4.9	6.4	67.7	209	5.1
66	V//CML505/CML509	0.8	0.8	0.8	4.5	0.9	2.8	11.0	7.0	4.2	7.4	64.7	183	5.7
67	W//CML312/CML442	1.5	1.1	1.3	4.5	0.8	3.0	8.8	4.9	5.1	6.3	63.8	194	5.4
68	W//CML395/CML444	1.3	0.8	1.1	4.0	0.7	2.5	7.1	4.7	3.9	5.2	65.5	194	4.4
69	W//CML505/CML509	1.8	0.7	1.2	1.5	0.9	2.5	7.9	4.7	4.4	5.7	63.7	185	5.0
70	X//CML312/CML442	1.5	0.5	1.0	3.5	0.8	2.6	7.8	5.6	5.1	6.2	66.5	197	5.2
71	X//CML395/CML444	1.2	0.7	1.0	6.0	0.9	2.5	11.1	4.2	4.7	6.7	66.5	196	5.4
72	X//CML505/CML509	1.1	0.5	0.8	2.0	1.0	2.2	8.6	3.3	4.4	5.4	64.7	184	4.7
73	Y//CML312/CML442	1.4	0.8	1.1	6.5	0.7	2.7	10.3	6.6	4.9	7.3	67.2	206	5.9
74	Y//CML395/CML444	0.6	1.2	0.9	1.0	1.0	2.5	9.1	7.1	5.9	7.4	67.0	209	5.9
75	Y//CML505/CML509	1.6	0.9	1.3	4.0	0.7	2.7	9.5	6.4	4.4	6.8	64.7	190	5.4
76	Z//CML312/CML442	1.8	0.8	1.3	8.5	0.6	1.9	8.9	6.3	5.0	6.7	66.8	198	5.5
77	Z//CML395/CML444	1.4	0.8	1.1	7.5	0.5	2.8	7.0	6.8	5.5	6.4	66.0	211	5.4
78	Z//CML505/CML509	0.8	0.6	0.7	4.5	0.5	2.6	6.9	8.3	5.0	6.7	63.3	192	5.3
79	AA//CML312/CML442	1.6	1.4	1.5	5.0	0.9	2.7	9.4	4.9	5.7	6.7	65.0	195	5.7
80	AA//CML395/CML444	1.2	1.0	1.1	5.5	0.7	2.3	8.6	6.2	5.9	6.9	66.7	205	5.8
81	AA//CML505/CML509	2.8	1.1	2.0	2.5	0.8	3.0	8.9	5.6	4.1	6.2	64.2	193	5.4
82	AB//CML312/CML442	0.8	0.8	0.8	7.5	0.8	2.3	9.5	5.2	4.9	6.5	66.3	203	5.2
83	AB//CML395/CML444	0.9	0.3	0.6	5.0	0.7	2.4	9.8	8.4	5.8	8.0	68.3	214	6.4
84	AB//CML505/CML509	1.2	0.6	0.9	4.0	0.9	2.2	9.6	5.6	4.1	6.5	64.2	183	5.2
85	AC//CML312/CML442	1.2	1.1	1.1	1.5	0.8	2.2	8.9	8.6	6.0	7.8	66.8	202	6.3
86	AC//CML395/CML444	0.6	0.9	0.8	14.0	0.4	2.5	9.1	8.2	5.2	7.5	67.5	203	5.8
87	AC//CML505/CML509	1.5	0.8	1.1	5.0	0.9	2.7	8.8	4.0	5.3	6.1	62.8	183	5.2
88	AD//CML312/CML442	2.1	0.3	1.2	5.5	0.6	2.3	8.0	5.9	4.9	6.3	67.2	187	5.3
89	AD//CML395/CML444	0.8	0.3	0.6	7.5	0.7	2.1	9.5	6.3	4.4	6.7	67.0	190	5.3
90	AD//CML505/CML509	2.0	0.6	1.3	4.0	0.8	2.6	10.1	5.7	4.1	6.6	62.8	187	5.5

Entry	Hybrid	Stressed Environments						Optimal Environments					Across Sites	
		HLN	CRS	Across stresses				ART	KRS	RARS	ACO			
		GY t/ha	GY t/ha	GY t/ha	ASI dys	EPP No	Sen 1-10	GY t/ha	GY t/ha	GY t/ha	GY t/ha	AD dys	PH cm	GY t/ha
91	AE//CML312/CML442	1.5	0.5	1.0	6.5	0.9	2.8	8.6	6.3	4.4	6.5	65.7	202	5.3
92	AE//CML395/CML444	1.2	0.7	1.0	3.0	0.8	2.5	10.3	5.0	6.5	7.3	68.5	200	6.1
93	AE//CML505/CML509	1.5	0.7	1.1	1.0	0.9	3.2	8.8	7.6	4.5	7.0	64.5	192	5.7
94	AF//CML312/CML442	0.6	1.3	1.0	2.0	0.8	2.5	8.7	6.4	5.2	6.8	67.7	213	5.5
95	AF//CML395/CML444	1.2	1.1	1.1	7.0	0.6	2.2	9.4	6.3	5.3	7.0	67.8	216	5.7
96	AF//CML505/CML509	1.0	0.8	0.9	6.5	0.7	2.4	8.7	4.6	5.8	6.4	64.7	189	5.4
97	AG//CML312/CML442	1.3	1.4	1.3	3.0	0.8	2.6	6.2	4.9	5.3	5.5	66.8	209	4.9
98	AG//CML395/CML444	1.2	1.1	1.1	6.0	0.6	2.3	10.4	7.8	4.7	7.7	67.8	206	5.9
99	AG//CML505/CML509	1.2	0.8	1.0	16.0	0.9	2.7	8.7	4.8	5.5	6.4	63.2	182	5.3
100	AH//CML312/CML442	0.9	0.7	0.8	12.5	0.5	2.9	10.4	6.0	5.3	7.2	68.0	217	5.7
101	AH//CML395/CML444	1.3	0.6	1.0	5.0	0.6	2.2	7.3	6.2	7.2	6.9	68.0	218	6.0
102	AH//CML505/CML509	1.4	0.6	1.0	4.0	0.6	2.9	9.5	7.5	4.4	7.1	64.0	197	5.7
103	AI//CML312/CML442	1.7	0.6	1.1	6.5	0.8	3.0	10.2	4.4	6.8	7.1	68.7	216	6.2
104	AI//CML395/CML444	1.9	0.3	1.1	19.0	0.8	2.5	8.3	5.6	6.3	6.8	69.7	227	5.9
105	AI//CML505/CML509	1.8	0.8	1.3	6.5	0.9	3.0	8.7	5.3	5.2	6.4	64.2	201	5.4
106	AJ//CML312/CML442	1.9	0.8	1.3	7.0	0.5	2.8	9.9	7.9	6.1	8.0	67.0	217	6.6
107	AJ//CML395/CML444	1.3	0.8	1.0	5.5	0.2	3.0	9.8	7.3	5.6	7.6	69.3	221	6.0
108	AJ//CML505/CML509	2.0	1.4	1.7	7.5	0.7	3.3	8.3	6.8	4.8	6.6	64.2	198	5.5
109	AK//CML312/CML442	1.0	1.1	1.0	9.0	0.6	2.8	9.6	8.3	4.2	7.4	66.7	210	5.6
110	AK//CML395/CML444	2.3	0.8	1.6	12.0	0.6	3.1	9.6	7.5	5.8	7.6	67.3	217	6.3
111	AK//CML505/CML509	1.5	0.9	1.2	4.5	1.0	2.6	8.3	8.1	3.7	6.7	63.0	199	5.4
112	AL//CML312/CML442	2.1	1.0	1.6	8.0	0.8	2.6	10.0	4.1	4.4	6.2	67.3	215	5.2
113	AL//CML395/CML444	1.6	1.2	1.4	8.0	0.6	2.4	7.7	6.6	5.8	6.7	69.8	230	5.7
114	AL//CML505/CML509	1.4	1.1	1.3	5.5	0.8	2.6	10.2	6.4	5.4	7.3	66.2	209	5.9
115	AM//CML312/CML442	0.9	1.0	1.0	6.0	0.5	2.7	7.9	7.7	3.7	6.4	67.2	202	4.9
116	AM//CML395/CML444	1.2	0.6	0.9	6.5	0.7	2.8	9.3	7.8	5.9	7.7	67.2	212	6.2
117	AM//CML505/CML509	1.8	0.3	1.1	1.0	0.8	2.0	8.9	5.4	3.8	6.1	64.5	184	5.1
118	AN//CML312/CML442	0.4	0.6	0.5	6.5	0.8	2.8	10.3	5.2	5.8	7.1	68.3	195	5.7

Entry	Hybrid	Stressed Environments						Optimal Environments					Across Sites	
		HLN	CRS	Across stresses				ART	KRS	RARS	ACO			
		GY t/ha	GY t/ha	GY t/ha	ASI dys	EPP No	Sen 1-10	GY t/ha	GY t/ha	GY t/ha	GY t/ha	AD dys	PH cm	GY t/ha
119	AN//CML395/CML444	1.1	1.1	1.1	4.5	0.7	2.7	11.5	6.0	6.0	7.8	68.0	215	6.4
120	AN//CML505/CML509	1.4	0.7	1.1	6.0	0.7	2.6	7.4	6.1	4.2	5.9	63.8	192	4.8
121	AO//CML312/CML442	1.0	1.2	1.1	5.0	0.7	3.0	9.2	7.3	6.1	7.5	66.5	214	6.2
122	AO//CML395/CML444	1.6	1.2	1.4	5.5	0.5	3.0	10.6	5.2	6.5	7.4	67.8	215	6.2
123	AO//CML505/CML509	1.9	0.8	1.3	6.5	0.7	3.1	10.3	6.4	4.7	7.1	64.2	196	5.7
124	AP//CML312/CML442	1.6	0.8	1.2	9.0	0.7	2.1	9.6	7.3	4.3	7.1	67.2	208	5.6
125	AP//CML395/CML444	2.1	0.8	1.5	20.5	0.6	2.2	9.6	6.7	5.8	7.4	67.8	215	6.1
126	AP//CML505/CML509	1.9	2.0	1.9	8.0	0.7	2.4	10.7	3.6	5.0	6.4	64.5	189	5.4
127	AQ//CML312/CML442	1.1	0.6	0.9	8.5	0.7	2.3	8.6	6.6	5.4	6.9	67.2	211	5.7
128	AQ//CML395/CML444	1.1	0.5	0.8	12.0	0.6	2.5	9.2	5.2	4.7	6.4	67.5	207	5.1
129	AQ//CML505/CML509	1.2	1.5	1.4	3.5	0.7	2.6	8.8	7.1	5.1	7.0	64.7	192	5.6
130	AR//CML312/CML442	2.3	0.8	1.6	17.0	0.3	2.4	9.2	5.8	6.7	7.2	72.0	227	6.2
131	AR//CML395/CML444	0.7	0.6	0.7	18.5	0.2	1.8	11.5	5.0	6.7	7.7	70.7	222	6.2
132	AR//CML505/CML509	0.6	1.1	0.8	7.0	0.6	3.1	8.8	7.2	5.2	7.1	68.0	215	5.6
133	AS//CML312/CML442	1.5	0.9	1.2	15.0	0.4	2.6	9.8	7.5	4.7	7.3	70.8	213	5.7
134	AS//CML395/CML444	1.6	1.2	1.4	13.5	0.4	2.3	10.4	7.6	5.1	7.7	71.3	215	6.1
135	AS//CML505/CML509	1.5	1.4	1.5	19.5	0.3	3.0	12.8	4.9	5.7	7.8	66.0	202	6.2
136	AT//CML312/CML442	1.4	0.5	0.9	17.0	0.3	2.4	10.4	4.8	6.0	7.1	71.0	218	5.8
137	AT//CML395/CML444	0.8	1.1	1.0	8.5	0.3	2.6	11.1	4.4	5.4	7.0	71.7	221	5.6
138	AT//CML505/CML509	1.2	0.6	0.9	11.5	0.4	2.8	9.7	5.7	4.5	6.6	67.8	211	5.2
139	AU//CML312/CML442	1.1	0.9	1.0	18.5	0.5	2.7	9.0	3.8	5.2	6.0	70.2	216	4.9
140	AU//CML395/CML444	1.1	1.1	1.1	11.0	0.2	2.2	11.3	4.6	5.0	7.0	70.5	215	5.5
141	AU//CML505/CML509	1.0	0.6	0.8	5.5	0.8	2.6	8.4	5.7	4.2	6.1	66.8	201	4.9
142	AV//CML312/CML442	1.3	0.9	1.1	11.5	0.3	2.5	12.7	8.3	5.5	8.8	71.2	211	6.7
143	AV//CML395/CML444	1.2	1.0	1.1	10.0	0.4	2.9	9.5	8.0	7.0	8.2	72.0	210	6.6
144	AV//CML505/CML509	1.6	0.8	1.2	9.5	0.4	2.9	8.0	5.3	3.3	5.5	68.8	205	4.4
145	AW//CML312/CML442	1.9	1.3	1.6	7.5	0.3	2.4	10.8	7.8	5.3	8.0	70.2	220	6.3
146	AW//CML395/CML444	1.6	0.8	1.2	12.5	0.3	2.5	8.9	4.5	6.6	6.6	71.2	207	5.7

Entry	Hybrid	Stressed Environments						Optimal Environments					Across Sites	
		HLN	CRS	Across stresses				ART	KRS	RARS	ACO			
		GY t/ha	GY t/ha	GY t/ha	ASI dys	EPP No	Sen 1-10	GY t/ha	GY t/ha	GY t/ha	GY t/ha	AD dys	PH cm	GY t/ha
147	AW//CML505/CML509	1.6	1.0	1.3	5.5	0.5	2.9	10.2	5.4	3.6	6.4	67.0	201	5.0
151	AX//CML312/CML442	1.9	1.0	1.4	6.0	0.6	2.4	9.6	9.7	4.6	8.0	66.5	208	6.4
152	AX//CML395/CML444	1.2	1.0	1.1	6.5	0.3	2.2	10.4	10.3	5.7	8.8	68.2	212	6.8
153	AX//CML505/CML509	1.2	0.9	1.1	4.5	0.7	2.4	8.0	6.2	5.9	6.7	63.3	197	5.6
157	AY//CML312/CML442	2.2	1.4	1.8	11.5	0.3	2.9	9.1	6.9	5.2	7.1	69.0	214	5.8
158	AY//CML395/CML444	1.1	0.9	1.0	20.5	0.3	2.8	10.1	5.6	6.5	7.4	70.5	221	6.0
159	AY//CML505/CML509	1.1	0.7	0.9	15.0	0.4	3.0	7.8	3.6	4.0	5.2	66.7	201	4.2
160	AZ//CML312/CML442	1.1	0.5	0.8	5.5	0.6	2.8	8.2	5.6	4.6	6.1	65.7	186	5.0
161	AZ//CML395/CML444	3.0	0.9	1.9	4.0	0.7	2.6	6.7	6.9	6.1	6.6	66.2	209	5.9
162	AZ//CML505/CML509	2.9	1.6	2.3	5.0	0.8	3.0	6.7	4.9	5.9	5.8	65.0	185	5.5
163	BB//CML312/CML442	1.7	1.0	1.3	9.5	0.5	2.4	8.4	8.7	5.5	7.5	69.7	204	6.1
164	BB//CML395/CML444	1.6	1.2	1.4	18.5	0.3	2.5	10.5	7.9	5.7	8.0	69.7	228	6.3
165	BB//CML505/CML509	1.9	0.8	1.3	7.5	0.5	3.3	8.6	8.0	4.9	7.2	68.0	208	5.8
166	BC//CML312/CML442	1.2	1.2	1.2	10.5	0.4	2.4	11.6	8.2	5.1	8.3	70.2	213	6.3
167	BC//CML395/CML444	1.6	1.2	1.4	18.0	0.3	2.8	7.4	3.6	5.0	5.4	72.3	207	4.6
168	BC//CML505/CML509	3.0	0.6	1.8	6.5	0.8	2.7	9.0	7.1	4.6	6.9	67.0	201	5.8
175	BD//CML312/CML442	1.5	0.7	1.1	15.5	0.3	2.7	8.3	3.7	4.9	5.6	69.5	214	4.8
176	BD//CML395/CML444	0.7	1.1	0.9	8.5	0.2	2.6	8.6	8.2	4.3	7.0	69.5	215	5.3
177	BD//CML505/CML509	0.7	0.6	0.7	12.0	0.3	3.1	6.6	3.7	3.5	4.6	66.5	197	3.7
181	BE//CML312/CML442	1.2	0.8	1.0	6.5	0.6	2.2	9.6	8.7	5.6	8.0	69.7	224	6.3
182	BE//CML395/CML444	1.5	0.8	1.1	6.5	0.4	2.4	6.9	7.2	5.6	6.6	72.0	227	5.5
183	BE//CML505/CML509	1.1	0.8	0.9	5.5	0.7	2.7	9.0	3.1	5.1	5.8	68.0	209	4.9
184	BF//CML312/CML442	0.8	1.0	0.9	-2.0	0.5	2.8	10.1	7.1	4.6	7.3	69.2	215	5.6
185	BF//CML395/CML444	0.9	0.4	0.6	8.5	0.5	2.8	7.3	4.0	5.3	5.5	71.2	215	4.7
186	BF//CML505/CML509	1.1	0.8	0.9	6.5	0.7	1.9	9.0	7.3	4.4	6.9	65.8	202	5.5
187	BG//CML312/CML442	1.0	0.7	0.9	8.0	0.7	2.7	11.1	7.3	5.7	8.0	69.8	208	6.3
188	BG//CML395/CML444	0.7	0.9	0.8	5.0	0.4	2.6	10.4	6.2	5.7	7.4	71.7	223	5.9
189	BG//CML505/CML509	1.3	0.5	0.9	3.0	0.8	3.1	8.6	5.1	4.3	6.0	67.8	198	4.9

Entry	Hybrid	Stressed Environments						Optimal Environments					Across Sites	
		HLN	CRS	Across stresses				ART	KRS	RARS	ACO			
		GY t/ha	GY t/ha	GY t/ha	ASI dys	EPP No	Sen 1-10	GY t/ha	GY t/ha	GY t/ha	GY t/ha	AD dys	PH cm	GY t/ha
190	BH//CML312/CML442	1.7	0.4	1.1	5.0	0.7	2.6	10.2	6.5	6.1	7.6	68.7	209	6.2
191	BH//ML395/CML444	1.4	0.7	1.0	8.0	0.6	2.5	10.0	6.8	5.5	7.4	69.8	224	6.0
192	BH//CML505/CML509	1.3	1.6	1.5	2.0	0.8	3.1	11.1	5.0	5.7	7.3	66.0	208	6.0
193	BI//CML312/CML442	1.2	1.4	1.3	12.5	0.7	2.6	8.7	6.6	6.1	7.2	68.0	213	5.9
194	BI//CML395/CML444	0.9	1.5	1.2	6.0	0.5	2.2	9.7	7.5	5.3	7.5	69.3	216	5.8
195	BI//CML505/CML509	1.0	1.1	1.0	3.0	0.8	2.8	10.4	7.6	4.5	7.5	65.5	197	5.8
196	BJ//CML312/CML442	1.5	0.7	1.1	8.0	0.5	2.6	10.1	4.7	4.5	6.4	69.3	214	5.2
197	BJ//CML395/CML444	1.3	1.1	1.2	20.5	0.3	2.8	13.1	7.1	5.6	8.6	71.3	222	6.6
198	BJ//CML505/CML509	0.9	1.0	0.9	7.0	0.6	3.0	8.5	5.7	4.0	6.1	66.8	194	4.7
199	BK//CML312/CML442	1.0	0.4	0.7	17.5	0.3	2.6	8.3	6.8	6.0	7.0	67.7	208	5.7
200	BK//CML395/CML444	2.2	0.3	1.3	12.0	0.4	2.6	10.1	5.3	5.4	7.0	71.3	216	5.8
201	BK//CML505/CML509	1.3	1.3	1.3	8.5	0.4	3.3	10.3	7.1	5.5	7.6	67.7	207	6.1
202	BL//CML312/CML442	0.8	1.0	0.9	12.5	0.4	2.9	7.8	6.7	4.6	6.3	69.3	217	5.1
203	BL//CML395/CML444	1.6	1.0	1.3	8.5	0.6	2.3	10.5	6.3	6.0	7.6	69.5	221	6.2
204	BL//CML505/CML509	1.4	1.5	1.5	3.0	0.7	2.2	8.8	3.1	4.5	5.5	66.2	193	4.6
208	BM//CML312/CML442	0.6	0.8	0.7	13.0	0.5	2.7	8.1	9.5	4.3	7.3	69.5	210	5.6
209	BM//CML395/CML444	1.2	1.0	1.1	12.0	0.6	2.8	11.7	8.0	5.0	8.2	70.7	215	6.3
210	BM//CML505/CML509	0.6	0.8	0.7	9.0	0.6	3.1	6.7	5.2	3.3	5.1	66.5	197	3.9
211	BN//CML312/CML442	1.6	0.4	1.0	4.5	0.6	2.3	10.9	6.5	5.5	7.6	68.8	212	6.1
212	BN//CML395/CML444	1.2	1.2	1.2	3.5	0.8	2.6	9.6	4.8	4.6	6.4	69.0	219	5.3
213	BN//CML505/CML509	1.0	0.3	0.6	5.0	0.6	2.9	10.6	4.6	5.2	6.8	66.2	206	5.4
214	BO//CML312/CML442	1.4	0.4	0.9	7.5	0.6	2.8	11.0	7.4	5.6	8.0	68.3	209	6.3
215	BO//CML395/CML444	1.5	1.4	1.4	3.5	0.7	2.4	10.2	8.5	5.9	8.2	69.8	212	6.6
216	BO//CML505/CML509	1.0	0.8	0.9	9.5	0.4	3.0	9.3	3.6	3.0	5.3	65.3	192	4.1
217	BP//CML312/CML442	1.6	0.6	1.1	3.5	0.8	2.3	12.4	8.2	6.3	9.0	68.8	209	7.2
218	BP//CML395/CML444	2.2	0.5	1.3	10.0	0.5	2.5	9.8	6.8	7.0	7.9	71.8	236	6.7
219	BP//CML505/CML509	1.3	0.5	0.9	6.5	0.8	2.6	7.8	2.6	4.2	4.9	67.3	197	4.3
220	BQ//CML312/CML442	1.5	1.3	1.4	6.0	0.8	3.1	10.6	6.3	4.9	7.3	69.2	196	5.8

		Stressed Environments						**Optimal Environments**					**Across Sites**	
Entry	**Hybrid**	**HLN**	**CRS**	**Across stresses**				**ART**	**KRS**	**RARS**	**ACO**			
		GY t/ha	GY t/ha	GY t/ha	ASI dys	EPP No	Sen 1-10	GY t/ha	GY t/ha	GY t/ha	GY t/ha	AD dys	PH cm	GY t/ha
221	BQ//CML395/CML444	1.2	1.1	1.1	25.5	0.3	2.7	9.6	6.9	5.0	7.2	70.8	214	5.6
222	BQ//CML505/CML509	0.7	1.1	0.9	0.5	0.7	2.9	6.1	4.4	3.3	4.6	67.0	178	3.7
223	BR//CML312/CML442	1.1	1.1	1.1	4.5	0.8	3.0	9.1	5.5	4.9	6.5	68.3	207	5.3
224	BR//CML395/CML444	1.8	0.4	1.1	3.0	0.6	2.1	10.9	7.0	5.1	7.7	69.5	206	6.2
225	BR//CML505/CML509	1.2	1.1	1.1	9.5	0.7	2.5	8.6	4.4	5.4	6.1	65.3	191	5.2
226	BS//CML312/CML442	0.8	0.6	0.7	9.0	0.3	2.3	8.4	7.2	6.0	7.2	69.0	204	5.8
227	BS//CML395/CML444	1.0	1.1	1.0	3.5	0.4	2.9	6.9	6.5	5.6	6.3	70.8	217	5.2
228	BS//CML505/CML509	0.9	0.6	0.7	2.0	0.8	2.9	8.6	5.4	5.3	6.4	67.2	203	5.2
232	BT//CML312/CML442	1.7	0.6	1.2	5.5	0.7	2.7	9.1	6.4	4.1	6.5	68.0	207	5.2
233	BT//CML395/CML444	1.2	1.2	1.2	4.0	0.7	2.7	9.7	6.0	5.2	7.0	70.0	222	5.6
234	BT//CML505/CML509	1.2	0.4	0.8	2.0	0.9	2.9	6.9	5.8	3.0	5.2	65.5	199	4.2
Mean		**1.36**	**0.84**		**7.4**	**0.63**	**2.6**	**9.10**	**6.26**	**5.15**			**203.8**	**5.57**
LSD (p<0.05)		**0.83**	**0.49**		**7.8**	**0.33**	**0.7**	**2.63**	**2.33**	**1.27**			**13.62**	**1.25**

Appendix 4. 4 General combining ability of experiment 2 single crosses in different environments

Single cross	ART Farm	Harare	Chiredzi	Kadoma	RARS	AC sites	ACO
1	-0.93	0.14	0.02	-0.45	0.62	-0.12	-0.25
2	1.30	0.05	0.17	-0.58	-0.29	0.13	0.14
3	-0.79	0.09	0.23	0.87	0.97	0.27	0.35
4	-1.05	0.39	0.25	0.33	0.71	0.13	0.00
5	0.91	-0.36	-0.15	0.38	0.23	0.20	0.51
6	0.11	0.04	0.31	1.02	1.01	0.50	0.71
7	0.63	-0.46	0.29	1.46	1.26	0.64	1.12
8	0.42	0.41	0.56	1.04	0.72	0.63	0.73
9	-0.11	-0.05	0.33	1.27	0.12	0.31	0.43
10	-0.98	0.39	0.17	-0.28	-0.36	-0.21	-0.54
11	-0.08	0.22	0.09	-0.21	0.83	0.17	0.18
12	-1.78	0.22	-0.05	0.69	-0.46	-0.28	-0.52
13	-1.03	-0.23	0.36	-0.62	0.01	-0.30	-0.55
14	-1.30	-0.44	0.16	0.16	0.01	-0.28	-0.38
15	0.08	0.28	0.06	-0.43	-0.26	-0.05	-0.20
16	-0.32	0.95	-0.01	0.25	-0.45	0.08	-0.17
17	1.03	0.29	-0.33	0.59	0.84	0.48	0.82
18	-0.62	0.21	0.07	-0.15	0.94	0.09	0.06
19	-0.15	-0.40	-0.14	-0.33	-1.12	-0.43	-0.53
20	-1.28	-0.28	-0.13	0.06	-0.38	-0.40	-0.53
21	-0.49	-0.48	-0.03	0.40	-1.10	-0.34	-0.40
22	-0.43	-0.54	0.04	0.68	-0.73	-0.20	-0.16
23	-1.14	0.24	0.55	-1.59	-0.64	-0.52	-1.12
24	0.13	0.01	0.50	-2.07	-0.85	-0.46	-0.93
25	0.03	-0.19	0.31	0.54	0.45	0.23	0.34
26	-1.03	-0.07	-0.14	1.55	0.69	0.20	0.40
27	0.09	0.45	0.44	-0.50	0.28	0.15	-0.04
28	0.08	-0.43	0.26	0.73	-0.61	0.01	0.07
29	0.14	-0.30	-0.01	0.56	0.33	0.14	0.34
30	-0.47	0.52	0.16	-0.40	-0.39	-0.12	-0.42
31	-0.69	0.19	0.36	-0.21	-0.16	-0.10	-0.35
32	0.01	-0.49	0.43	-0.46	-0.30	-0.16	-0.25

Single cross	ART Farm	Harare	Chiredzi	Kadoma	RARS	AC sites	ACO
33	-0.84	-0.26	0.11	-0.35	-0.10	-0.29	-0.43
34	0.23	-0.23	0.04	0.52	0.38	0.19	0.38
35	-0.53	0.57	0.26	-1.32	0.99	-0.01	-0.29
36	0.34	0.26	-0.11	1.22	0.29	0.40	0.62
37	1.15	0.26	0.35	2.27	-0.69	0.67	0.91
38	0.43	0.30	0.02	-0.63	0.66	0.16	0.15
39	-0.09	-0.15	0.38	0.55	-0.47	0.04	0.00
40	0.86	-0.54	0.32	-0.48	-0.24	-0.02	0.05
41	0.40	0.11	0.09	-0.01	0.24	0.17	0.21
42	1.34	0.45	-0.06	-0.32	0.49	0.38	0.50
43	-1.00	-0.21	0.06	-0.06	-0.23	-0.29	-0.43
44	1.24	-0.12	-0.46	-0.22	0.90	0.27	0.64
45	1.37	0.23	-0.49	0.15	0.10	0.27	0.54
46	1.21	-0.29	-0.55	-1.26	-0.13	-0.20	-0.06
47	0.74	-0.48	-0.27	-1.88	-0.90	-0.56	-0.68
48	0.96	-0.01	-0.52	1.14	-1.10	0.09	0.33
49	1.74	0.45	-0.46	0.15	0.45	0.47	0.78
51	0.83	0.07	0.10	2.77	1.30	1.01	1.63
53	0.40	-0.03	-0.62	-0.97	-0.15	-0.27	-0.24
54	-1.95	1.06	-0.02	-0.35	-0.24	-0.30	-0.85
55	0.70	0.55	-0.38	2.01	0.42	0.66	1.04
56	-0.30	0.90	-0.29	-0.24	-0.07	0.00	-0.20
59	-1.23	-0.42	-0.57	-1.09	-0.85	-0.83	-1.06
61	-1.02	-0.05	0.01	-0.22	0.47	-0.16	-0.26
62	-0.59	-0.54	-0.01	-0.28	-0.40	-0.36	-0.42
63	0.72	-0.48	-0.18	-0.29	-0.42	-0.13	0.00
64	1.25	0.12	0.04	-0.51	0.40	0.26	0.38
65	0.25	-0.36	0.09	0.82	0.20	0.20	0.42
66	1.33	-0.20	-0.47	-0.83	-0.37	-0.11	0.04
67	0.45	0.22	-0.52	-0.02	0.87	0.20	0.43
68	-0.37	-0.19	-0.11	-1.32	0.32	-0.33	-0.46
70	-0.96	-0.64	-0.25	0.82	-0.87	-0.38	-0.34
71	1.58	-0.17	0.04	-1.14	0.01	0.06	0.15
72	0.81	-0.12	-0.22	0.00	-0.29	0.04	0.17

Single cross	**ART Farm**	**Harare**	**Chiredzi**	**Kadoma**	**RARS**	**AC sites**	**ACO**
73	0.89	0.28	0.11	-0.84	-0.37	0.01	-0.11
74	-0.51	-0.30	-0.29	-0.56	-1.40	-0.61	-0.82
75	0.02	0.13	0.02	-0.74	-0.51	-0.22	-0.41
76	-1.78	-0.42	-0.37	0.20	0.00	-0.47	-0.53
78	-0.42	-0.07	-0.07	-0.36	-0.78	-0.34	-0.52
LSD (p<0.05)	**2.15**	**0.68**	**0.40**	**1.91**	**1.03**		