COMBINING ABILITY FOR EARLY MATURITY IN MAIZE (*Zea mays* L) UNDER DROUGHT AND LOW NITROGEN CONDITIONS.

BY

THOKOZILE NDHLELA

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Department of Crop Science

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APPROVAL

The University of Zambia approves this dissertation of Thokozile Ndhlela as fulfilling the requirements for the award of the degree of Master of Science in Agronomy.

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

DECLARATION

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

Ndhlela 29/06/2007

Signature

ABSTRACT

The unpredictable rainfall patterns increased the demand for early maturing maize cultivars. The two most limiting production constraints in maize are drought and low nitrogen. In most national breeding programs in Southern Africa there are no early maturing testers for use in the early phases of breeding. This study was conducted with a view to validate the suitability of CML509/CML505 as a tester for the identification of early maturing inbred lines with a potential in the development of drought and low nitrogen resistant hybrid cultivars. Fifty inbred lines were crossed to this and other two testers, CML312/CML442 and CML395/CML444, for comparison. The research assessed the relative importance of general and specific combining ability effects (GCA and SCA) for grain yield (GY), days to anthesis (AD), anthesis-silking interval (ASI), plant height (PH), ear-height (EH), ears per plant (EPP), root-lodging (RL) and husk cover (HC), of the fifty inbred lines. The three-way hybrids were evaluated under low nitrogen, drought and optimum conditions.The testers grouped the lines into different heterotic groups with CML509/CML505 proving to be a good early maturing single cross tester for heterotic group A after it managed to group most of the lines that were originally in group A into the same group again. The inbred lines were grouped into heterotic groups by the three testers using the SCA effects for GY. A total of ten lines were grouped into an unidentified group after they exhibited negative SCA effects with a group A and group B tester respectively. General combining ability and SCA analysis showed that additive genetic variance was more important for grain yield and days to anthesis, a proxy parameter for maturity. This has an implication on the breeding strategy in that the parents with good GCA can be crossed and early testing of genotypes becomes more effective and promising hybrids can be identified and selected based on their prediction from GCA effects. The tester, CML505/CML509, showed good GCA effects for most of the traits. The line LF47 had the best GCA effect for GY (0.60 t ha^{-1}) and LF49 had the poorest GCA effect for GY (-0.62 t ha^{-1}). The mean days to anthesis of the crosses with CML509/CML505 were 61.8 days and mean grain yield was 8.9 t ha^{-1} under, optimum conditions. CML509/CML505 also showed fairly good heterosis with most of the lines under both drought and low nitrogen conditions.

DEDICATION

To my husband the late Solomon Gurajena and my sons Eugene, Ginola, Winstone and Munashe who are the source of my inspiration and hard work. Special dedication also goes to my dearest parents Moses and Lillian Ndhlela who have been with me through difficult times.

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Table Of Contents

LIST OF TABLES

LIST OF APPENDICES

Chapter 1
Introduction

Maize (*Zea mays* L.) is the staple food in Southern Africa where over 12 million hectares is grown (FAOSTAT, 2003). In spite of maize yield potential of above 10t/ha, fertilizer use averages less than 25kg/ha and seems to have decreased over the past 10 years as farmers have faced increasing input costs and decreasing product prices (FAOSTAT, 2003). Maize is a member of the grass family, *Graminieae* to which all the major cereals belong. Maize ranks second among world cereal crops (Doswell, Paliwal and Cantrell., 1996). It has the highest grain yield potential of all the cereals. Maize has been put to a wider range of uses than any other cereal as a human food, as a feed grain, a fodder crop and for hundreds of industrial purposes. This has been possible due to its broad global distribution, low price relative to other cereals, diverse grain types and wide range of biological and industrial properties (Doswell *et al.*, 1996).

About 66% of the global maize harvest is fed to livestock, 20% is consumed directly by humans, 8% is used in industrially processed food and non-food products and 6% is seed (Doswell *et al.*, 1996). As food for humans, maize comprises about 75-80% by weight of the food intake, particularly for monogastric animals like poultry and pigs. Maize is the primary staple food crop and occupies about half of the agricultural land in Zimbabwe. The country requires 1.8 m tonnes of maize and 64% of this is required for human consumption (Mashingaidze, 2006). Maize is a staple food of Southern and Eastern Africa, therefore production of the crop has a unique strategic importance for food security and socio-economic stability (CIMMYT

Report 1997/1998). Demand for maize is set to increase from the 1995 levels by 50% globally and by 93% in Sub-Saharan Africa (SSA) by 2020 (Pixley and Bjarnason, 2002). The SSA region has by far the largest variability in maize yields in the developing world mainly due to variation in rainfall (CIMMYT Report 1997/1998). Average yield levels are at 1.2t/ha, which barely result in self-sufficiency of the region despite the strategic importance of maize. As average yields are lower and the agricultural sector of greater importance, this yield variability is of greater socio-economic importance than in any other part of the world (Heisey and Edmeades, 1999).

Drought and low soil nitrogen (N) are the two most important stresses destabilizing maize production in Africa. Drought is thought to cause average annual maize yield losses in maize of about 17% per year in the tropics (Edmeades, Bolanos and Lafitte, 1992), but losses in individual seasons have approached 60% in regions such as Southern Africa (Rosen and Scott, 1992). These stresses are encountered practically in all production environments where maize is grown and this has led to extensive efforts by the Centro Internacional De Mejoramiento De Maiz Y Trigo (CIMMYT), International Institute for Tropical Agriculture (IITA) and several programs within Zimbabwe to develop germplasm suitable for the two types of stresses. Maize crops in the tropics are continually exposed to drought and low N stress. The incidence of stress may increase, due partly to global climate changes, partly due to the displacement of maize by high value crops to more marginal environments and partly to declines in soil organic matter reducing soil fertility and water holding capacity (Banziger, Edmeades, Beck and Bellon, 2000). Conditions of this nature

require that a single variety withstand a wide range of drought stress levels and low nitrogen availability.

Due to the increasing unpredictability of global weather patterns, mainly rainfall amount and distribution, the planting early maturing maize cultivars has become a strategy farmers can use to reduce the risks associated with smallholder farming. The demand for early maturing maize is particularly great among resource poor farmers. Early maturing maize provides options regarding intercrops, relay crops, late planted crops, drought avoidance and of course earlier harvest (CIMMYT-Zimbabwe, 2000). However, under favorable conditions, early maturing maize is inherently lower yielding than later maturing types. An early maturing maize variety can be defined as a variety that flowers within 55-60 days and attains physiological maturity at 120 days after emergence at Harare (1500m above sea level, latitude 17^{o} 48^{1}) (CIMMYT-Zimbabwe, 2000). The estimates for area planted to early maturing maize in East and Southern Africa is 2 690 000 ha (CIMMYT-Zimbabwe, 2000) of which 1000 000 ha are in Zimbabwean Mid-altitude areas. Hybrid success in Zimbabwe has been due in part to the fact that the hybrids have been purposely bred to fit a new ecological niche in dryland farming. The new hybrids are early flowering and drought tolerant. These traits are not found in existing open pollinated varieties in Zimbabwe (Duvick, 1997)

The Zimbabwe national maize breeding program has developed high performance germplasm adapted to tropical mid-altitude growing regions, roughly from 1000 to 1800m above sea level (m.a.s.l) and less than 23^{0} from the equator (Doswell *et al.*, 1996). Since inception, in 1909, open pollinated and hybrid maize varieties have

been developed for production in different ecological niches. Increasingly, exotic germplasm from CIMMYT, IITA, USA, Europe, the SADC and other African countries have been used in combination with local germplasm. In 1960, the commercial single-cross hybrid SR52 was released. The single-cross was based on the inbred lines SC5522 (SC from Southern Cross) and N3-2-3-3 (N3 from Salisbury White) (Doswell *et al.*, 1996). The national program is currently using these two inbred lines, N3.2.3.3 and SC5522 as testers and these have shortcomings such as in seed production and three-way hybrid development. Inbred line testers also have a weakness in that they fail to clearly separate their testcrosses into distinct heterotic groups (Pixley, 1994).

To complement efforts in the Zimbabwean national maize breeding program CIMMYT has established a regional program focusing on early maturing single cross testers. Knowledge about the combining ability and heterotic patterns among CIMMYT's maize germplasm is essential for hybrid work at CIMMYT as well as other national programs using CIMMYT germplasm (Vasal, Srinivasan, Beck, Crossa, Pandey and De Leon, 1992). Single cross testers are vigorous in growth, give high seed yields and produce more pollen than inbred line testers. Initial work by Pswarayi (2004) identified a potential group A tester, a single cross L7/L8 now referred to as CML509/CML505. There is need to verify the single cross tester and this forms the basis of this research. There is also need for grouping and re-grouping of inbred lines being used in the research into heterotic groups. The move by CIMMYT to develop early maturing single cross testers will assist the national program to group its early maturing materials into heterotic groups which will further help in speeding up development of early maturing hybrids.

1.1 Objectives:

1) To group inbred lines into heterotic groups.

2) To verify heterotic groups of already grouped inbred lines.

3) To verify new single cross early maturing group A tester.

1.2 Hypothesis:

The combining ability of inbred lines can be used to identify suitable testers for given heterotic groups in maize.

Chapter 2

Literature Review

In testing for either early or late maturity the most important consideration is the choice of a tester to evaluate combining ability. Abiotic stress conditions, especially drought and low N stress, limit maize production (Banziger, Setimela, Hodson and Vivek, 2006). There is an urgent need to increase maize crop productivity in developing countries in order to meet future food and feed requirements. The performance of inbred lines can be sub-divided into two categories that is general and specific combining ability (Rojas and Sprague, 1952). Superiority of a line on the basis of combining ability estimates can only be decided precisely when the purpose of a breeding programme has been delineated. This would be either to develop high yielding open pollinated varieties or cultivars with a superior hybrid performance.

2.1 Combining Ability

Combining ability is a measure of the value of genotypes based on the performance of their offspring produced in some definite mating system (Allard, 1960). It can rarely be predicted purely on the basis of parental phenotype and therefore is assessed only by progeny testing. Parental plants are said to have good combining ability when they produce vigorous offspring (Vasal, Cordova, Pandey and Srinivan, 1986). Combining ability cannot be predicted from the parental phenotype. It is assessed through progeny testing that involves controlled matings. It was initially a general concept considered collectively for classifying an inbred line relative to its cross performance but was later refined and the two expressions of general combining ability (GCA) and specific combining ability (SCA) have had a

significant impact on inbred line evaluation and population improvement in maize breeding (Sprague and Tatum, 1942).

2.1.1 General Combining Ability Versus Specific Combining Ability

When parents show a high average combining ability in crosses they are said to have good general combining ability while if their ability to combine well is restricted to a specific cross they are said to have good specific combining ability. According to Allard (1960) GCA is defined as the average performance of a strain in a series of crosses whilst SCA is defined as the deviation from performance predicted on the basis of GCA. Sprague and Tatum (1942) defined GCA as the average performance of a line in hybrid combinations and 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.

Estimates of GCA and SCA are relative to and dependent on the particular set of inbred lines included in the hybrids under test. The lines with higher GCA effects can be used in synthetic variety development more effectively. However when high yielding specific combinations are desired especially in hybrid maize development, SCA effects could help in the selection of parental material for hybridization. The GCA component is primarily a function of the additive gene action and on the other hand SCA variance is mainly a function of dominance variance (Singh, 2003).

2.2 Use of testers

2.2.1 Important Concepts

Testers are genotypes of good GCA belonging to well-defined heterotic groups. Good GCA is manifested as good yields in hybrids made between the tester and many different lines. Matzinger (1953) defined a desirable tester as one that combines the greatest simplicity in use with the maximum information on performance to be expected from tested lines when used in other combinations or grown in other environments. On the other hand Rawlings and Thompson (1962) defined a good tester as one that classifies correctly relative performance of lines and discriminates efficiently among lines under test. For improvement of breeding populations Allison and Curnow (1966) defined the best tester as one that maximizes the expected mean yield of the population produced from random mating of selected genotypes.

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. However Vasal, Srinivan and Vergara (1995) define a practical tester as a genotype which is unrelated and shows simplicity in functionality. The tester must provide information that correctly classifies the merit of the tested genotypes into heterotic groups and must differentiate effectively among the genotypes being evaluated. It must also increase the variance of testcross progenies and provide the maximum genetic gain for the tested genotypes.

The materials that can be used as testers include inbred lines, single cross hybrids and heterogeneous materials, which include open pollinated varieties (OPVs),

synthetics or populations. These can be classified into two broad groups namely types with a broad genetic base as well as types with a narrow genetic base. The materials that fall into broad genetic base testers are the heterogeneous materials whilst the single crosses and inbred lines fall into narrow genetic base testers. A broad genetic based tester is used when selecting for GCA whereas a narrow genetic base tester is said to be for SCA.

Testers may change with the objectives of a program and the types of hybrids developed. However, studies by several people have shown that an inbred line tester gives relatively more information for GCA than SCA (Hallauer and Miranda, 1988). The choice of the initial tester is based on experience with most commercial hybrid development programs using inbred parents with proven hybrid performance. Breeders use information on the pedigree of the genotypes being tested along with the knowledge of the performance of the tester with the parents of these genotypes in making this choice. No single tester fulfills all these requirements for all circumstances since the value of a tester is determined to a considerable extent by the use to be made of a particular group of lines. The best compromise for an inbred tester is to select a successful line unrelated to the inbreds being tested and from the target environment for the hybrid. At the onset of any hybrid evaluation, the breeder needs to determine the relative combining ability for the new inbred lines.

2.2.2 Evolution of testers in CIMMYT's Hybrid Maize Program

In the mid 1980s in response to increasing demand for hybrids in developing countries, CIMMYT conducted eight combining ability studies on its populations and pools using diallels/design II (CIMMYT Research Highlights, 1986). During 1988-1990, 92 tropical and 88 subtropical lines were crossed with four inbred line

testers and the resulting 720 single-cross hybrids evaluated in multi-location trials to classify the lines into groups A and B. CIMMYT also attempted using elite single crosses as testers and evaluating the resulting three way hybrids in several multi-location trials. Based on these results in 1993 CIMMYT began systematically categorizing its inbred lines into heterotic groups.

In 2004 an early maturing single cross L7/L8 was identified as a potential group A tester. The tester combined the following good traits, stability in yielding under diverse environments, exhibited no inbreeding depression, and showed intra-group heterosis and positive specific combining ability effects in all environments (Pswarayi and Vivek, 2004). Finally the line compensated for deficiencies found in other lines namely those of grain yield (GY), anthesis silking interval (ASI), plant height (PH) and senescence (SEN).

2.3 Gene Action

Betran, Ribaut, Beck and Gonzalez De Leon. (2003) reported significant interactions for combining abilities under low and high N. According to their findings additive gene effects were more important under drought whereas dominance effects were more important under low N. This suggests real benefits of incorporating drought tolerance in both parental inbreds to enhance hybrid performance under drought (Betran *et al.*, 2003). Gene action is deduced through the estimates of GCA and SCA variances and effects (Singh, 2003).

GCA is a function of additive variance whilst on the other hand SCA variance is mainly a function of dominance variance but it would include all the three types of

epistatic interaction components if epistasis were present. The amount of heterosis shown by a particular cross depends among other things on the differences of gene frequency between the two populations crossed. The failure of wide crosses to show the heterosis that might have been expected can be attributed to epistatic interaction (Goodnight, 1997). Where epistasis is defined as a condition whereby one gene affects more than one trait (Goodnight, 1997).

2.4 Heterosis

Hybrid vigor or heterosis refers to the increase in size or rate of growth of offspring over parents. Hybrid vigor in plants can be observed as an increase in yield of grains or reduction in number of days to flower (Duvick, 1997). Falconer and Mackay (1996) defined heterosis or hybrid vigor as the difference between the hybrid and mean of two parents. Shull (1952) defined heterosis concept as the interpretation of increased vigor, size, fruitfulness, speed of development, resistance to disease and to insect pests or to climatic rigors of any kind, manifested by crossbred organisms. Field crops such as maize are produced as hybrids in increasing amounts in the developing world. Virtually all-commercial maize hybrids are made from crosses of inbred lines.

Betran *et al.* (2003) evaluated lines and their hybrids separately in trials under drought stress, low N and optimal conditions in a total of 12 environments. The differences in grain yield between hybrids and inbreds (i.e heterosis) increased with the intensity of drought stress (Betran *et al.*, 2003). Duvick (1997) reported that, inbreds are low yielding compared to their hybrids due to high degree of heterosis for yield as well as for other traits such as maturity and plant height. Maize hybrids

typically yield two to three times as much as their inbred parents, but superior hybrid genotypes from the farmer's point of view are not necessarily genotypes with high heterosis (Duvick, 1997). High yielding hybrids owe their yield not only to heterosis but also to other heritable factors that are not necessarily influenced by heterosis.

2.4.1 Heterotic groups

Heterotic patterns are specific crosses, between genotypes, which show high level of heterosis (Warbuton, Xia, Crossa, Franco, Melchinger, Frisch, Bohn and Hoisington, 2002). An understanding of the heterotic relationship between populations is needed to exploit exotic germplasm intelligently. Several authors have reviewed heterotic patterns used in the major maize production regions of the world (Wellhausen, 1978; Ron Parra and Hallauer, 1997). The classification of inbreds into heterotic groups facilitates the exploitation of heterosis in maize, which can contribute to hybrid performance (Bhatnagar, Betran and Rooney, 2004).

Heterotic groups were not identified until extensive yield test data of different combinations of inbred lines in double crosses became available (Hallauer, 1997). Initially the groups were identified by how lines performed in crosses i.e AxB crosses were superior to either AxA or BxB crosses where A and B represent different germplasm sources (Hallauer, 1997). Positive SCA effects between inbred lines generally indicate that lines are in opposite heterotic groups (Vasal *et al.*, 1992). Crosses for breeding purposes are made only between lines included in the same group. Lines in the same heterotic group tend to exhibit negative SCA effects when crossed together (Vasal *et al.*, 1992).

In Eastern and Southern Africa, the heterotic groups are based on Southern Cross (SC), Salisbury White (N3), K64r/M162W and Natal Potchefstroom Pear Elite Selection (NPPES) varieties. SC, N3 and NPP ES were developed from materials imported from the USA, while K64r is a direct import from the USA (Mickelson, Cordova, Pixley and Bjarnason, 2001). CIMMYT has developed a number of heterotic groups from some of the above broad groups to suit its lowland tropical, sub tropical, and highland breeding programs. In its programs of southern and eastern Africa, there are two heterotic groups, A and B. Group A includes the following germplasm: Tuxpeno, Reid Yellow Dent and N3, whilst group B has ETO, Lancaster Sure Crop and SC germplasm (Mickelson *et al.*, 2001).

2.5 Screening for drought and Low Nitrogen

Given average maize yields of 1.3t/ha for maize varieties with increased abiotic stress tolerance and significant genetic gains at the lower yield level, breeding for abiotic stresses could probably have a greater impact on maize production and food security in Africa. CIMMYT started in the 1970s and 1980s to improve tropical maize for drought and nitrogen (N) stress tolerance, respectively, given that the two stresses are important factors limiting maize production in low income countries (Edmeades, Bolanos, Lafitte, Pfeiffer, Rajaram and Fischer, 1989).

Early work in maize suggested that selection under dryland conditions may significantly reduce selection gains (Arboleda-Rivera and Compton, 1974; Hallauer and Sears, 1969) whereas selection under irrigated conditions may have some spill over to dryland conditions (Johnson and Geadelmann, 1989). As a result of this, many breeders adopted selection under high potential conditions followed by

extensive multi-environment testing as the most effective approach to maize improvement, (Banziger *et al.*, 2006). However, it was concluded that modern maize hybrids have increased stress tolerance rather than a higher yield potential. The results produced by Banziger *et al.* (2006) show that including selection under high priority abiotic stresses such as drought and low N in a routine breeding program and with adequate weighting can significantly increase maize yields in a highly variable drought prone environment and particularly at lower yield levels.

2.5.1 Drought

A working definition of drought may be defined as the inadequacy of water availability including precipitation and soil moisture storage capacity in quantity and distribution during the life cycle of a crop to restrict expression of its full genetic yield potential (Singh, 2003). Water stress develops in the plants as the demand exceeds the supply of water. Water stress can then be defined as the failure of plants to meet their evapo-transpirational demand.

There are three types of environments associated with drought, which include stored moisture environment, variable moisture environment and optimal moisture environment. The breeding methodology adopted would largely depend on the drought environment to which the crop will be subjected.

Under the stored moisture environment the crop completes its life cycle on moisture stored in the soil prior to the rainy season. The level of moisture stress to which the crop is subjected largely depends on the amount of moisture that was stored in the soil, number of days to maturity of the crop and lastly the rate of evapotranspiration.

The likelihood of success of breeding for drought resistance is rather high (Singh, 2003).

The variable moisture environment is characterized by alternate dry and wet periods of varying lengths and crops under this environment must be able to take advantage of the periodic rainfall. Under the optimal moisture environment the crop is grown with adequate moisture during most of its life cycle and drought occurs occasionally at highly unpredictable stages of growth and development. Effects of drought in such an environment are likely to be severe in view of the inadequate time available for plants to become adjusted to water stress. Therefore breeding for drought resistance in such environments may be extremely difficult.

2.5.2 Effect of drought on maize production

Drought stress particularly affects the ability of the maize plant to produce grain at three critical stages of plant growth; early in the growing season, at flowering and during mid to late grain filling. Robins and Domingo (1953) first quantified the large yield reductions that occur when drought stress coincides with the flowering period. When Denmead and Shaw (1960) reduced plant water status to the wilting point during pre-flowering, flowering and post-flowering stages, yield reductions were 25%, 50% and 21% respectively. Claasen and Shaw (1970) observed that stressing plants to wilting prior to silking reduced grain yields by 15%; at silking by 53%; and when stress was applied in the three weeks after silking by 30%.

However Grant, Jackson, Kiniry and Arkin (1989) suggested that extreme sensitivity was confined to the period between 2 days and 22 days after silking, with a peak at 7 days after silking, when kernel numbers were reduced to 45% of the control. Yield

reductions as high as 90% and an incidence of barrenness reaching 77% were recorded by NeSmith and Ritchie (1992) when plants were stressed in the interval from just prior to tassel emergence to the beginning of grain filling. Maize is thought to be more susceptible to drought at flowering than other crops because its florets develop virtually simultaneously and are usually borne on a single ear on a single stem. Grain yield of maize grown under severe drought stress at flowering is highly correlated with kernel number per plant (r=0.90) and with ASI (-0.60) (Bolanos and Edmeades, 1996).

Silk growth and kernel number appear to depend directly on the flow of photosynthetic products produced during the three weeks of extreme sensitivity that bracket flowering (Schussler and Westgate, 1995). Pollination in many cases has been shown to be successful in drought stressed plants, only to be followed by abortion of the kernels a few days later (Westgate and Boyer, 1986). Earlier studies suggested that water deficit effects might influence acid invertase activity and cause partial reductions in the flux of photoassimilates suitable for growth to the developing ear (Schussler and Westgate, 1995). Zinselmeier, Jeong and Boyer(1999); Zinselmeier, Habben, Westgate and Boyer (2000) demonstrated that acid invertase indeed has a central role in providing the necessary sugars for the developing ear and that its activity is sensitive to drought effects.

When maize encounters water deficits, there is a decline in photosynthesis per plant. This can be due to a reduction in light interception as leaf expansion is reduced or as leaves senesce, and to reductions in carbon fixation per unit leaf area as stomata close or as photo-oxidation damages the photosynthetic mechanism (Wesley *et al.*,

2001). Edmeades, Bolanos, Hernandez and Bello (1993) found that delayed silking under drought or high plant density was related to less assimilate being partitioned to growing ears around anthesis, which resulted in lower ear growth rates, increased ear abortion, and more barren plants. Selection for reduced growth of stems and tassel may reduce competition for assimilates at flowering and thereby decrease kernel abortion (Banziger *et al.,* 2000).

2.5.3 Effects of drought on physiological traits at cellular level in maize

Many of the changes due to dehydration stress in maize plants include the accumulation of a variety of sugars, proline and glycine betaine in addition to changes in protein levels (Bartels and Nelson, 1994; Ingram and Bartels, 1996; Zinselmeier *et al.*, 1999). The changes are associated with osmotic adjustment and the protection of membranes from damage as cell contents desiccate.

Abscisic acid (ABA) is produced to high levels in response to drought (Singh, 2003). The accumulation of ABA may enhance survival through stimulation of leaf rolling and stomatal closure, but it reduces productivity (Mugo, Banziger and Edmeades, 2000). Photo-oxidation of chlorophyll takes place under drought conditions and this affects mostly the photosystem I whereby the electrons become uncoupled resulting in free high -energy electrons in the leaf (Banziger *et al.,* 2000). This therefore leads to photo oxidation of chlorophyll and loss of photosynthetic capacity.

2.5.4 Breeding strategies and methods for drought prone environments

The first principle of crop improvement is to fit the variety to the growing season (Ludlow and Muchow, 1990). It is important that drought resistance be incorporated

in materials with high genetic potential for yield. Yield and yield components are best evaluated under optimal conditions while drought resistance must be evaluated under water stress.

2.5.4.1 Drought escape

Drought escape describes the situation where an otherwise drought susceptible variety performs well in a drought environment simply by avoiding period of drought (Singh, 2003). The season length for maize under rainfed conditions is often defined as that time when precipitation is equal to or exceeds 50% of potential evapotranspiration as determined by radiation, wind and temperature (Banziger *et al.,* 2000). In this case the goal for breeding would be to develop varieties that can escape drought by being early in maturity as to complete their life cycle within a given season length. This was the basis for some earlier success stories in maize breeding for dry environments such as the R200 series of hybrids in Zimbabwe (Mashingaidze, 1994). However it should be noted that early varieties generally have lower leaf area index, lower total evapotranspiration and lower yield potential (Singh, 2003).

2.5.4.2 Drought tolerance

Plant breeders have amassed considerable knowledge about improving drought tolerance (Boyer, 1996). Drought tolerance can be defined as the mechanism causing minimum loss of yield in a drought environment relative to the maximum yield in a constraint free optimal environment of the crop (Singh, 2003). At CIMMYT for example selection for drought tolerance began in 1975 and expanded in the mid-1980s (Edmeades, Bolanos, Banziger, Chapman, Ortega, Laffite, Fischer and Pandey, 1997a).

Beck, Betran, Banziger, Edmeades, Ribaut, Willcox, Vasal and Ortega (1997a) and Vasal, Cordova, Beck and Edmeades (1997) have reviewed a variety of options for developing drought tolerant maize which include the conventional breeding approach, development of stress tolerant maize under carefully managed drought stress conditions and selection for secondary traits that are thought to increase plant adaptation to drought. The development of enhanced stress tolerance in CIMMYT's lowland tropical germplasm has been based on a combination of selection under managed stress and selection for secondary traits, a strategy well-suited to environments where severe drought stress can be expected.

2.5.4.3 Secondary traits in selection for drought

Selection for improved performance under drought based on grain yield alone has often been considered inefficient, but the use of secondary traits of adaptive value whose genetic variability increases under drought can increase selection efficiency (Bolanos and Edmeades, 1996). Grain yield and secondary traits are employed in conjuction with each other in screening for drought tolerance, with yield being the main trait (Banziger *et al.,* 2000). Grain yield is normally highly correlated with the kernel number per unit area and per plant rather than with weight per kernel (Bolanos and Edmeades, 1996; Edmeades, Bolanos, Chapman, Lafitte and Banziger, 1999; Andrade, Vega, Uhart, Cirilo, Cantarero and Valentinuz, 1999). Yield potential is important in determining yield under moderate stress, but it becomes less important when yield falls below 50-60% of potential (Banziger and Laffitte, 1997), when stress-adaptive secondary traits assume a real significance.

Consideration of secondary traits could improve selection efficiency under stress conditions (Banziger and Laffitte, 1997). A suitable secondary trait is genetically associated with grain yield under drought, highly heritable, stable and feasible to measure and finally not associated with yield loss under ideal growing conditions (Edmeades, Cooper, Lafitte, Zinselmeier, Ribaut, Habben, Loffler and Banziger, 2001). Experience in CIMMYT and Pioneer Hi-Bred indicates that key secondary traits under drought are reduced barrenness, ASI, stay green and to a lesser extent leaf rolling (Banziger *et al.*, 2000b). Selection for delayed foliar senescence under drought stress has apparently not only delayed foliar senescence under drought (Bolanos and Edmeades, 1993), but also has resulted in a more efficient use of leaf N for grain production across N levels. Selection for stay green should increase intercepted radiation and hence grain yields (Edmeades *et al.*, 1999).

In work done by Edmeades *et al.* (1997a) at CIMMYT it was concluded that it was best to select for a combination of secondary traits in addition to yield as a way of faster improvements in yield under drought stress and not selecting for yield alone. Data collected during selection revealed faster progress with the use of these secondary traits in addition to grain yield per se, and that the correlation between these and yield under drought were generally high and significant (Fischer, Edmeades and Johnson, 1989). Bolanos and Edmeades, (1993b) discovered that the only secondary trait that registered significant change from selection was a reduction in ASI under drought associated with increased ears and kernels per plant.

Selection for tolerance to mid-season drought stress consistently reduced ASI and increased ear numbers of four tropical maize populations when evaluated across N

levels ranging from well fertilized to severely N stressed (Banziger, Edmeades and Lafitte, 2002). Banziger *et al.* (2006) found that selection differentials were largest between 2 and 5 t/ha and they became less significant at higher yield levels. An Eberhart –Russell stability analysis estimated a 40% advantage at the 1 t yield, which decreased to 2.5% at the 10 t yield level (Banziger *et al.*, 2006). Fischer *et al.* (1989) reported faster progress with the use of secondary traits in addition to grain yield per se, and that the correlation between these and yield under drought were generally high.

2.6 Selection Indices

A selection index is a summary of the worth of a genotype, which is used as a selection tool to identify superior genotypes. Selection is for an index that seeks to maintain or increase grain yield under well-watered conditions, increase grain yield under drought and decrease ASI, barrenness, the rate of leaf senescence and leaf rolling under drought (Bolanos and Edmeades, 1993a; Bolanos *et al.*, 1993; Byrne *et al.*, 1995; Beck *et al.*, 1996; Edmeades *et al.*, 1999). Superior genotypes are those whose indices have the largest values. Selection indices are either used to improve a single quantitative trait (e.g. drought tolerance) by making measurements on a number of traits, or to improve two or more traits simultaneously in an organism.

Table 2.1: Selection indices for Drought Stress.

Trait	Weight	Sign
Grain yield	*5*	*+(Increased grain yield)*
Ears per plant	3	+(Increased no.of ears per plant)
ASI	2	-(Decreased ASI)
Leaf senescence	2	-(Decreased leaf senescence)
Tassel size	2	-(Decreased tassel size)
Leaf rolling	1	-(Decreased leaf rolling)

(Adapted from Banziger *et al.* 2000)

A positive sign is given to a trait where larger values are desired (e.g. grain yield); while a negative sign is given where lower values are desired (e.g. lodging, ASI).

2.7 Managing drought Stress

Selection studies have shown that the tolerance of tropical maize to drought and N stress can be improved more rapidly when selection environments comprise managed levels of those stresses than when the same germplasm is selected only under high –yielding, non-stressed conditions, or under randomly occurring levels and types of stresses (Bolanos and Edmeades, 1993; Byrne *et al.*, 1995; Edmeades *et al.*, 1997; Lafitte and Edmeades, 1994). Selection for tolerance to midseason drought stress increased grain yields under drought in the four maize populations by 93 kg/ha/year (Edmeades *et al.*, 1997). It can be suggested that constitutive stress tolerance mechanisms may exist in maize germplasm and that some of them may be related to the establishment of reproductive structures (Banziger *et al.*, 2006). Maize produces many more potential ears, ovules and kernels than those that survive to maturity (Tolenaar, 1977).

Managing drought stress is done by conducting experiments partly, or entirely in the dry season and the stress is managed through irrigation. Test environments need to be established where the probability of drought stress is high, where timing, duration and intensity of stress can be modulated by irrigation, and where there are obvious similarities to the area of adaptation of the germplasm under examination. One tropical maize population that had been improved for tolerance to mid-season drought stress showed decreased kernel and ear abortion under drought (Edmeades *et al.*, 1993; Chapman and Edmeades, 1999). Of importance also is the uniformity of stress the more uniform the stress is over space and time the easier it is to observe

genetic differences making breeding progress much greater. Experiments should be grouped so that flowering time coincides for all experiments being subjected to a single stress treatment and genotypes in one experiment should be of similar maturity (Banziger *et al.*, 2000).

2.7.1 Irrigating drought experiments before the drought stress period

It is desired that irrigation intervals and other agronomic practices be designed in such a way that the crop is subjected to optimum growing conditions for establishment and growth before the period when the drought stress is applied (Banziger *et al.*, 2000). There is need to calculate the time of the last irrigation so that the drought stress is sufficiently intense at the critical growth stage. In order to calculate the crop water balance there is need first to determine the average anthesis date, which would largely depend on the temperature. The temperature sum between planting and flowering can help in determining the anthesis date and it is calculated using the following formula:

$$\textbf{Temperature sum} = \textbf{sum}((T_{max} + T_{min})/2\text{-}8)$$

It is also important to estimate the daily water consumption of the maize plant, determine soil texture and determine the plant available water. The amount of water available to the plant until first stress symptoms are visible can be estimated since it is known that maize will start to show symptoms of stress when 55-65% of (Plant available water * Root depth) is used (Banziger *et al.*, 2000). This can be done using the following formula:

$$W = RD/10 * PAW * 0.65$$

Where W= water

RD= root depth

PAW= plant available water

Lastly the time of the last irrigation also needs to be calculated:

$\mathbf{T_2 = AD - 2 * T_1}$

Where T_2= time of last irrigation

AD= anthesis date

T_1= time until maize shows first symptoms of drought stress

$\mathbf{T_1 = AW/DWC}$

2.7.2 Application of drought stress at targeted growth stages of maize

a) Drought stress applied at flowering stage

Drought at flowering commonly results in barrenness and this is thought to be due to a reduction in the flux of assimilate to the developing ear below some threshold level necessary to sustain grain formation and growth (Westgate and Bassetti, 1990; Schussler and Westgate, 1995). One universal phenomenon observed when maize flowers are under drought is the delay of silking in relation to pollen shed, giving rise to the anthesis-silking interval (ASI) whose duration is highly correlated with kernel set (DuPlessis and Dijkhuis, 1967; Edmeades, Bolanos, Elings, Ribaut, Banziger and Westgate, 2000). Under such conditions, pollen can arrive after it has desiccated, when silks have withered or senesced (Bassetti and Westgate, 1993a, b) or after ovaries have exhausted their starch reserves (Saini and Westgate, 2000; Zinselmeier *et al.*, 2000). Application of stress at flowering results in ASI being averaged to 4-8days and the ears per plant 0.3-0.7 to give an average yield of 1-2t/ha (Banziger, *et al.*, 2000). The ability of a cultivar to produce an ear under stress is the most important characteristic associated with drought tolerance (Bolanos and Edmeades, 1996).

b) Drought stress applied at grain filling

The stress is applied such that drought develops directly after flowering and leaf senescence is accelerated. At this stage kernel weight is the one that is affected because photosynthesis during grain filling will be reduced as a result of accelerated senescence. Drought stress at this stage can reduce yield potential by 50%. Grain yield reductions from mid to late grain filling are not nearly as severe as those produced by a similar stress during flowering. Drought lessens the capacity of developing kernels to use available assimilates because the functioning of a key enzyme, acid invertase is impaired (Zinselmeier *et al.*, 1995; Westgate, 1997). Once the kernels enter the linear phase of biomass accumulation about two to three weeks after pollination they develop the capacity to access reserve assimilates stored in the stem and husk. If kernels successfully reach this stage, they normally grow to at least 30% of the weight of kernels on unstressed environment, even though the drought may become more severe (Bolanos and Edmeades, 1996).

2.8 Nitrogen

Crops can only assimilate inorganic forms of nitrogen such as nitrate (NO_3^-) and ammonium (NH_4^+). In warm well aerated and slightly alkaline soils absorption of the NO_3^- form will usually predominate. NH_4^+-N in soils is retained mostly in the immobile exchangeable form and to become positional available it must be sought out by plant roots whereas NO_3^- is mobile in the soil so it moves rather easily to roots either with or through soil water. The two forms of nitrogen are together referred to as mineral N. Mineral N in the soil can be increased by mineralization of soil organic matter, fertilizer application, release of NH_4^+ from clay minerals and slightly through rain. Nitrogen mineralization is the process by which organic nitrogen is converted to available inorganic forms. The rate of mineralization is

generally high in soils which are regularly fertilized with organic manure and also when nitrogen fertilizers have been applied in excess.

2.8.1 Duration of N uptake, assimilation and Nitrogen use efficiency (NUE)

At the start of the season mineral N supply usually exceeds the uptake capacity of maize. As the season progresses maize depletes the mineral pool since uptake rises to as much as 4-5kg/ha per day and this rate of uptake normally exceeds N mineralization, which would be less than 1kg/ha/day (Banziger, *et al.,* 2000). Maize continues to take up N until 4-6weeks after flowering. Laffitte and Edmeades, (1994); Kling *et al.*, (1996) suggested that cultivar traits such as maximum rooting depth and the capacity of the roots to absorb nutrients enable plants to take up N from different soil layers. NUE is defined as grain production per unit of N available in the soil (Moll, Kamprath, Jackson, 1982).

The low N tolerant cultivars are superior in the utilisation of available N, either due to enhanced uptake capacity or because of more efficient use of absorbed N in grain production (Laffitte and Edmeades, 1994). NUE of absorbed N is around 30-70kg grain per kg N at low levels of N availability. A ratio of 20-40kg grain/kg applied N at levels of applied N<50kgN/ha should be expected on highly deficient soils with improved cultivars (Banziger, *et al.,* 2000). Efficiency in uptake and utilisation of N in the production of grain requires that those processes associated with absorption, translocation, assimilation and redistribution of N operate effectively (Moll *et al.*, 1982). Stay green is an important component of genetic variation in NUE since a given amount of N in leaves can be used for photosynthesis and carbon dioxide (CO_2) assimilation over a longer time than in a plant where leaf senescence occurs earlier.

2.8.2 Effect of low N stress on maize

Depending on the timing of N stress different yield determining factors are affected. Banziger *et al.*, (1999) found that N stress reduced grain yields in the low N experiments by 20% in 1992 and by 50% in 1992-1993 compared with the high N experiments. Nitrogen mineralization in the soil is usually less than 1kgN/ha/ day as mentioned earlier whilst a healthy maize crop will take up and assimilate 4-5kgN/ha/day (Banziger *et al.*, 2000). Low nitrogen stress reduces leaf area, accelerates leaf senescence and reduces radiation efficiency (Wolfe *et al.*, 1988; Muchow and Sinclair, 1994; Uhart and Andrade, 1995). When N becomes scarce, plants reallocate N from older tissue to younger tissue leading to early senescence of older, lower leaf tissue. N stress during the flowering stage results in kernel and ear abortion. However it is unclear which processes determine the abortion of reproductive structures under N stress (Banziger *et al.*, 2002). Carbohydrate reserves typically accumulate in the stem of N-stressed plants (Mumera and Below, 1993) indicating that factors other than carbohydrates may limit ear growth and the establishment of reproductive structures.

Below *et al.* (2000) concluded that N plays an important and direct role in kernel development maybe through lower enzyme levels or enzyme activity that reduce the processing of sucrose arriving at the ovaries. Nitrogen stress reduces radiation use efficiency. Under severe stress both pollen shed and silking are delayed, with delay being more in silking such that the anthesis silking interval (ASI) is lengthened. As with drought, silking delay is correlated with kernel and ear abortion. Nitrogen stress delays silking of maize and thereby widens ASI (Jacobs and Pearson, 1991). A

longer ASI indicates that fewer ears reach silking or that more ears reach silking at a later date.

2.8.3 Breeding strategy for N stressed environments

If yields in target environment are less than 40% of the yields obtained under well fertilized conditions germplasm should be evaluated under severe N stress as part of selection (Banziger *et al.*, 2000). There is no relationship between genotype performance under well-fertilized environments and severely stressed environments for nitrogen (Banziger *et al.*, 1997). The use of secondary traits is also recommended in screening for low N tolerance. Using the selection theory, Banziger and Laffitte (1997) showed that the use of secondary traits plus yield, improved selection gains for maize yield under low N by 20% versus selection for yield alone with the gains increasing as N deficiency intensified. Banziger and Laffitte (1997) concluded that secondary traits could increase the efficiency of selection for grain yield in maize breeding programs targeting low N environments. These traits include grain yield, ears per plant, leaf senescence and anthesis silking interval. For grain yield selection is for high grain weight and the measurement is done on shelled grain adjusted for moisture.

Banziger *et al.* (1997) carried out experiments at CIMMYT, Mexico on the effectiveness of using secondary traits in improving selection efficiency under stressed conditions. Secondary traits used were ASI, number of ears per plant, leaf chlorophyll concentration and an estimate of leaf senescence. Grain yield, as a primary trait, was used in conjunction with the secondary traits. Laffitte and Edmeades (1994) obtained significant genetic correlations between grain yield and leaf chlorophyll concentration, ear leaf area, plant height, ASI and leaf senescence

among full sib progenies under low N, indicating the potential value of these traits in a low N selection program. Banziger *et al.* (1997) found significant genetic correlation of secondary traits with grain yield averaging – 0.47 for ASI, 0.78 for ears per plant, and 0.42 for leaf senescence. Banziger and Laffitte (1997) concluded that ears per plant were the most effective secondary selection criterion followed by leaf senescence.

2.8.4 Low N Stress management

The key to breeding for low N tolerance is to manage stress such as to simulate farmer's fields and the objective being to measure genotypic low N tolerance. In managing low N stress the experiments are conducted under fields depleted of N. The timing of the stress is very important and should be such that the growth stages targeted are susceptible to stress. Stress intensity should be severe enough so that traits important for yield become distinct from those which affect yield under non-stressed conditions. Of importance also is the uniformity of stress the more uniform the stress is over space and time the easier it is to observe genetic differences making breeding progress much greater.

An ideally managed low N stress should result in yield levels that are about 25-30% of those obtained under well fertilized conditions (Banziger *et al.*, 2000). If the yield potential of a given area under optimal fertilization is 7t/ha yield under well managed low N should be 1.5-2.5t/ha. Under these conditions genetic variation for low N tolerance can be observed mainly because the traits that affect yield are different from those relating to yield under non-stress conditions.

Low N stress can be managed by using the same low N field over several seasons. The intensity of the stress can be increased by choosing a field with sandy soil texture and where no other factor other than N limit growth. Non –leguminous crops with high biomass production can be grown in the field so that more N can be removed. Nitrogen fertilizers should not be applied in the field except when yields are expected to fall below 25% of yields measured under well-fertilized conditions.

Table 2.2: Selection indices for Low Nitrogen Stress.

Trait	Weight	Sign
Grain yield	5	+(Increased grain yield)
Ears per plant	2	+(Increased no.of ears per plant)
Leaf senescence	2	-(Decreased leaf senescence)
ASI	1	-(Decreased ASI)

(Adapted from Banziger *et al.*, 2000)

2.9 North Carolina Design II

In design II, different sets of parents are used as males and females. The number of crosses increases rapidly as the number of parents included increases in both design II and diallel but the number of crosses would be considerably less for design II particularly when greater numbers of parents are used (Hallauer and Miranda, 1988). Half as many crosses are produced when 10 or more parents are used. The sources of variation include the males and the females and the interaction of males with females. The expectations of males and females are equivalent to general combining ability (GCA) and the male x female source is equivalent to specific combining ability (SCA) of the diallel analysis. Because of the two sets of parents in design II there are two independent estimates of GCA (Hallauer and Miranda, 1988). Similar to the diallel design model I analysis in design II would provide estimates of GCA effects for males and females and SCA effects for males x females. The other

advantages of design II over diallel is that two independent estimates of σ^2_A are available and an estimate of σ^2_D can be determined directly from the mean squares.

The design II method is suitable where there is a large size of germplasm and where there are established heterotic groups, or proven testers. It is mainly used to broaden the genetic basis of established heterotic groups with germplasm of similar heterotic response (Gutierrez-Gaitam, Corttez- Mendoza, Wathika, Gardner and Darrah, 1996). The main criterion used for the choice and grouping of materials is GCA and SCA values of testcrosses made between the known heterotic groups or the testcrosses between the proven testers and the populations to be grouped. Ninety-two CIMMYT maize inbred lines were assigned to Tropical Heterotic Groups A and B using this method. Four testers, two dents and two flints of known heterotic groups, were used to make testcrosses with the ninety-two lines. All lines which showed negative SCA with dents but positive with flints were assigned to group A, and all lines showing positive SCA with the dents and negative with the flints were assigned to group B (Vasal *et al.*, 1992).

Chapter 3

Materials and Methods

3.1 Germplasm

Fifty inbred lines (Table 3.1) were used and these were crossed to three single cross testers CML312/CML442 (originally used as group A tester), CML395/CML444 (originally used as group B tester) and CML509/CML505 (identified potential group A tester). North Carolina mating design II was used to produce the crosses at Mzarabani during the winter season. Each female, which, represents the inbred lines, were crossed to each male which are the testers to produce 150 crosses.

3.2 Evaluation sites

The crosses were planted in separate trials at four sites. The sites were CIMMYT station (Harare; 17.80^{0}S, 31.05^{0}E, 1468 masl), ART Farm (Harare; 17.43^0 S, 31.5^0 E, 1480 masl), Chiredzi Research Station (21.02^0 S, 31.58^0 E 433 masl) and Kadoma Research Station (18.32^{0}S, 30.90^{0}E, 1155 masl). The trials at CIMMYT Station (Harare) (Nitrogen stress site) were grown under low nitrogen conditions and optimum conditions whereas trials at ART Farm and Kadoma were conducted under optimum conditions. In Chiredzi the trials (water stress) were grown under high nutrient levels but subjected to drought stress. According to the FAO classification the soils at CIMMYT Harare Station and ART Farm are of the *Rhodustalf* greater group with texture code ICG. Whilst the soils at Chiredzi are of the greater group *Haplustalf* code LXh7 and texture code ICH. The average rainfall received per annum at CIMMYT Harare is about 820 mm whilst that received at ART Farm is about 891 mm. In Kadoma soils are of the greater group *Haplustox*, code FRr14 and texture code DCE and average rainfall is 727 mm/annum.

Table 3.1. Parents, Pedigrees of Materials Used

Parent	Pedigree
LF1	[HWSA (FG)C1-9-1-B/CML395//NAW-50-2]-B-3-4-1-1-1
LF2	[P24/CML312//COMPE20]-B-3-4-1-3
LF3	Chivara-3-1-1-1
LF4	Chivara-3-1-1-3
LF5	Chivara-3-1-1-5
LF6	Chivara-3-3-1-1
LF7	[CML197/N31/FR808]-X-8-2B-2-1-BB
LF8	ZEWAc1F2-80-1-1-B-1-BB
LF9	ZEWAc1F2-13-3-2-B-1-BB
LF10	ZEWAc1F2-300-2-2-B-1-BB
LF11	ZEWAc1F2-219-4-3-B-1-BB
LF12	ZEWBc1F2-216-2-2-B-2-BB
LF13	[SC/CML204//FR812]-X-30-2-3-2-1-BB
LF14	ZEWBc1F2-158-1-2-B-1-BB
LF15	ZEWBc1F2-149-1-1-B-1-BB
LF16	ZM303c1-260-3-B-3-1-BB
LF17	ZM303c1-32-3-B-1-2-BB
LF18	ZM303c1-243-3-B-1-1-BB
LF19	NIP25-98-1-2-B-1-BB
LF20	NIP25-20-1-1-B-1-BB
LF21	(87036/87923)-X-800-3-1-X-1-BB-1-1-1-BBB
LF22	[[[K64R/G16SR]-39-1/[K64/G16SR]-20-2]-5-1-2-B*4/CML390]-B-39-2-B-4-#-1-BBB
LF23	[[[NAW5867/P30SR]-111-2/[NAW5867/P30SR]-25-1]-9-2-3-B-2-B/CML388]-B-35-2-B-1-#-1-BBB
LF24	[[[NAW5867/P30SR]-40-1/[NAW5867/P30SR]-114-2]-16-2-2-B-2-B/CML395-6]-B-20-1-B-3-#-1-BB
LF25	[[[NAW5867/P49SR//NAW5867]-43-1/[NAW/P49//NAW]-12-7]-4-1-1-B-1-B/CML390]-B-14-1-B-3-#-BBB
LF26	[89[G2/TEWTSRPooL]#-278-2-X-B/[COMPE2/P43SR//COMPE2]F#-20-1-1]-B-32-2-B-7-#-1-BBB
LF27	Ent320:92SEW2-77/[DMRESR-W] Early Sel-#1-2-4-B/CML390]-B-13-2-B-4-#-1-BBB
LF28	[Ent52:92SEW1-2/[DMRESR-W]EarlySel-#1-2-1-B/CML386]-B-22-1-B-2-#-2-BB
LF29	[Ent67:92SEW1-17/[DMRESR-W]EarlySel-#1-3-3-B/CML391]-B-31-B-3-#-1-BBB
LF30	[MSRXG9]C1F2-176-4-1-4-X-X-2-BB-2-1-1-BBB
LF31	[NAW5867/P49SR(52#)//NAW5867]F#-48-2-1-B-7-BB-1-B-#-BBB
LF32	[P30/P45//M162W/MSR]97-323-3-1-5-B-1-#-1-B
LF33	[P501c2/[EV7992#/EV8449-SR]C1F2-334-1(OSU8i)-1-1-X-X-B-B]-4-1-1-4-1-6-B
LF34	[TEWDSR-DrtTolSyns1#-8-XX-1-B*4/CML390]-B-28-1-B-3-#-BBBB
LF35	[TEWDSR-DrtTolSyns1#-8-XX-1-B*4/CML390]-B-6-1-B-2-#-1-BBBB
LF36	[TIWD-EarlySelSyns1#-2-XX-2-B/[SWISR/COMPE1-W]-126-2-1-B]-B-11-4-B-2-#-1-BBB
LF37	[TIWD-EarlySelSyns1#-2-XX-2-B/[SWISR/COMPE1-W]-126-2-1-B]-B-27-4-B-2-#-1-BBB
LF38	CML205-B
LF39	CML440-B
LF40	P300C5S1B-33-4-4-##1-1-4-BBB
LF41	P300C5S1B-33-4-5-##1-6-4-B*4
LF42	[[K604R/P30SR]-82-2/[K64R/P30SR]-87-4]-7-3-4-B-2-B-4-B*4-#-BB
LF43	[[K64R/G16SR]-39-1/[K64R/G16SR]-20-2]-5-1-2-B*4-1-BBB
LF44	[[K64R/P30SR]-4-3/[K64R/P30SR]-87-4]-3-1-2-B-1-B-1-BBB
LF45	[[NAW5867/P30SR]-111-2/[NAW5867/P30SR]-25-1]-9-2-3-B-1-BB
LF46	[[NAW5867/P30SR]-43-2]-1-1-2-B*4-1-BBB
LF47	[NAW5867/P30SR(52#)]FF#-93-2-1-B-2-BBB
LF48	P402c2F2-216-1-B*4
LF49	P402c2F2-772-1-BB-1-BB
LF50	P401c2F2-248-1-BBB

The sites were selected mainly on the basis that they are a representation of the maize growing areas in Zimbabwe. The low nitrogen trial was grown at CIMMYT-Harare because this is the site where there is the managed low nitrogen site.

3.3 Crop husbandry

All sites were ploughed to a depth of 30 cm. Discing was done to break down the clods. For the summer trials this was done in the months of June and July whilst for winter trials this was done in the months of March to April.

Maize fert (N-8, P16, K-8) was applied as basal dressing by machine and disced into the soil before planting. The rates differed with sites with ART Farm and Chiredzi receiving (400 kg/ha each of maize fert) which translates to 64 kg/ha N, 128 kg/ha P_2O_5 and 64 kg/ha K. At the low N site, CIMMYT Harare station 400 kg/ha single super phosphate and 150 kg/ha Muriate of Potash were applied as basal dressing. Ammonium nitrate (AN) was applied for top dressing and it was split applied. Agricultural Research Trust Farm received two applications of 138 kg/ha N whilst Chiredzi received 82.8 kg/ha N for each application. At the low N site no top dressing was applied. At Kadoma 56 kg/ha N, 112 kg/ha P_2O_5 and 56 kg/ha K was applied as basal dressing and 69 kg/ha of N was split applied at 4 weeks and 8 weeks after crop emergence as topdressing.

The in-row spacing used was 0.25 m whilst the inter-row used was 0.75 m. At most four seeds were planted per station and plants were thinned to one plant per station at 3 weeks after emergence to achieve the targeted plant population of 53 000 plants/ha. At ART Farm two plants were left per station. Irrigation was applied to field capacity soon after planting to facilitate germination. At ART Farm planting

was done on the 22nd of November 2005 whilst at CIMMYT Harare station planting was done on the 23rd of November 2005. At Kadoma planting was done on the 7th of December 2005. The winter planting at Chiredzi was done on the 18th of May 2006.

Herbicides were used at ART Farm and CIMMYT Harare station. At ART Farm a mixture of Atrazine and Lasso was used at the rates of 3.5 and 3.1 L/ha respectively. Whilst at CIMMYT Station a mixture of Atrazine, gramoxone and dual were used at the following rates 4.5 L, 1.51 L and 1.81 L respectively. Hand weeding was done to control late weeds. Four weeks after crop emergence Dipterex 2.5% granules were applied to control stalk borer.

3.4 Managing nitrogen stress at CIMMYT Research Station

The low nitrogen site used had already been depleted of nitrogen and this was achieved through, growing summer maize and irrigated winter wheat continuously for six years. There was no nitrogen applied to the crop and the nitrogen from soil mineralisation supplied the crop's needs. According to the soil analysis results the soil had the capacity to supply nitrogen since it contained 7 ppm in the top 30 cm of the soil and 7 ppm in the soil depth 30-60 cm. In terms of kg/ha this translates to 54 kg/ha.

3.5 Managing water stress in Chiredzi

A total of 250 mm was applied in the first fifty days of the crop's growth. This resulted in drought coinciding with flowering and grain filling. The level of stress applied was projected to achieve a yield of 15-20% (1-2 t/ha) of yields achieved under well -watered conditions. This stress level delays silking and causes ear

abortion in non-stress tolerant genotypes. Such stress levels achieve an ASI of between four to eight days and 0.3-0.7 EPP.

3.6 Experimental design on trial sites

Two row plots 4 m long were planted using alpha (0,1) lattice design where replications were divided into incomplete bocks. There were two replications included in each site.

3.7 Traits measured/derived

Table 3.2 Measured and derived traits

Trait	Procedure
	Yield Traits
Grain yield (GY)	It was calculated from shelled grain weight per plot adjusted to 12.5% grain moisture and converted to tons per hectare.
Ears per plant (EPP)	It is calculated as a ratio of the number of ears with at least one fully developed grain divided by the number of harvested plants.
	Flowering Traits
Anthesis (AD)	Taken as number of days after planting when 50% of the plants start shedding Pollen
Anthesis-silking interval (ASI)	Derived from anthesis date and silking date as follows: ASI= SD- AD
	Plant Characteristics
Plant height (PH)	Measured as the height between the base of a plant and the insertion of the first tassel branch.
Ear height (EH)	Measured as the height between the base of a plant to the insertion of the top ear
Husk cover	It is measured as a score
	Lodging Characteristics
Root lodging (RL)	Measured as a percentage of plants that showed lodging by being inclined 45°
Stem lodging (SL)	Measured as a percentage of plants that were broken below the ear.

3.8 Data analysis

Data were analyzed using the procedures for the North Carolina Design II.

Table 3.3 ANOVA framework for design II

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

f: female fm:male x female
m: male

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

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

Where: X_{ijk}= performance of the cross between the i^{th} and the j^{th} genotypes in the k^{th} replication, u= overall mean, g_i= GCA effects for the i^{th} and j^{th} parents respectively, s_{ij}= the SCA effect for the cross between the i^{th} and j^{th} genotypes, e_{ijk}= error effect associated with the ijk^{th} observation.

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

3.8.1 Heritability

Heritability in a narrow sense was calculated using the Mather and Jinks (1952) formula. Narrow sense heritability (h^2_{ns}) = ½DR/ ½DR + ¼HR + Ew

Where DR= additive gene effects, HR= non-additive gene effects (dominance gene effects), Ew= error

Chapter 4

Results

The trials were conducted in two seasons that is summer and winter. The optimum and low nitrogen trials were conducted during summer whilst the drought trial was conducted in winter. The trials were located in three different agro-ecological zones of Zimbabwe namely natural regions (NR) II, III and IV. Zimbabwe is partitioned into five agro-ecological zones. NR I is for specialized farming, which excludes commercial maize production, whilst NR II has been shown to be the region where maize productivity is highest under dryland conditions (Machida, 1996).

4.1 Combined Analysis of variance

4.1.1 Yield Traits

The combined analyses of variance across sites for GY and EPP of lines and testers and their interactions are presented in Table 4.1. Sites, lines and testers were all significantly different (P< 0.01) for GY and EPP. Significant interactions were observed (P<0.01) for line x tester, site x line and site x tester.

Table 4.1 Analysis of Variance for grain yield (GY) (t/ha) and ears per plant (EPP) across five sites in Zimbabwe in 2005/06 season

	GY			EPP		
Source	**DF**	**MS**	**F**	**DF**	**MS**	**F**
Site	4	3990.86	**	4	230542.48	**
Entry	149	2.72	**	149	1197.63	**
Line	49	2.48	**	49	1421.79	**
Tester	2	61.01	**	2	33214.48	**
Line*Tester	98	1.65	**	98	432.15	**
Site*Entry	592	1.08	**	596	275.96	**
Site*Line	196	1.14	**	196	292.26	**
Site*Tester	8	14.57	**	8	2480.69	**
Site*Line*Tester	388	0.76	Ns	392	222.81	Ns
Error	716	0.81		750	212.95	

F: F-value DF: Degrees of Freedom
MS: Mean Squares ** denotes significance at P=0.01 ns, not significant

4.1.2 Flowering Traits

Table 4.2 presents results for analysis of variance for AD and ASI. Sites, lines and testers were significantly different (P< 0.01) for AD, with significant interactions (P<0.05) between site x line and line x tester. Site x tester interactions were not significant.

Table 4.2 Analysis of Variance for days to anthesis (AD) and anthesis silking interval (ASI) across five sites in Zimbabwe in 2005/06 season

	AD			ASI	
Source	**DF**	**MS**	**F**	**MS**	**F**
Site	4	188883.12	**	667.67	**
Entries	149	77.28	**	11.95	*
Line	49	93.44	**	15.99	**
Tester	2	2899.62	**	6.89	ns
Line*Tester	98	11.60	**	10.04	ns
Site*Entry	596	5.70	*	9.70	ns
Site*Line	196	6.68	**	11.79	**
Site*Tester	8	8.62	ns	19.68	ns
Site*Line*Tester	392	5.15	ns	8.39	ns
Error	740	4.89		9.55	
TOTAL	1489				

F: F-value DF: Degrees of Freedom * denotes significance at P=0.05
MS: Mean Squares ** denotes significance at P=0.01 ns, not significant

4.1.3 Plant Characteristics

Table 4.3 presents analysis of variance results for HC, PH and EH. There were highly significant interactions (P< 0.01) for line x tester, site x line and site x tester. .

4.1.4 Lodging Characteristics

The combined analysis of variance for RL and SL is presented in Table 4.4. Sites were significantly different (P< 0.01). The lines and testers recorded significant differences for RL. The site x line and site x tester interaction were also significant (P<0.05).

Table 4.3 Analysis of variance for, husk cover (HC), plant height (PH) and ear height (EH) across five sites in Zimbabwe in 2005/06 season

	HC			PH			EH	
Source	**DF**	**MS**	**F**	**DF**	**MS**	**F**	**MS**	**F**
Site	3	9360.75	**	4	230542.48	**	127250.60	**
Entries	149	102.77	**	149	1197.63	**	749.02	**
Line	49	130.66	**	49	1421.79	**	986.32	**
Tester	2	272.92	**	2	33214.48	**	21268.37	**
Line*Tester	98	85.35	**	98	432.15	**	211.61	*
Site*Entry	447	75.94	**	596	275.96	**	202.65	**
Site*Line	147	106.70	**	196	292.26	**	210.35	**
Site*Tester	6	310.68	**	8	2480.69	**	980.85	**
Site*Line*Tester	294	55.77	ns	392	222.81	Ns	182.92	ns
Error	599	52.03		750	212.95		163.97	

F: F-value DF: Degrees of Freedom * denotes significance at P=0.05
MS: Mean Squares ** denotes significance at P=0.01 ns, not significant

Table 4.4 Analysis of variance for root lodging (RL) and stalk lodging (SL) across five sites in Zimbabwe in 2005/06 season

		RL		SL	
Source	**DF**	**MS**	**F**	**MS**	**F**
Site	4	610.28	**	4749.16	**
Entries	149	92.78	**	153.64	ns
Line	49	115.85	**	133.41	ns
Tester	2	362.06	**	81.11	ns
Line*Tester	98	75.75	ns	165.24	ns
Site*Entry	596	91.85	**	140.16	ns
Site*Line	196	91.12	**	147.82	ns
Site*Tester	8	505.49	**	44.87	ns
Site*Line*Tester	392	83.78	*	138.27	ns
Error	749	69.89		134.24	

F: F-value DF: Degrees of Freedom * denotes significance at P=0.05
MS: Mean Squares ** denotes significance at P=0.01 ns, not significant

4.1.5 GCA and SCA sum of squares

The contribution of GCA and SCA sum of squares to entry sum of squares showed that SCA sum of squares generally had predominance over the GCA sum of squares (Table 4.5). However, predominance of GCA sum of squares to SCA sum of squares was observed for AD, PH and EH.

Table 4.5 Contribution (%) of GCA and SCA to entry sums of squares

Trait	GCA%	SCA%
GY	30	40
AD	40	10
ASI	44	55
PH	39	24
EH	43	19
RL	41	54
SL	27	71
HC	42	55
EPP	43	47

4.1.6 GCA and SCA variances

General combining ability variances for GY, AD, PH, EH, HC and EPP had predominance over SCA variances (Table 4.8). Specific combining ability variances for ASI, RL and SL had predominance over GCA variances.

4.1.7 Heritability

Ears per plant had the highest heritability value of 80% (Table 4.6), whilst ASI had the lowest heritability value of 7.9%. GY, AD, PH, EH and RL had heritability values above 50% (Table 4.6). SL and HC had heritability values below 50%. GY had narrow sense heritability of 63.0%.

Table 4.6 General combining ability and Specific combining ability variances and heritability for the measured traits

Trait	GCA Variance	SCA Variance	Heritability (%)
GY	26.4	4.48	63.0 ±0.1
AD	1286.0	35.4	65.9 ±0.7
ASI	1.6	2.56	7.9 ±0.03
PH	14596.3	1169.1	64.9 ±2.47
EH	9379.2	254.1	67.2 ±1.98
RL	128.32	31.2	61.7 ±0.23
SL	76.48	165.28	22.1 ±0.18
HC	84.56	177.76	47.4 ±0.19
EPP	0.16	0.016	80.0 ±0.008

4.1.8 Line GCA effects

The line GCA effects for all the measured traits are presented in Table 4.7. For GY the positive GCA effects are desirable. Nineteen lines LF1, LF3, LF4, LF5, LF6, LF7, LF9, LF13, LF14, LF15, LF21, LF23, LF26, LF31, LF36, LF37, LF39, LF47 and LF50 (Table 4.7) had positive GCA effects for grain yield (GY). LF47 had the best GCA effect for GY (0.60 t ha^{-1}). Line LF47 yielded 8.03 t ha^{-1} under optimum conditions, 3.34 t ha^{-1} under low nitrogen conditions and 0.92 t ha^{-1} under drought conditions in a cross involving the new tester, CML509/505 (Appendix 2.). The poorest lines for grain yield were line LF49, LF2, LF42 and LF44 with GCA values: -0.62, -0.56, -0.48 and –0.47 respectively. The study was focusing on early maturity so the good GCA effects for AD would be the ones that are negative. The lines LF15, LF18, LF42, LF9 and LF17 with GCA effects for AD of –4.83, -3.13, -2.40, -2.44 and -2.10 respectively (Table 4.7) were considered to be the earliest lines in terms of days to flowering. LF40 had the highest positive GCA value for AD of 4.04, indicating that it might be late maturing.

The best line in terms of plant height was LF20 (GCA value –16.24) followed by LF10 (-11.60) (Table 4.7). The same lines also had negative GCA effects for EH of -7.43 and -12.70 respectively. A positive GCA effect for EPP is considered to be ideal. The line with the best GCA value for EPP (0.11) was LF37 and this line also had a positive GCA value for GY (0.22). Negative GCA effects are desirable for RL. LF29, LF26, LF15 and LF16 were the best lines in terms of RL with GCA values –3.46, -2.65, -2.39 and –2.13 respectively (Table 4.7).

4.1.9 Tester GCA effects

Table 4.8 shows the GCA effects for the three testers. There were significant differences ($P<0.05$) among the testers for GY, AD, PH and EH. Only CML312/CML442 and CML395/CML444 had positive GCA effects for GY. CML509/CML505 on the other hand had good GCA effect for AD which confirmed its earliness. Again CML509/CML505 was the only tester with negative GCA effects for both PH and EH of -9.10 and -6.15 respectively.

4.1.10 Heterotic groups of lines as determined by testers CML 312/442, CML 395/444 and CML 509/505

The SCA effects and grouping of the lines into heterotic groups by the testers are presented in Table 4.9. Specific combining ability effects for GY were used to classify the lines, where the lines that exhibited negative SCA with the tester were grouped into the same group. Of the fifty lines included in the study nineteen were already classified into heterotic groups whilst thirty-one were not. Lines LF1, LF2, LF19, LF20, LF21, LF24, LF29, LF37, LF41 and LF49 were classified into heterotic group B whilst LF22, LF23, LF27, LF28, LF34, LF35, LF47, LF48 and LF50 were classified into heterotic group A. Of the lines already classified into heterotic groups some were classified into the same groups as before whilst others were re-classified into new groups. Lines LF42, LF43, LF44 and LF45 were originally grouped into heterotic group B but in this study they were re-classified into heterotic group A because they had negative SCA effects for GY with group A testers and positive SCA effects with the group B tester. The old testers re-grouped most of the lines into the same groups as before. The new group A tester was in agreement with the old group A tester in grouping most of the lines.

Table 4.7 Line GCA effects for different traits

Line	GY	AD	ASI	PH	EH	RL	EPP
LF47	0.60	1.34	-0.06	-0.90	-0.26	-0.56	-0.03
LF5	0.53	-0.56	1.06	6.50	8.44	-1.44	-0.01
LF50	0.47	-0.53	-0.09	0.86	-3.83	-0.07	-0.02
LF21	0.46	-0.03	-0.32	7.63	6.00	-1.03	0.01
LF6	0.45	-0.13	-0.58	-1.77	-1.90	-1.41	-0.04
LF7	0.43	-1.06	-0.19	3.76	3.24	-1.95	0.01
LF13	0.42	0.14	-0.24	10.40	5.87	0.47	-0.03
LF23	0.30	-1.66	-0.48	3.60	-1.13	0.27	0.03
LF31	0.30	1.37	-0.05	9.70	11.20	-1.30	-0.03
LF4	0.23	0.94	0.13	7.26	3.30	4.88	-0.04
LF37	0.22	1.17	0.56	2.76	7.07	-0.18	0.11
LF15	0.20	-4.83	-0.20	3.86	-3.03	-2.39	0.01
LF39	0.20	-1.17	0.79	-7.10	-4.76	-0.71	0.02
LF36	0.19	-0.53	-0.70	7.80	7.40	-1.92	0.04
LF3	0.17	1.50	0.99	8.30	7.17	-0.76	-0.03
LF14	0.14	-1.00	-0.76	-0.07	-0.03	-0.17	0.01
LF9	0.13	-2.44	-0.90	-1.60	-3.36	-1.06	0.05
LF26	0.13	-1.31	-0.40	-4.84	-6.06	-2.65	0.04
LF1	0.12	3.07	0.46	1.70	2.60	-1.17	-0.10
LF33	0.09	3.60	0.43	-6.50	-1.33	-0.52	0.04
LF18	0.09	-3.13	0.35	-6.34	-8.50	-1.63	0.02
LF35	0.03	0.34	-0.02	-8.64	-6.86	-0.84	0.00
LF32	0.02	-1.00	0.03	-2.27	1.14	-1.59	0.02
LF38	-0.03	0.67	-0.01	5.56	7.70	1.33	-0.01
LF29	-0.03	1.14	-1.37	0.53	1.97	-3.46	-0.03
LF8	-0.04	-0.73	1.92	1.06	-2.86	0.25	-0.03
LF16	-0.05	-1.83	1.31	2.10	-6.76	2.08	-0.03
LF48	-0.06	-0.46	-0.25	-3.14	-3.93	-0.76	-0.02
LF25	-0.06	2.37	-0.27	12.33	10.87	-1.97	-0.03
LF46	-0.06	0.37	0.13	11.76	5.20	4.32	0.02
LF43	-0.10	0.14	-0.59	-3.14	5.14	-1.36	-0.01
LF24	-0.10	-0.33	1.20	-0.40	-6.66	3.33	-0.01
LF30	-0.10	0.94	-0.28	9.63	5.37	-0.44	-0.05
LF20	-0.10	-0.10	0.34	-16.24	-7.43	-2.13	0.05
LF28	-0.11	1.00	0.79	-5.84	-4.96	2.34	-0.11
LF41	-0.16	3.30	-0.65	1.90	2.57	0.23	0.06
LF34	-0.17	1.00	-0.08	-4.10	-3.40	2.38	0.01
LF12	-0.18	-1.33	-0.04	-1.87	1.04	-0.53	0.05
LF19	-0.22	0.47	-0.27	-8.24	-5.53	-1.37	0.05
LF45	-0.23	-1.10	-0.64	-10.84	-3.20	5.42	0.01
LF10	-0.25	-0.36	-0.40	-11.60	-12.70	-0.85	-0.06
LF27	-0.26	1.17	1.20	-6.27	-2.76	2.19	0.03
LF40	-0.26	4.04	-0.76	7.50	7.24	1.40	0.00
LF11	-0.34	-2.00	0.61	-10.40	-4.66	1.13	-0.03
LF17	-0.35	-2.10	0.63	1.66	5.60	-0.36	-0.03
LF22	-0.42	-0.80	-0.24	8.03	4.47	0.26	0.01
LF44	-0.47	-1.16	-1.40	-7.10	-7.96	-0.38	0.06
LF42	-0.48	-2.40	1.34	-5.54	-6.70	3.67	0.03
LF2	-0.56	3.28	-1.87	6.60	2.97	1.81	-0.05
LF49	-0.62	0.77	-0.32	-8.04	-2.96	-0.72	0.08
Mean	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
LSD (0.05)	**0.05**	**0.31**	**13.66**	**13.65**	**10.52**	**3.90**	**0.001**

Table 4.8 Tester GCA effects for different traits

Testers	GY	AD	ASI	PH	EH	RL	EPP
CML312/CML442	0.2	0.36	0.13	2.47	-0.7	-0.64	-0.02
CML395/CML444	0.21	2.21	-0.1	6.63	6.84	0.97	-0.01
CML509/CML505	-0.4	-2.57	0.02	-9.1	-6.15	-0.32	0.03
LSD	**0.29**	**0.21**	**0.32**	**3.57**	**2.24**	**1.61**	**0.05**

Table 4.9. Specific combining ability effects (t/ha) and heterotic groups for hybrids between testers (CML 312/442, CML 395/444 and CML 509/505)

LINES	SCA EFFECTS			HETEROTIC GROUP	
	CML 312/442	CML 395/444	CML509/505	Original	New
LF1	0.35	-0.32	0.06	*	B
LF2	0.71	-1.04	0.42	*	B
LF3	-0.27	0.64	-0.21	A	A
LF4	0.07	0.22	-0.26	A	A
LF5	0.08	0.13	-0.19	A	A
LF6	-0.27	0.21	0.02	A	A
LF7	0.53	0.10	-0.57	A	A
LF8	-0.08	0.12	-0.06	A	A
LF9	-0.28	0.31	0.01	A	A
LF10	0.83	-0.57	-0.17	A	*
LF11	-0.20	0.16	0.03	A	A
LF12	0.14	-0.07	-0.08	B	*
LF13	0.29	-0.53	0.27	B	B
LF14	-0.01	-0.20	0.27	B	B
LF15	0.12	-0.29	0.16	B	B
LF16	0.37	-0.59	0.26	AB	B
LF17	-0.00	0.12	-0.13	AB	A
LF18	0.21	-0.26	0.05	AB	B
LF19	0.05	-0.24	0.19	*	B
LF20	0.18	-0.33	0.19	*	B
LF21	0.01	-0.36	0.29	*	B
LF22	-0.05	0.06	-0.02	*	A
LF23	-0.34	0.52	-0.11	*	A
LF24	0.09	-0.32	0.22	*	B
LF25	-0.16	-0.10	0.24	*	*
LF26	0.58	-0.28	-0.15	A	*
LF27	-0.08	0.88	-0.80	*	A
LF28	0.65	0.42	-1.08	*	A
LF29	0.09	-0.21	0.14	*	B
LF30	-0.02	0.01	-0.00	*	A
LF31	-0.19	0.54	-0.36	A	A
LF32	0.38	-0.04	-0.28	*	A
LF33	-0.52	-0.14	0.65	A	A
LF34	-0.26	0.33	-0.08	*	A
LF35	0.12	0.10	-0.20	*	A
LF36	-0.12	-0.23	0.34	*	*
LF37	0.06	-0.64	0.57	*	B
LF38	-0.08	0.22	-0.14	B	A
LF39	0.02	-0.18	0.17	AB	B
LF40	-0.11	-0.12	0.22	*	*
LF41	0.00	-0.25	0.24	*	B
LF42	-0.50	0.44	0.05	B	A
LF43	0.02	0.18	-0.18	B	A
LF44	-0.28	0.22	0.05	B	A
LF45	-0.36	0.13	0.23	B	A
LF46	-0.05	-0.00	0.04	*	*
LF47	-0.16	0.80	-0.45	*	A
LF48	-0.18	0.59	-0.42	*	A
LF49	0.01	-0.12	0.10	*	B
LF50	-0.77	0.35	0.42	*	A
LSD(0.05)	**0.10**	**0.10**	**0.10**		

***Heterotic group not identified**

4.1.11 Heterosis of hybrids for grain yield under drought and low nitrogen conditions

Table 4.10 and Table 4.11 show the best ten hybrids and the worst ten hybrids in terms of mid-parent heterosis under drought and low nitrogen conditions. It can be seen that the lines generally showed high level of mid-parent heterosis under drought conditions compared to Low nitrogen conditions. Tester, CML509/CML505 generally produced better crosses under drought conditions, compared to CML312/CML442 whose hybrids mostly had mean yields below 1.0 t ha^{-1} (Table 4.10). LF16 showed good heterosis with CML509/CML505 under drought conditions and good heterosis with CML312/CML442 under low nitrogen conditions. LF1, LF2 and LF26 demonstrated very low heterosis with CML 312/CML442 of –100% under drought conditions (Table 4.10). LF50 showed very good heterosis with CML509/CML505 (97.7%) with a mean yield of 1.38 t ha^{-1} but showed very bad heterosis (-62.1%) with CML312/CML442 with a mean yield of 0.22 t ha^{-1} (Table 4.10). LF21 and LF16 showed good heterosis with CML509/CML505 under low nitrogen conditions of 41.1% and 37.9%, respectively, and the mean yields were 4.05 t ha^{-1} and 3.63 t ha^{-1} ,respectively (Table 4.11).

Table 4.10 Mid Parent heterosis of selected hybrids for grain yield (t/ha) under drought conditions with CML312/442 and CML509/505

Line	Tester	Mean Hybrid (μ)	Female	Male	Parent Mean (MP)	Diff from MP(μ-MP)	Heterosis over MP (μ-MP/MP*100)
			The best ten hybrids				
LF6	CML509/CML505	1.22	0.43	0.74	0.59	0.63	108.2
LF14	CML509/CML505	1.62	0.84	0.74	0.79	0.84	104.6
LF50	CML509/CML505	1.38	0.65	0.74	0.70	0.68	97.7
LF43	CML312/CML442	0.99	0.55	0.48	0.52	0.47	91.7
LF38	CML312/CML442	0.90	0.47	0.48	0.47	0.43	90.0
LF33	CML509/CML505	1.45	0.78	0.74	0.76	0.68	89.9
LF4	CML312/CML442	0.80	0.39	0.48	0.44	0.36	82.6
LF25	CML509/CML505	0.89	0.25	0.74	0.50	0.39	79.8
LF7	CML312/CML442	1.06	0.71	0.48	0.59	0.47	78.7
LF16	CML509/CML505	1.15	0.60	0.74	0.67	0.48	71.7
			The least ten hybrids				
LF1	CML312/CML442	0.00	0.22	0.48	0.35	-0.35	-100
LF2	CML312/CML442	0.00	0.71	0.48	0.60	-0.60	-100
LF26	CML312/CML442	0.00	0.75	0.48	0.61	-0.61	-100
LF27	CML509/CML505	0.17	1.06	0.74	0.90	-0.73	-81.1
LF47	CML312/CML442	0.14	0.66	0.48	0.57	-0.43	-75.4
LF4	CML509/CML505	0.14	0.39	0.74	0.57	-0.43	-75.3
LF28	CML312/CML442	0.09	0.19	0.48	0.34	-0.25	-73.2
LF25	CML312/CML442	0.11	0.25	0.48	0.36	-0.25	-69.8
LF50	CML312/CML442	0.22	0.65	0.48	0.57	-0.35	-62.1
LF33	CML312/CML442	0.24	0.78	0.48	0.63	-0.39	-61.9

Table 4.11 Mid Parent heterosis of selected hybrids for grain yield (t ha^{-1}) under Low nitrogen conditions with CML312/442 and CML509/505

Line	Tester	Mean Hybrid (μ)	Female	Male	Parent Mean (MP)	Diff from MP (μ- MP)	Heterosis over MP (μ-MP/MP*100)
			The best ten hybrids				
LF21	CML509/CML505	4.05	3.42	2.32	2.87	1.18	41.1
LF16	CML312/CML442	3.93	2.85	2.85	2.85	1.08	37.9
LF28	CML312/CML442	3.34	2.09	2.85	2.47	0.87	35.2
LF15	CML509/CML505	3.63	3.07	2.32	2.70	0.94	34.7
LF30	CML312/CML442	3.98	3.09	2.85	2.97	1.01	34.0
LF18	CML312/CML442	3.95	3.08	2.85	2.97	0.99	33.2
LF20	CML312/CML442	3.74	2.86	2.85	2.86	0.89	31.0
LF47	CML509/CML505	3.34	2.94	2.32	2.63	0.71	27.0
LF12	CML312/CML442	3.48	2.67	2.85	2.76	0.72	26.1
LF34	CML509/CML505	3.10	2.66	2.32	2.49	0.61	24.5
			The least ten hybrids				
LF28	CML509/CML505	0.43	2.09	2.32	2.21	-1.78	-80.5
LF48	CML509/CML505	1.00	2.60	2.32	2.46	-1.46	-59.3
LF2	CML509/CML505	1.11	1.84	2.85	2.35	-1.24	-52.7
LF16	CML509/CML505	1.27	2.85	2.32	2.59	-1.32	-50.9
LF38	CML312/CML442	1.60	2.68	2.85	2.77	-1.17	-42.1
LF40	CML312/CML442	1.33	1.53	2.85	2.19	-0.86	-39.3
LF25	CML509/CML505	1.46	2.38	2.32	2.35	-0.89	-37.9
LF22	CML509/CML505	1.59	2.74	2.32	2.53	-0.94	-37.2
LF8	CML312/CML442	1.65	2.34	2.85	2.60	-0.95	-36.4
LF42	CML312/CML442	1.56	1.84	2.85	2.35	-0.79	-33.5

4.1.12 GCA and SCA effects, grain yield and days to anthesis of hybrids with testers CML312/442 and CML509/505

Table 4.12 presents line GCA effects for GY and SCA effects for GY for the two group A testers (CML509/CML505 and CML312/CML442).The line with the highest GCA effect for grain yield, (0.60 t ha^{-1}) LF47, exhibited negative SCA effects for grain yield with the two testers. This line produced mean yields of 8.03t/ha and 11.52t/ha under optimum conditions with the two testers respectively. Days to anthesis for LF47 were 63.1 with CML509/CML505 and 64.0 with CML312/CML442 (Table 13). The line LF5 with the second highest GCA effect for yield (0.53) had negative SCA effect for grain yield (-0.19) with CML509/CML505

and positive SCA effect with CML312/CML442 (0.08). Of the ten top lines in terms of GCA effects six had negative SCA effects with CML509/CML505 and five had negative SCA effects with CML312/CML442. Mean days to anthesis for CML509/CML505 were 62.8 and for CML312/CML442 were 64.4 days. The number of days to anthesis for CML509/CML505 ranged between 60.9-64.9 whilst for CML312/CML442 they ranged between 60.0-69.5 (Table 4.13)

Table 4.12 GCA and SCA effects for grain yield, and days to anthesis for optimal conditions for testers CML509/505 and CML312/442

Line	GCA effects GY (t/ha)	SCA effects GY (t/ha) CML509/505	SCA effects GY (t/ha) CML312/442	GY (t/ha) CML509/505	GY (t/ha) CML312/442	Days to anthesis CML509/505	Days to anthesis CML312/442
LF47	0.60	-0.45	-0.16	8.03	11.52	63.1	64.0
LF5	0.53	-0.19	0.08	9.35	12.11	62.5	63.0
LF50	0.47	0.42	-0.77	10.38	11.37	63.3	64.5
LF21	0.46	0.29	0.10	9.97	10.91	63.1	61.5
LF6	0.45	0.02	-0.27	9.16	10.69	62.7	64.5
LF7	0.43	-0.56	0.53	8.51	12.97	62.3	63.5
LF13	0.42	0.27	0.29	11.48	12.71	62.4	66.0
LF23	0.30	-0.11	-0.34	8.95	10.01	62.3	62.5
LF31	0.30	-0.36	-0.19	9.59	11.91	63.4	65.0
LF4	0.23	-0.26	0.07	9.61	10.79	62.8	63.0
LF37	0.22	0.57	0.06	10.43	10.89	63.5	65.0
LF15	0.20	0.16	0.12	8.77	11.60	60.9	60.0
LF39	0.20	0.17	0.02	10.8	10.09	62.8	62.5
LF36	0.19	0.34	-0.12	10.55	11.02	63.1	62.0
LF3	0.17	-0.21	-0.26	7.91	11.36	63.1	64.0
LF14	0.14	0.27	-0.08	8.96	10.55	61.9	63.5
LF9	0.13	0.01	-0.28	8.24	9.09	61.4	63.5
LF26	0.13	-0.15	0.58	9.48	11.50	61.9	63.5
LF1	0.12	0.06	0.35	10.58	10.58	64.3	68.0
LF18	0.09	0.05	0.20	9.55	11.97	61.0	64.5
LF33	0.09	0.65	-0.52	10.44	8.70	64.5	68.5
LF35	0.03	-0.20	0.12	9.78	10.72	62.8	63.5
LF32	0.02	-0.28	0.38	7.21	9.33	61.8	63.5
LF29	-0.03	0.14	0.09	10.86	10.12	63.3	65.5
LF38	-0.03	-0.14	-0.08	7.43	11.88	63.1	65.0
LF8	-0.04	-0.06	-0.08	8.24	11.48	62.1	63.5
LF16	-0.05	0.26	0.37	9.16	9.42	61.9	64.5
LF25	-0.06	0.24	-0.16	9.22	10.70	64.2	67.5
LF46	-0.06	0.04	-0.05	8.29	11.39	63.0	64.0
LF48	-0.06	-0.42	-0.18	8.41	10.10	62.8	65.0
LF20	-0.10	0.18	0.18	8.79	9.55	63.1	64.5
LF24	-0.10	0.22	0.09	8.26	9.64	62.9	64.0
LF30	-0.10	0.00	-0.02	8.85	9.78	63.3	65.5
LF43	-0.10	-0.18	0.02	8.18	9.87	62.9	65.0
LF28	-0.11	-1.08	0.65	7.44	10.22	63.2	64.5
LF41	-0.16	0.24	0.00	10.11	10.67	64.7	66.5
LF34	-0.17	-0.08	-0.26	7.86	8.75	63.4	64.5
LF12	-0.18	-0.08	0.14	7.64	10.32	62.5	62.5
LF19	-0.22	0.19	0.05	8.74	10.02	63.4	65.0
LF45	-0.23	0.22	-0.36	10.29	9.69	62.0	64.0
LF10	-0.25	-0.17	0.83	8.2	11.46	62.8	65.5
LF26	-0.26	-0.80	-0.08	6.88	9.28	63.3	66.0
LF40	-0.26	0.22	-0.11	9.75	9.50	64.5	69.5
LF11	-0.34	0.03	-0.20	8.07	9.41	61.8	62.5
LF17	-0.35	-0.13	0.00	7.25	10.47	62.9	64.0
LF22	-0.42	-0.02	-0.05	8.31	9.16	62.3	63.5
LF44	-0.47	0.05	-0.27	8.14	7.32	60.9	64.5
LF42	-0.48	0.05	-0.50	7.54	7.49	61.8	62.5
LF2	-0.56	0.42	0.71	10.62	8.92	64.9	65.5
LF49	-0.62	0.10	0.01	7.08	9.66	63.2	63.5
Mean	**0.00**	**0.00**	**0.00**	**8.9**	**10.4**	**62.8**	**64.4**
LSD(0.05)	**0.05**	**0.1**	**0.1**	**3.6**	**3.6**	**6.1**	**6.1**

Chapter 5

Discussion

5.1 Performance of lines crossed to three different testers

The performance of lines and testers differed significantly for grain yield under different environments (Table 4.1). Differences of this nature were observed for genotypes evaluated under different environments by Vasal *et al.* (1992) who reported mean grain yields of 4.59 Mg ha^{-1} under subtropical environments and 4.35 Mg ha^{-1} under temperate environments (Lsd= 0.05). Similar results have been reported by other researchers (Narro *et al.* 2003; Kim and Ajala, 1996; Mungoma and Pollak, 1988. The current study results indicated that there was differential response of genotypes in different environments (Appendix B). Yield reductions of about 20% were observed under drought conditions (Appendix B). Banziger *et al.* (2000) reported yields reductions of 15-20% under drought conditions. The influence of environment on performance of genotypes was pointed out by Narro *et al.* (2003) who reported that topcross performance is not only a consequence of gamete segregation and recombination, but also of the environmental effect where cultivars are evaluated. The differential performance of genotypes over environments, as found in the current study, has implications on breeding presenting the question of whether to breed, for specificity or general adaptation. On the other hand such information is useful in identifying a suitable genotype for specific environments.

There were highly significant interactions for line x tester, site x line and site x tester (Table 4.1) for grain yield signifying differential responses for testers and lines across sites and more importantly that the potential of a line in a cross was different

depending on tester being used. These findings are in agreement with what other authors reported such as Betran *et al.* (2003) who reported significant site x line interaction effect for grain yield and Narro *et al* (2003) who also reported highly significant line x tester interaction. The highly significant line x tester interaction is an indication that each specific cross was unique from the other. The significance of line x tester interaction also shows that the testers showed markedly different combining ability effects. This observation has implications in that selection can be done by assessing the performance of each individual cross. Significant site x line and site x tester interactions make it possible to select the best specific combiners under the different environments.

The lines and testers differed significantly for anthesis date under different environments (Table 4.2). The number of days to anthesis among lines differed across the given environments (Appendix C). Betran *et al* (2003); Mungoma and Pollak (1988) reported significant differences for AD under different environments and the results agree with the findings in this study. The mean days to anthesis were more under stress conditions (drought and low nitrogen) due to the negative effects the stress had on the growth of the maize crop. Vasal *et al.* (1992) recorded mean days to anthesis of 71 under temperate environments and 54 under subtropical environments. This has the implication on breeding in that selection for AD has to be done under optimum conditions to cater especially for seed production. The number of days to anthesis also differed within the specific combinations. Lines LF15 and LF18 crossed to CML509/CML505 had mean days to anthesis of 57 respectively (Appendix C) and they were the earliest. Line LF2 crossed to CML395/CML444 was the latest to flower with the number of days to flowering of

74. Therefore good specific combiners for earliness can be identified and selected for using the results from this study.

The lines used in the study were classified and re-classified into new heterotic groups using one group B tester and two group A testers (Table 4.9). This was done to test the validity of a new group A tester (CML505/CML509) by comparing its performance to other two testers. Classification of maize lines into heterotic groups was done by Vasal *et al.* (1992). Vasal *et al.* (1992) evaluated 92 CIMMYT tropical lines, which were crossed to four testers and using the test cross data the lines were grouped into two tropical heterotic groups (THG) 'A' and 'B'. This was done to provide basic material for use in CIMMYT's hybrid development work and various national programs in the tropics and it is for the same reason this study was conducted.

The classification of inbreds into heterotic groups facilitates the exploitation of heterosis in maize, which can contribute to hybrid performance (Bhatnagar *et al.*, 2004). Heterotic patterns are specific crosses, between genotypes, which show a high level of heterosis (Warbuton *et al.*, 2002). LF3, LF8, LF17, LF22, LF23, LF27, LF30, LF31, LF38, LF47 and LF48 were grouped into heterotic group A by testers CML312/CML442 and CML509/CML505. The new tester grouped six lines differently from the old tester (Table 4.9). Rawlings and Thompson (1962) reported that testers belonging to the same group might classify germplasm differently because of the differences in the alleles they might be carrying. It is from these differences that testers differ in the way they classify lines, some are more efficient than others.

Lines LF42, LF43, LF44, LF45, LF16, LF17 and LF18 changed groups from previous classification. Hallauer and Miranda (1988) showed that the heterotic group of materials can be made from germplasm of opposing groups and this was shown by the single cross B73*Mo17. The B73 line was derived from the Reid Yellow Dent heterotic group while the line Mo17 was derived by pedigree selection from the cross of (187-2*C103). Line 187-2 was derived from an improved line (Krug), an improved line of the Reid Yellow Dent heterotic group. The changing of groups showed that heterotic groups are not absolute, but change depending on the materials in use (Hallauer and Miranda 1988). Nine lines were grouped into an unidentified group because they exhibited negative SCA effects with testers from opposite groups (A and B) and according to Warburton *et al.* (2002) when a genotype under test shows high heterosis with both testers from opposing groups (e.g A and B groups), that genotype belongs to neither group A nor B, but a totally different group altogether. The establishment of heterotic patterns has an implication in a breeding program in that it enables heterosis to be exploited to the maximum because germplasm and heterotic groups reduce by half the amount of work breeders must do in identifying materials to cross in making hybrids.

Narrow sense heritability estimates from this study were 63.0% for GY, 80% for EPP, 65.9% for AD and 64.9% for PH. Hallauer and Miranda (1981) reported narrow sense heritability estimates for such maize traits which were lower in magnitude than the ones found in the current study. They found heritability estimates of 18.7% for GY, 39% for EPP, 57.9% for AD and 56.9% for PH. The magnitudes of heritability estimates depends on the population being tested, the

environments within which the testing is done and traits being measured (Falconer and Mackay, 1996). To this end therefore the differences in the magnitudes observed here is a manifestation of the differences in these three determinants of the heritability estimates. It should, therefore, be understood that whenever a value is stated for the heritability of a given character, it refers to a particular population under particular conditions. Bolanos and Edmeades (1996) reported narrow sense heritability estimates of 60% for GY under optimal conditions and 40% under drought stress. The relatively high heritability estimates for GY, AD, PH and EPP in the current study are an indication that these traits are mainly controlled by additive genes. This implies that these traits can be used to identify good parents that can be crossed to produce good hybrids. This speeds up the selection process.

Highly significant positive GCA effects for GY were reported from the study (Table 4.7) ranging from 0.60-0.42 t /ha^{-1}. Beck *et al.* (1989) working with CIMMYT's tropical early and intermediate maturity maize also reported highly significant positive GCA effects for GY in the range of 0.68 Mg ha^{-1}and 0.54 Mg ha^{-1}. In the current study the best general combiners contributed a large number of favourable genes for high grain yield. Line LF47 was the best general combiner (0.60 t ha^{-1}) and LF49 the worst general combiner (-0.62 t ha^{-1}) for GY. The ZEWA based lines (which is an early maturing germplasm) (LF10, 11, 12, 16 and 17) were poor general combiners for GY. It was observed that the lines with negative GCA effects for GY also had negative GCA effects for AD. It should be noted that earliness is often associated with low grain yield (Beck *et al.*, 1989).

General combining ability variance for GY was higher than the SCA variance (Table 4.6). This shows that additive gene effects were more important in the control of GY within the lines in this study. Several studies involving inheritances have revealed dosage effect of additive gene actions (Stangland *et al.*, 1983; Zambezi *et al.*, 1986). General combining ability variances higher than SCA variances indicate that additive genetic effects are more important (Gethi and Smith, 2004). This has the implication that good parents can be identified using the GCA effects and then crossed to produce high yielding hybrids. Early testing of inbred lines becomes more effective and good hybrids can be identified in the early stages of breeding using GCA effects (Melchinger, *et al.*, 1998). Horner *et al.* (1976) reported the effectiveness of selection primarily for GCA when using a single-cross as tester. In this study single crosses were used as testers so this further supports the use of GCA effects in selection. This makes hybrid cultivar development more efficient and less costly through less time taken to release hybrids and fewer materials carried in breeding programs.

The line GCA effects for other traits are also presented in Table 4.7. The study focused mainly on earliness so high negative GCA effects for AD are more desirable. The earliest lines had GCA effects for AD of -4.83, -3.13, -2.40 and -2.44 and these were LF15, LF18, LF9 and LF42 respectively. Mungoma and Pollak (1988) recorded negative GCA effects for AD of -4.38 and -1.85, which are similar to the ones recorded in the study. Days to anthesis was also controlled by additive gene effect in this study as indicated by the GCA variance being higher than SCA variance (Table 4.6). Therefore early identification of good parents can be done and

crossed to produce early maturing hybrids, which would help the breeding program to come up with early materials much faster.

Negative GCA effects for ASI are also more desirable because they are an indication of tolerance to drought and low nitrogen conditions (Banziger *et al.*, 2000). A combination of a negative GCA effect for AD and ASI would be good in the early maturing maize breeding program. In this study ASI was mainly controlled by non additive gene effect and this has an implication in breeding in that good parents cannot be identified using this trait instead good specific combiners are the ones that can be selected for. LF50, LF21 and LF6 showed negative GCA effects for both traits and they were good general combiners for grain yield.

General combining ability variances showed predominance over SCA variances for other traits such as PH, EH and EPP (Table 4.6). Zambezi *et al.* (1986) reported findings that were similar to those reported in this study where GCA variances for GY, EH and HC were higher than SCA variances. Betran *et al.* (2003) reported that additive genetic effects across environments accounted for 61% of total genetic variation in GY and they assumed importance over non-additive variances. The results indicate the relative importance of additive genetic effects in controlling the expression of these traits in the lines. When GCA variances predominate SCA variances early generation testing of genotypes becomes more effective and promising hybrids can be identified and selected based on their prediction from GCA effects (Melchinger, *et al.*, 1998). This again has the implication in that GCA effects for these traits can be used to identify good parents.

Significant SCA effects with the two testers CML505/CML509 and CML312/CML442 were reported in the study (Table 4.12). Similar to the findings in this study Zambezi *et al.* (1986) also reported significant SCA effects ($P<0.01$) for grain yield and husk cover and at 0.05 level for ear height. The presence of significant SCA is a consequence of fluctuations in dominance relationships among parents (Wassimi *et al.*, 1986). Among the best five lines with good GCA LF21 can be considered to have good SCA effects with both group A testers. LF47 was the best general combiner (0.60 t ha^{-1}) but was a poor specific combiner with the two testers and this indicated that a parent with a good GCA effect need not necessarily produce better hybrids (Tyagi and Lal, 2005). LF49 had the worst GCA effect but proved to be a good specific combiner with a significant yield ($P<0.05$) with CML509/CML505 and above mean yield with CML312/CML442. A parent with poor GCA might produce better hybrids (Tyagi and Lal, 2005) and this agrees with some of the findings in this study where bad general combiners produced some good hybrids with the testers. This has the implication in breeding in that lines should be selected based on both GCA and SCA effects. Selection of lines based only on SCA would be advisable if the GCA is negligible (Narro *et al.*, 2003). The tester, CML509/CML505 proved to be a good specific combiner with most of the lines and LF13 x CML509/CML505 had the highest mean yield of 11.5 t ha^{-1} amongst the crosses for the new tester. CML509/CML505 proved to be a good early maturing group A tester and it can be used in the breeding program to identify good early maturing hybrids.

Chapter 6

Conclusion

The lines were successfully grouped into heterotic groups using the three testers, CML312/CML442, CML509/CML505 and CML395/CML444. CML509/CML505 managed to re-group 66% of the lines that were originally in heterotic group A into the same group. The performance of the tester was close to that of the originally used group A tester CML312/CML442 since they managed to group almost the same number of lines into heterotic group A and it managed to group the lines differently from the group B tester. The tester proved that it does not suffer in-breeding depression by demonstrating high levels of heterosis both under drought and low nitrogen conditions.

The results from the current study have confirmed that CML509/CML505 is a good early maturing single cross tester for heterotic group A, therefore, the tester is suitable in the early maturing maize breeding program as a group A tester. There is now need to put the tester into a wider use by incorporating it into the national breeding programs in order to facilitate grouping of inbred lines and subsequent identification of good performing three-way hybrids for release. Early maturing heterotic group B tester has not been identified yet, so there is need to carry out another study to identify this tester.

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APPENDICES

Appendix A. SCA Effects for the traits AD, ASI, PH, EH, RL, SL and EPP with the three testers

Line	ADT1	ADT2	ADT3	ASI T1	ASIT2	ASIT3	PHT1	PHT2	PHT3	EHT1	EHT2	EHT3	RLT1	RLT2	RLT3	SLT1	SLT2	SLT3	EPPT1	EPPT2	EPPT3
LF1	-0.65	1.62	-1.00	0.01	-0.76	0.67	-3.37	-2.63	6.00	-3.30	0.36	2.95	0.52	-1.89	1.48	-1.75	4.13	-2.69	-0.05	-0.01	0.07
LF2	-1.94	3.18	-0.70	1.94	-4.31	1.69	7.33	-19.13	11.80	2.33	-4.41	2.08	-4.60	3.52	1.08	-2.68	1.79	0.89	-0.05	-0.02	0.07
LF3	-0.26	0.99	-0.73	0.31	0.77	-0.96	1.73	-4.63	2.90	3.93	-2.31	-1.62	4.03	-1.06	-2.98	-1.71	1.17	0.54	-0.04	-0.02	0.06
LF4	-0.40	0.75	-0.36	0.03	-0.06	-0.01	10.06	-13.50	3.43	7.00	-9.74	2.75	-4.08	10.64	-6.56	-3.12	4.28	-1.16	-0.00	0.02	-0.01
LF5	-0.10	0.45	-0.36	0.23	-0.56	0.36	-6.57	-1.03	7.60	1.96	-5.48	3.51	0.96	-1.23	0.27	-1.91	1.90	0.01	-0.07	0.09	-0.01
LF6	1.37	-0.07	-1.73	-0.01	-0.02	0.04	-5.10	1.74	3.37	0.30	1.16	-1.45	0.38	-0.15	-0.23	-3.43	-2.50	5.94	0.03	0.03	-0.06
LF7	0.80	0.05	-0.86	-0.29	-0.06	0.32	-3.64	8.30	-4.67	-7.84	10.32	-2.49	-0.14	-0.47	0.61	6.67	-3.26	-3.41	0.06	-0.04	-0.02
LF8	-0.63	-0.08	0.71	-0.26	-1.61	1.87	-2.44	0.90	1.53	0.46	-3.28	2.81	3.16	-2.56	-0.60	1.72	-1.10	-0.61	0.04	-0.02	-0.03
LF9	0.28	0.46	-0.48	-0.03	-0.01	0.03	7.13	-9.73	2.60	7.66	-5.78	-1.89	-0.60	0.60	0.00	-1.80	3.34	-1.54	0.07	-0.09	0.02
LF10	0.30	-0.55	0.24	0.70	0.27	-0.87	-1.57	2.57	-1.00	1.10	-0.64	-0.45	2.22	-1.08	-1.14	-2.50	-2.17	4.67	0.05	-0.01	-0.04
LF11	-0.76	-0.41	1.17	1.75	-0.51	-1.38	5.23	-3.83	-1.40	5.06	-2.68	-2.39	2.62	-0.61	-2.01	-3.83	-0.63	4.47	-0.03	0.02	0.01
LF12	-0.33	-0.18	0.51	-0.44	0.14	0.27	4.50	-0.56	-3.93	1.86	-1.38	-0.49	-2.33	1.86	0.47	-1.51	0.90	0.62	-0.02	0.09	-0.07
LF13	0.60	0.15	-0.76	-2.43	0.44	1.56	-5.77	13.07	-7.30	-10.37	6.69	3.68	-3.22	3.13	0.09	-2.29	-3.63	5.92	-0.06	0.03	0.03
LF14	0.24	1.39	-1.63	-0.61	0.63	-0.01	-0.70	-2.26	2.97	0.03	0.29	-0.32	0.68	-2.30	1.62	-2.74	-1.21	3.96	0.01	-0.06	0.05
LF15	-0.03	0.02	0.01	-0.13	0.20	-0.07	3.56	-2.90	-0.67	5.73	-1.71	-4.02	0.20	0.55	-0.76	1.86	0.24	-2.10	0.02	-0.06	0.03
LF16	0.17	0.12	-0.29	-1.68	1.39	0.15	8.03	-7.33	-0.70	7.56	-6.18	-1.39	-0.20	0.71	-0.51	-3.14	-4.72	7.86	-0.03	0.04	-0.01
LF17	0.74	-2.01	1.27	-0.87	-0.03	0.90	-0.44	3.00	-2.57	0.90	1.86	-2.75	-3.06	-0.10	3.16	-2.51	-1.25	3.77	0.03	-0.01	-0.02
LF18	0.87	0.42	-1.29	0.50	0.55	-1.11	-1.74	-0.20	1.93	-1.80	2.56	-0.75	0.23	1.28	-1.51	-2.06	-1.15	3.22	0.03	0.02	-0.04
LF19	0.17	-0.78	0.61	-0.57	0.57	0.00	-5.14	1.20	3.93	-2.57	-1.91	4.48	-0.23	-1.89	2.12	0.10	-2.66	2.56	-0.02	-0.03	0.04
LF20	0.54	-0.41	-0.13	-0.27	0.36	-0.11	-5.94	-4.20	10.13	-1.27	-0.21	1.48	0.02	-1.53	1.51	5.72	-2.38	-3.34	0.01	-0.02	0.01
LF21	-2.33	-0.98	3.11	0.06	-0.88	0.84	-0.30	3.14	-2.83	0.60	-4.44	3.85	2.28	-2.21	-0.07	8.37	-5.73	-2.63	0.03	0.02	-0.05
LF22	0.74	-1.11	0.37	-0.43	0.66	-0.24	0.90	3.64	-4.53	-4.57	4.19	0.38	-0.34	-0.05	0.39	-2.24	4.17	-1.93	-0.03	-0.03	0.07
LF23	-0.70	0.85	-0.16	-0.67	0.45	0.20	0.33	2.07	-2.40	-2.57	3.29	-0.72	-2.35	1.26	1.09	-0.27	6.69	-6.42	0.00	-0.02	0.02
LF24	-0.03	0.82	-0.79	-0.02	0.70	-0.67	4.43	-8.53	4.10	-0.24	-0.98	1.21	-1.90	7.00	-5.10	-0.61	2.99	-2.38	-0.03	-0.03	0.06
LF25	0.47	-0.58	0.11	0.01	-0.65	0.50	-3.10	-4.86	7.97	-1.17	-0.51	1.68	-0.68	1.14	-0.46	1.73	-1.21	-0.52	0.02	0.01	-0.03
LF26	0.39	0.50	-0.82	-0.51	0.10	0.33	-1.54	2.90	-1.37	-0.84	-2.38	3.21	-0.13	-2.37	2.50	11.47	-4.55	-6.92	-0.10	0.01	0.08
LF27	-0.43	-0.28	0.71	-0.63	-0.20	0.83	2.60	11.44	-14.03	-4.74	10.52	-5.79	1.22	-2.19	0.97	0.51	0.38	-0.88	0.09	-0.00	-0.08
LF28	-0.96	-0.81	1.68	0.06	-0.84	0.67	11.66	-0.30	-11.37	9.66	-3.48	-6.19	2.12	-2.42	0.30	-8.43	6.36	2.08	0.06	0.04	-0.11
LF29	0.10	0.25	-0.36	0.95	0.81	-1.41	2.90	0.44	-3.33	1.73	1.39	-3.12	1.16	-1.56	0.40	4.84	-2.10	-1.84	-0.02	-0.02	0.04
LF30	0.10	-0.75	0.64	-1.98	0.98	0.81	-7.30	7.74	-0.43	-2.27	3.09	-0.82	0.41	-2.13	1.72	-0.70	1.11	-0.40	0.02	-0.02	-0.00
LF31	1.47	-0.18	-1.29	0.31	-0.25	-0.13	2.43	3.27	-5.70	2.90	-3.54	0.65	0.80	0.45	-1.25	-0.31	0.23	0.08	0.03	-0.01	-0.02
LF32	0.64	-0.31	-0.23	-0.40	0.87	-0.50	-2.80	10.54	-7.73	-0.94	3.92	-2.99	0.86	0.69	-1.55	6.11	-3.58	-2.53	0.03	-0.03	0.00
LF33	-0.66	1.59	-0.93	0.23	0.37	-0.60	0.33	-2.03	1.70	2.23	-0.71	-1.52	-0.05	1.96	-1.91	-2.04	1.96	0.08	0.02	-0.03	0.01
LF34	-0.86	-0.31	1.17	0.84	-0.72	-0.20	5.63	2.17	-7.80	5.20	-0.74	-4.45	-5.21	0.40	4.81	-4.31	5.56	-1.24	0.01	-0.02	0.00

Appendix A. SCA Effects for the traits AD, ASI, PH, EH, RL, SL and EPP with the three testers cont'd

LINE	ADT1	ADT2	ADT3	ASIT1	ASIT2	ASIT3	PHT1	PHT2	PHT3	EHT1	EHT2	EHT3	RLT1	RLT2	RLT3	SLT1	SLT2	SLT3	EPPT1	EPPT2	EPPT3
LF35	-1.00	-0.05	1.04	0.68	-0.66	-0.19	-0.74	2.40	-1.67	-0.94	1.52	-0.59	-0.43	-1.37	1.80	-0.27	-4.42	4.42	0.12	-0.10	-0.02
LF36	-1.33	0.22	1.11	-0.13	0.90	-0.77	-3.17	1.17	2.00	-6.00	1.66	4.35	-0.82	1.92	-1.10	-0.58	1.79	-1.21	-0.07	0.12	-0.05
LF37	0.37	0.12	-0.49	0.60	0.24	-0.84	-2.34	0.70	1.63	-1.57	-0.71	2.28	-1.42	3.09	-1.67	1.49	-0.92	-0.57	-0.03	-0.01	0.04
LF38	1.17	-0.38	-0.79	0.07	0.01	-0.09	-2.94	3.80	-0.87	-4.50	2.86	1.65	2.76	-0.38	-2.38	-2.54	0.43	2.11	0.07	-0.06	-0.01
LF39	-0.08	0.56	-0.45	-0.05	0.31	-0.26	-3.47	1.27	2.20	-3.84	3.12	0.71	-2.04	-0.28	2.32	3.22	-2.47	-0.74	-0.03	0.05	-0.02
LF40	0.20	-1.05	0.84	0.47	0.62	-0.92	-1.17	-3.03	4.20	1.36	-3.18	1.81	0.80	1.44	-2.24	4.46	-3.75	-0.70	-0.00	0.01	-0.00
LF41	0.24	-1.01	0.77	-0.38	0.52	-0.12	3.43	-10.23	6.80	0.33	-5.91	5.58	4.13	-0.76	-3.37	3.96	-1.69	-2.26	-0.05	-0.02	0.07
LF42	1.34	-1.01	-0.33	-0.98	-0.47	1.39	-0.44	-1.90	2.33	-3.70	0.86	2.85	1.39	0.33	-1.72	-2.13	1.47	0.66	-0.01	0.05	-0.04
LF43	0.05	-0.45	0.44	0.33	-1.71	1.42	-2.74	2.10	0.63	-2.44	5.42	-2.99	-1.46	-2.95	4.41	4.06	-0.76	-3.29	-0.02	0.02	0.01
LF44	-0.80	-0.95	1.74	0.77	1.10	-1.87	-2.67	3.07	-0.40	2.46	2.02	-4.49	-0.90	-0.29	1.19	-3.41	2.60	0.81	-0.02	0.02	-0.01
LF45	0.84	-0.31	-0.53	1.00	-1.96	0.96	-5.54	6.80	-1.27	-3.40	7.26	-3.85	-0.06	-1.74	1.80	-1.41	6.24	-4.82	0.01	0.00	-0.01
LF46	-0.43	-0.38	0.81	0.73	0.47	-1.34	-4.04	3.50	0.53	-0.80	-2.84	3.65	3.70	-4.51	0.81	2.88	-1.35	-1.52	0.00	-0.02	0.02
LF47	-0.10	0.85	-0.76	0.14	0.13	-0.22	6.23	-0.43	-5.80	5.56	-4.28	-1.29	1.24	-1.00	-0.24	-2.48	5.50	-3.01	-0.03	-0.04	0.06
LF48	-0.70	-0.45	1.14	0.31	-0.15	-0.18	-3.04	-0.30	3.33	-5.47	1.79	3.68	0.55	-0.68	0.13	-0.35	-0.73	1.08	-0.03	0.05	-0.02
LF49	-0.13	1.02	-0.89	-0.22	0.07	0.14	6.46	-9.80	3.33	2.26	1.32	-3.59	-1.99	1.82	0.17	0.23	-2.77	2.54	0.04	-0.02	-0.02
LF50	1.17	-0.18	-0.99	0.05	0.29	-0.34	-5.24	10.40	-5.17	-3.07	1.89	1.18	-0.24	-1.99	2.23	-0.49	-2.09	2.58	-0.07	0.13	-0.07
LSD	**0.63**	**0.63**	**0.63**	**27.31**	**27.31**	**27.31**	**27.31**	**27.31**	**27.31**	**21.03**	**21.03**	**21.03**	**7.81**	**7.81**	**7.81**	**17.22**	**17.22**	**17.22**	**0.004**	**0.004**	**0.004**

AD- anthesis days
ASI- anthesis silking interval
PH- plant height
EH- ear height
RL- root lodging
SL- stalk lodging
EPP- ears per plant
T1- tester 1 (CML312/CML442)
T2- tester 2 (CML395/CML444)
T3- tester 3 (CML509/CML505)
LSD- Least significant difference

Appendix B. Grain yield t/ha for the hybrids with the three testers under optimum, drought and Low N conditions in 2005/06

	Optimum			Low N			Drought		
Line	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
LF1	10.58	10.81	10.58	1.85	2.53	1.92	0.00	0.30	0.18
LF2	8.92	5.98	10.62	2.63	1.78	1.11	0.00	0.21	0.97
LF3	11.36	12.03	7.91	2.40	3.05	2.16	0.51	0.16	0.76
LF4	10.79	12.42	9.61	3.09	2.47	1.75	0.80	0.08	0.14
LF5	12.11	13.05	9.35	2.44	3.42	2.62	0.25	0.84	0.37
LF6	10.69	11.94	9.16	2.50	4.16	2.66	0.25	0.22	1.22
LF7	12.97	12.52	8.51	2.82	3.26	2.09	1.06	0.39	0.85
LF8	11.48	11.48	8.24	1.65	2.78	2.59	0.61	0.43	0.45
LF9	9.09	11.00	8.24	2.94	2.51	3.09	0.90	1.53	1.23
LF10	11.46	8.31	8.20	3.64	2.22	2.25	0.73	0.31	0.49
LF11	9.41	10.06	8.07	3.14	3.70	2.30	0.38	0.38	0.52
LF12	10.32	10.23	7.64	3.48	2.63	1.91	0.68	0.92	0.93
LF13	12.71	8.85	11.48	3.62	3.02	2.68	0.31	0.88	0.34
LF14	10.55	10.28	8.96	3.44	2.57	2.40	0.43	0.47	1.62
LF15	11.60	10.57	8.77	3.07	2.52	3.63	0.61	0.81	0.90
LF16	9.42	8.38	9.16	3.93	3.36	1.27	0.45	0.40	1.15
LF17	10.47	11.01	7.25	2.57	2.37	2.74	0.11	0.35	0.34
LF18	11.97	11.52	9.55	3.95	2.81	2.49	0.26	0.39	0.75
LF19	10.02	8.85	8.74	2.33	3.26	1.82	0.43	0.76	0.96
LF20	9.55	10.46	8.79	3.74	2.15	2.70	0.30	0.54	0.51
LF21	10.91	11.97	9.97	3.45	2.76	4.05	0.60	0.79	0.45
LF22	9.16	8.92	8.31	3.07	3.57	1.59	0.45	0.39	0.96
LF23	10.01	11.85	8.95	3.38	4.40	3.58	0.49	0.88	0.77
LF24	9.64	9.32	8.26	3.56	3.08	2.96	0.42	0.45	0.86
LF25	10.70	10.76	9.22	2.23	3.46	1.46	0.11	0.07	0.89
LF26	11.50	11.20	9.48	1.73	2.34	1.99	0.00	0.68	0.82
LF27	9.28	11.88	6.88	2.88	4.25	1.85	0.94	2.07	0.17
LF28	10.22	11.82	7.44	3.34	2.51	0.43	0.09	0.03	0.45
LF29	10.12	10.20	10.86	2.93	1.91	2.40	0.14	0.63	0.35
LF30	9.78	10.46	8.85	3.98	2.85	2.46	0.24	0.27	0.46
LF31	11.91	13.11	9.59	2.50	3.97	2.28	0.45	0.33	0.45
LF32	9.33	10.16	7.21	3.77	3.30	2.60	0.73	0.30	1.04
LF33	8.70	12.53	10.44	3.28	2.20	2.69	0.24	0.66	1.45
LF34	8.75	11.97	7.86	2.51	2.38	3.10	0.68	0.50	0.59
LF35	10.72	10.51	9.78	3.35	2.87	2.49	0.41	0.11	0.43
LF36	11.02	10.75	10.55	2.63	2.79	2.90	0.30	0.96	0.58
LF37	10.89	8.50	10.43	3.13	3.15	3.10	0.78	0.43	1.24
LF38	11.88	12.11	7.43	1.60	3.49	2.96	0.90	0.14	0.37
LF39	10.09	10.17	10.80	3.23	3.59	2.18	0.42	0.69	0.85
LF40	9.50	11.00	9.75	1.33	1.68	1.60	0.34	0.16	0.73
LF41	10.67	10.54	10.11	2.61	2.11	1.73	0.21	0.20	0.95
LF42	7.49	11.05	7.54	1.56	2.16	1.80	1.11	0.96	1.08
LF43	9.87	11.27	8.18	3.10	4.20	1.81	0.99	0.21	0.68
LF44	7.32	9.61	8.14	2.91	2.66	1.75	0.85	1.00	1.01
LF45	9.69	10.76	10.29	2.33	2.08	2.01	0.29	0.37	0.42
LF46	11.39	11.49	8.29	2.67	2.46	2.17	0.16	0.85	1.10
LF47	11.52	12.65	8.03	2.07	3.41	3.34	0.14	0.00	0.92
LF48	10.10	11.96	8.41	3.29	3.53	1.00	0.31	0.19	0.85
LF49	9.66	8.88	7.08	2.45	1.72	2.47	0.58	0.65	0.91
LF50	11.37	13.58	10.38	2.49	4.01	3.40	0.22	0.73	1.38
Mean	**10.37**	**10.81**	**8.94**	**2.85**	**2.91**	**2.32**	**0.45**	**0.52**	**0.76**

1- CML312/CML442
2- CML395/CML444
3- CML509/CML505

Appendix C. Number of days to anthesis of the hybrids with the testers under optimum, drought and Low N conditions in 2005/06

	Optimum			Low N			Drought		
Line	1	2	3	1	2	3	1	2	3
LF1	68.0	70.5	61.5	76.0	76.5	72.0	93.0	98.0	91.0
LF2	65.5	74.0	65.0	73.0	84.0	72.5	89.5	94.0	86.5
LF3	64.0	66.0	60.5	73.5	78.5	71.5	90.0	95.5	87.5
LF4	63.0	66.0	62.5	75.0	76.0	69.5	90.0	97.0	87.5
LF5	63.0	65.5	60.5	70.0	72.0	66.0	90.0	92.5	88.0
LF6	64.5	65.0	61.0	74.0	73.0	66.0	93.0	92.0	86.0
LF7	63.5	64.5	60.0	71.0	72.0	68.5	91.0	90.0	83.5
LF8	63.5	65.0	64.0	72.0	73.0	65.5	87.5	91.0	89.5
LF9	63.5	64.5	60.0	68.5	73.0	67.5	88.0	90.0	82.5
LF10	65.5	64.0	63.5	71.0	74.5	67.0	92.0	89.5	85.0
LF11	62.5	63.5	62.5	67.5	70.0	68.0	87.0	90.5	83.5
LF12	62.5	63.5	61.0	69.0	73.0	67.5	90.0	87.5	84.0
LF13	66.0	67.5	60.0	73.5	76.5	71.5	89.0	88.0	84.5
LF14	63.5	66.0	59.0	71.5	76.0	66.0	90.0	93.0	83.0
LF15	60.0	62.0	57.0	65.0	67.0	62.0	83.0	86.0	84.5
LF16	64.5	65.0	61.0	68.5	70.0	67.0	86.0	91.0	83.0
LF17	64.0	64.5	62.0	68.5	58.0	66.5	88.5	89.5	84.0
LF18	64.5	63.5	57.0	69.0	71.5	63.5	86.5	85.0	82.5
LF19	65.0	67.0	62.0	72.5	73.0	68.5	89.5	89.0	88.0
LF20	64.5	65.5	62.0	70.0	73.5	67.5	92.0	90.5	84.0
LF21	61.5	64.5	64.0	71.5	71.5	71.5	90.0	90.0	90.0
LF22	63.5	63.5	59.5	72.0	71.5	68.0	92.0	87.5	85.0
LF23	62.5	64.5	60.0	68.0	72.5	64.5	86.0	91.5	86.5
LF24	64.0	66.5	61.0	70.0	75.5	65.0	90.5	90.0	86.0
LF25	67.5	69.0	64.5	74.0	74.5	70.5	93.5	91.5	88.5
LF26	63.5	64.5	61.0	73.0	73.0	65.5	90.0	90.0	85.0
LF27	66.0	67.5	63.0	74.0	73.5	70.5	89.0	95.0	89.0
LF28	64.5	64.5	65.5	73.0	76.5	74.5	88.5	92.0	88.0
LF29	65.5	68.5	62.5	72.5	75.0	68.0	91.0	92.5	88.0
LF30	65.5	66.5	63.0	70.0	75.5	70.0	91.0	87.0	88.5
LF31	65.0	68.0	64.0	75.0	75.5	58.0	93.5	90.5	89.0
LF32	63.5	64.5	62.0	72.5	72.0	67.5	95.0	91.0	88.0
LF33	68.5	69.5	63.5	75.0	78.5	72.0	92.5	100.0	88.0
LF34	64.5	66.5	63.0	73.0	73.5	72.5	89.0	93.5	87.5
LF35	63.5	65.5	64.5	71.0	74.5	69.0	89.0	92.0	88.0
LF36	62.0	65.0	61.0	69.0	73.0	67.5	88.0	93.0	88.0
LF37	65.0	67.0	62.0	74.0	77.5	69.5	90.0	91.5	87.0
LF38	65.0	65.5	61.5	74.0	72.0	68.0	93.0	95.0	85.5
LF39	62.5	66.0	61.0	69.5	71.5	66.5	91.0	90.0	84.0
LF40	69.5	70.0	66.0	74.0	77.0	75.0	98.5	95.0	91.0
LF41	66.5	68.5	66.0	74.5	76.5	72.0	95.0	93.0	90.5
LF42	62.5	61.5	58.5	71.5	72.5	65.0	88.5	87.0	83.0
LF43	65.0	64.0	62.0	72.5	74.0	71.5	92.0	91.0	85.5
LF44	64.5	63.5	60.0	68.0	73.0	79.0	86.0	89.0	86.0
LF45	64.0	66.0	61.0	72.5	71.0	67.5	89.0	89.5	84.5
LF46	64.0	68.0	62.5	72.0	70.0	73.0	88.5	91.5	89.0
LF47	64.0	66.5	62.5	75.0	75.0	69.5	89.5	99.5	87.0
LF48	65.0	65.5	60.5	69.5	71.5	69.5	87.5	91.0	88.5
LF49	63.5	67.0	62.0	72.0	75.5	69.0	92.0	94.0	85.5
LF50	64.5	66.0	60.5	71.0	68.5	65.5	90.5	90.5	84.0
Mean	**64.4**	**65.9**	**61.8**	**71.7**	**73.5**	**68.6**	**90.1**	**91.5**	**86.4**
Lsd	**2.54**	**2.54**	**2.54**	**6.83**	**6.83**	**6.83**	**5.05**	**5.05**	**5.05**

1- CML312/CML442
2- CML395/CML444
3-CML509/CML505

Appendix D. GCA and SCA effects for grain yield and anthesis days under drought conditions for testers CML509/CML505 and CML 312/CML442

Line	GCA effects GY (t ha-1)	SCA effects GY (t ha-1) CML509/CML505	SCA effects GY (t ha-1) CML312/CML442	GY (t ha-1) CML509/CML505	GY (t ha-1) CML312/CML442	AD (days) CML509/CML505	AD (days) CML312/CML442
LF47	0.60	0.11	-0.40	0.92	0.14	87.0	89.5
LF5	0.53	-0.31	-0.17	0.37	0.25	88.0	90.0
LF50	0.47	0.58	-0.33	1.38	0.22	84.0	90.5
LF21	0.46	-0.31	0.10	0.45	0.60	90.0	90.0
LF6	0.45	0.64	-0.07	1.22	0.25	86.0	93.0
LF7	0.43	0.00	0.47	0.85	1.06	83.5	91.0
LF13	0.42	-0.32	-0.09	0.34	0.31	84.5	89.0
LF23	0.30	-0.06	-0.07	0.77	0.49	86.5	86.0
LF31	0.30	-0.11	0.15	0.45	0.45	89.0	93.5
LF4	0.23	-0.40	0.52	0.14	0.80	87.5	90.0
LF37	0.22	0.28	0.08	1.24	0.78	87.0	90.0
LF15	0.20	-0.02	-0.05	0.90	0.61	84.5	83.0
LF39	0.20	0.00	-0.17	0.85	0.42	84.0	91.0
LF36	0.19	-0.18	-0.20	0.58	0.30	88.0	88.0
LF3	0.17	0.07	0.08	0.76	0.51	87.5	90.0
LF14	0.14	0.63	-0.30	1.62	0.43	83.0	90.0
LF9	0.13	-0.08	-0.15	1.23	0.90	82.5	88.0
LF26	0.13	-0.08	0.00	0.82	0.00	85.0	90.0
LF1	0.12	-0.19	0.00	0.18	0.00	91.0	93.0
LF33	0.09	0.52	-0.43	1.45	0.24	88.0	92.5
LF18	0.09	0.14	-0.10	0.75	0.26	82.5	86.5
LF35	0.03	-0.08	0.17	0.43	0.41	88.0	89.0
LF32	0.02	0.21	0.16	1.04	0.73	88.0	95.0
LF38	-0.03	-0.25	0.55	0.37	0.90	85.5	93.0
LF29	-0.03	-0.17	-0.11	0.35	0.14	88.0	91.0
LF8	-0.04	-0.20	0.23	0.45	0.61	89.5	87.5
LF16	-0.05	0.40	-0.03	1.15	0.45	83.0	86.0
LF48	-0.06	0.25	-0.03	0.85	0.31	88.5	87.5
LF25	-0.06	0.49	-0.02	0.89	0.11	88.5	93.5
LF46	-0.06	0.25	-0.43	1.10	0.16	89.0	88.5
LF43	-0.10	-0.02	0.55	0.68	0.99	85.5	92.0
LF24	-0.10	0.13	-0.04	0.86	0.42	86.0	90.5
LF30	-0.10	-0.01	0.03	0.46	0.24	88.5	91.0
LF20	-0.10	-0.12	-0.06	0.51	0.30	84.0	92.0
LF28	-0.11	0.11	0.01	0.45	0.09	88.0	88.5
LF41	-0.16	0.35	-0.13	0.95	0.21	90.5	95.0
LF34	-0.17	-0.15	0.20	0.59	0.68	87.5	89.0
LF12	-0.18	-0.06	-0.05	0.93	0.68	84.0	90.0
LF19	-0.22	0.09	-0.17	0.96	0.43	88.0	89.5
LF45	-0.23	-0.08	0.04	0.42	0.29	84.5	89.0
LF10	-0.25	-0.12	0.38	0.49	0.73	85.0	92.0
LF27	-0.26	-1.03	-0.01	0.17	0.94	89.0	89.0
LF40	-0.26	0.16	0.03	0.73	0.34	91.0	98.5
LF11	-0.34	-0.05	0.07	0.52	0.38	83.5	87.0
LF17	-0.35	-0.08	-0.04	0.34	0.11	84.0	88.5
LF22	-0.42	0.22	-0.04	0.96	0.45	85.0	92.0
LF44	-0.47	-0.09	0.01	1.01	0.85	86.0	86.0
LF42	-0.48	-0.11	0.17	1.08	1.11	83.0	88.5
LF2	-0.56	0.10	0.00	0.97	0.00	86.5	89.5
LF49	-0.62	0.05	-0.02	0.91	0.58	85.5	92.0
mean	**0.00**	**0.02**	**0.01**	**0.76**	**0.45**	**86.44**	**90.10**
sd	**0.05**	**0.10**	**0.10**	**1.18**	**1.18**	**1.61**	**1.61**

Appendix E. GCA and SCA effects for grain yield and anthesis days under low nitrogen conditions for testers CML509/CML505 and CML 312/CML442

Line	GCA effects GY (t ha-1)	SCA effects GY (t ha-1) CML509/CML505	SCA effects GY (t ha-1) CML312/CML442	GY (t ha-1) CML509/CML505	GY (t ha-1) CML312/CML442	AD (days) CML509/CML505	AD (days) CML312/CMI
LF47	0.60	0.77	-1.02	3.34	2.07	69.5	75.0
LF5	0.53	0.16	-0.54	2.62	2.44	66.0	70.0
LF50	0.47	0.47	-0.96	3.40	2.49	65.5	71.0
LF21	0.46	1.00	-0.12	4.05	3.45	71.5	71.5
LF6	0.45	-0.08	-0.76	2.66	2.50	66.0	74.0
LF7	0.43	-0.26	-0.06	2.09	2.82	68.5	71.0
LF13	0.42	-0.06	0.36	2.68	3.62	71.5	73.5
LF23	0.30	0.16	-0.56	3.58	3.38	64.5	68.0
LF31	0.30	-0.27	-0.57	2.28	2.50	58.0	75.0
LF4	0.23	-0.32	0.50	1.75	3.09	69.5	75.0
LF37	0.22	0.34	-0.15	3.10	3.13	69.5	74.0
LF15	0.20	0.93	-0.16	3.63	3.07	62.0	65.0
LF39	0.20	-0.45	0.07	2.18	3.23	66.5	69.5
LF36	0.19	0.50	-0.30	2.90	2.63	67.5	69.0
LF3	0.17	-0.01	-0.29	2.16	2.40	71.5	73.5
LF14	0.14	-0.04	0.48	2.40	3.44	66.0	71.5
LF9	0.13	0.62	-0.06	3.09	2.94	67.5	68.5
LF26	0.13	0.34	-0.45	1.99	1.73	65.5	73.0
LF1	0.12	0.19	-0.40	1.92	1.85	72.0	76.0
LF33	0.09	0.34	0.40	2.69	3.28	72.0	75.0
LF18	0.09	-0.23	0.71	2.49	3.95	63.5	69.0
LF35	0.03	-0.05	0.29	2.49	3.35	69.0	71.0
LF32	0.02	-0.26	0.39	2.60	3.77	67.5	72.5
LF38	-0.03	0.65	-1.24	2.96	1.60	68.0	74.0
LF29	-0.03	0.35	0.36	2.40	2.93	68.0	72.5
LF8	-0.04	0.62	-0.85	2.59	1.65	65.5	72.0
LF16	-0.05	-1.22	0.92	1.27	3.93	67.0	68.5
LF48	-0.06	-1.24	0.53	1.00	3.29	69.5	69.5
LF25	-0.06	-0.55	-0.31	1.46	2.23	70.5	74.0
LF46	-0.06	0.11	0.08	2.17	2.67	73.0	72.0
LF43	-0.10	-0.86	-0.09	1.81	3.10	71.5	72.5
LF24	-0.10	0.13	0.20	2.96	3.56	65.0	70.0
LF30	-0.10	-0.26	0.73	2.46	3.98	70.0	70.0
LF20	-0.10	0.21	0.72	2.70	3.74	67.5	70.0
LF28	-0.11	-1.30	1.09	0.43	3.34	74.5	73.0
LF41	-0.16	-0.05	0.31	1.73	2.61	72.0	74.5
LF34	-0.17	0.81	-0.31	3.10	2.51	72.5	73.0
LF12	-0.18	-0.39	0.65	1.91	3.48	67.5	69.0
LF19	-0.22	-0.28	-0.29	1.82	2.33	68.5	72.5
LF45	-0.23	0.24	0.04	2.01	2.33	67.5	72.5
LF10	-0.25	-0.09	0.78	2.25	3.64	67.0	71.0
LF27	-0.26	-0.77	-0.27	1.85	2.88	70.5	74.0
LF40	-0.26	0.43	-0.36	1.60	1.33	75.0	74.0
LF11	-0.34	-0.38	-0.07	2.30	3.14	68.0	67.5
LF17	-0.35	0.55	-0.15	2.74	2.57	66.5	68.5
LF22	-0.42	-0.78	0.17	1.59	3.07	68.0	72.0
LF44	-0.47	-0.32	0.32	1.75	2.91	79.0	68.0
LF42	-0.48	0.33	-0.43	1.80	1.56	65.0	71.5
LF2	-0.56	-0.36	0.63	1.11	2.63	72.5	73.0
LF49	-0.62	0.63	0.08	2.47	2.45	69.0	72.0
Mean	**0.00**	**0.00**	**0.00**	**2.32**	**2.85**	**68.6**	**71.7**
Lsd	**0.05**	**0.10**	**0.10**	**1.19**	**1.19**	**1.44**	**1.44**

Appendix F. Grain yield of crosses in t/ha, SCA and GCA effects for GY with the three testers across five sites in 2005/06 season

Entry	Line	Tester	Mean Yield t/ha	Line GCA	Tester GCA	SCA
1	1	1	4.47	0.12	0.20	0.35
2	1	2	3.81	0.12	0.21	-0.32
3	1	3	3.57	0.12	-0.40	0.06
4	2	1	4.16	-0.56	0.20	0.71
5	2	2	2.41	-0.56	0.21	-1.04
6	2	3	3.26	-0.56	-0.40	0.42
7	3	1	3.91	0.17	0.20	-0.26
8	3	2	4.82	0.17	0.21	0.64
9	3	3	3.35	0.17	-0.40	-0.21
10	4	1	4.30	0.23	0.20	0.07
11	4	2	4.45	0.23	0.21	0.21
12	4	3	3.37	0.23	-0.40	-0.26
13	5	1	4.62	0.53	0.20	0.08
14	5	2	4.67	0.53	0.21	0.13
15	5	3	3.74	0.53	-0.40	-0.19
16	6	1	4.18	0.45	0.20	-0.27
17	6	2	4.67	0.45	0.21	0.20
18	6	3	3.87	0.45	-0.40	0.02
19	7	1	4.97	0.43	0.20	0.53
20	7	2	4.54	0.43	0.21	0.09
21	7	3	3.26	0.43	-0.40	-0.56
22	8	1	3.88	-0.04	0.20	-0.08
23	8	2	4.09	-0.04	0.21	0.12
24	8	3	3.30	-0.04	-0.40	-0.06
25	9	1	3.85	0.13	0.20	-0.28
26	9	2	4.45	0.13	0.21	0.31
27	9	3	3.53	0.13	-0.40	0.01
28	10	1	4.58	-0.25	0.20	0.83
29	10	2	3.20	-0.25	0.21	-0.57
30	10	3	2.98	-0.25	-0.40	-0.17
31	11	1	3.46	-0.34	0.20	-0.20
32	11	2	3.84	-0.34	0.21	0.16
33	11	3	3.09	-0.34	-0.40	0.03
34	12	1	3.96	-0.18	0.20	0.14
35	12	2	3.76	-0.18	0.21	-0.07
36	12	3	3.14	-0.18	-0.40	-0.08
37	13	1	4.71	0.42	0.20	0.29
38	13	2	3.91	0.42	0.21	-0.53
39	13	3	4.09	0.42	-0.40	0.27
40	14	1	4.06	0.14	0.20	-0.08
41	14	2	3.96	0.14	0.21	-0.20
42	14	3	3.81	0.14	-0.40	0.27
43	15	1	4.33	0.20	0.20	0.12
44	15	2	3.92	0.20	0.21	-0.29
45	15	3	3.76	0.20	-0.40	0.16
46	16	1	4.32	-0.05	0.20	0.37
47	16	2	3.36	-0.05	0.21	-0.59
48	16	3	3.60	-0.05	-0.40	0.26
49	17	1	3.65	-0.35	0.20	0.00
50	17	2	3.78	-0.35	0.21	0.12
51	17	3	2.92	-0.35	-0.40	-0.13
52	18	1	4.29	0.09	0.20	0.20
53	18	2	3.84	0.09	0.21	-0.26
54	18	3	3.53	0.09	-0.40	0.05
55	19	1	3.83	-0.22	0.20	0.05
56	19	2	3.55	-0.22	0.21	-0.24
57	19	3	3.37	-0.22	-0.40	0.19
58	20	1	4.08	-0.10	0.20	0.18
59	20	2	3.57	-0.10	0.21	-0.33
60	20	3	3.48	-0.10	-0.40	0.18
61	21	1	4.56	0.46	0.20	0.10
62	21	2	4.11	0.46	0.21	-0.36
63	21	3	4.15	0.46	-0.40	0.29
64	22	1	3.53	-0.42	0.20	-0.05
65	22	2	3.64	-0.42	0.21	0.05
66	22	3	2.96	-0.42	-0.40	-0.02
67	23	1	3.97	0.30	0.20	-0.34
68	23	2	4.83	0.30	0.21	0.52
69	23	3	3.58	0.30	-0.40	-0.11
70	24	1	3.99	-0.10	0.20	0.09
71	24	2	3.59	-0.10	0.21	-0.32
72	24	3	3.52	-0.10	-0.40	0.22
73	25	1	3.79	-0.06	0.20	-0.16
74	25	2	3.85	-0.06	0.21	-0.10
75	25	3	3.58	-0.06	-0.40	0.24
76	26	1	4.71	0.13	0.20	0.58
77	26	2	3.86	0.13	0.21	-0.28
78	26	3	3.37	0.13	-0.40	-0.15

Appendix F. Grain yield of crosses in t/ha, SCA and GCA effects for GY with the three testers across five sites in 2005/06 season cont'd

79	27	1	3.66	-0.26	0.20	-0.08
80	27	2	4.63	-0.26	0.21	0.88
81	27	3	2.33	-0.26	-0.40	-0.80
82	28	1	4.54	-0.11	0.20	0.65
83	28	2	4.32	-0.11	0.21	0.42
84	28	3	2.21	-0.11	-0.40	-1.08
85	29	1	4.06	-0.03	0.20	0.09
86	29	2	3.76	-0.03	0.21	-0.21
87	29	3	3.51	-0.03	-0.40	0.14
88	30	1	3.88	-0.10	0.20	-0.02
89	30	2	3.92	-0.10	0.21	0.01
90	30	3	3.30	-0.10	-0.40	0.00
91	31	1	4.11	0.30	0.20	-0.19
92	31	2	4.85	0.30	0.21	0.54
93	31	3	3.34	0.30	-0.40	-0.36
94	32	1	4.40	0.02	0.20	0.38
95	32	2	3.99	0.02	0.21	-0.04
96	32	3	3.14	0.02	-0.40	-0.28
97	33	1	3.57	0.09	0.20	-0.52
98	33	2	3.96	0.09	0.21	-0.14
99	33	3	4.13	0.09	-0.40	0.65
100	34	1	3.57	-0.17	0.20	-0.26
101	34	2	4.16	-0.17	0.21	0.33
102	34	3	3.14	-0.17	-0.40	-0.08
103	35	1	4.16	0.03	0.20	0.12
104	35	2	4.15	0.03	0.21	0.10
105	35	3	3.23	0.03	-0.40	-0.20
106	36	1	4.07	0.19	0.20	-0.12
107	36	2	3.98	0.19	0.21	-0.23
108	36	3	3.93	0.19	-0.40	0.34
109	37	1	4.28	0.22	0.20	0.06
110	37	2	3.59	0.22	0.21	-0.64
111	37	3	4.18	0.22	-0.40	0.57
112	38	1	3.89	-0.03	0.20	-0.08
113	38	2	4.20	-0.03	0.21	0.22
114	38	3	3.22	-0.03	-0.40	-0.14
115	39	1	4.22	0.20	0.20	0.02
116	39	2	4.03	0.20	0.21	-0.18
117	39	3	3.77	0.20	-0.40	0.17
118	40	1	3.63	-0.26	0.20	-0.11
119	40	2	3.63	-0.26	0.21	-0.12
120	40	3	3.36	-0.26	-0.40	0.22
121	41	1	3.84	-0.16	0.20	0.00
122	41	2	3.59	-0.16	0.21	-0.25
123	41	3	3.48	-0.16	-0.40	0.24
124	42	1	3.02	-0.48	0.20	-0.50
125	42	2	3.97	-0.48	0.21	0.44
126	42	3	2.96	-0.48	-0.40	0.05
127	43	1	3.92	-0.10	0.20	0.02
128	43	2	4.09	-0.10	0.21	0.18
129	43	3	3.11	-0.10	-0.40	-0.18
130	44	1	3.26	-0.47	0.20	-0.27
131	44	2	3.75	-0.47	0.21	0.21
132	44	3	2.98	-0.47	-0.40	0.05
133	45	1	3.41	-0.23	0.20	-0.36
134	45	2	3.91	-0.23	0.21	0.13
135	45	3	3.39	-0.23	-0.40	0.22
136	46	1	3.89	-0.06	0.20	-0.05
137	46	2	3.95	-0.06	0.21	0.00
138	46	3	3.37	-0.06	-0.40	0.04
139	47	1	4.45	0.60	0.20	-0.16
140	47	2	5.42	0.60	0.21	0.80
141	47	3	3.55	0.60	-0.40	-0.45
142	48	1	3.77	-0.06	0.20	-0.18
143	48	2	4.55	-0.06	0.21	0.59
144	48	3	2.92	-0.06	-0.40	-0.42
145	49	1	3.40	-0.62	0.20	0.01
146	49	2	3.28	-0.62	0.21	-0.12
147	49	3	2.88	-0.62	-0.40	0.10
148	50	1	3.70	0.47	0.20	-0.77
149	50	2	4.83	0.47	0.21	0.35
150	50	3	4.29	0.47	-0.40	0.42

Appendix G. Heterosis of hybrids for grain yield (t/ha) under drought conditions

Line	Tester	Mean Hybrid	Female	Male	Parent Mean (MP)	Better Parent (BP)	Diff from MP	Heterosis over MP (%)	Diff from BP	Heterosis over BP (%)
1	1	0.00	0.22	0.48	0.70	0.48	-0.70	-100.00	-0.48	-100.00
	2	0.30	0.22	0.54	0.76	0.54	-0.46	-60.50	-0.24	-44.38
	3	0.18	0.22	0.74	0.96	0.74	-0.78	-81.29	-0.56	-75.74
2	1	0.00	0.71	0.48	1.19	0.71	-1.19	-100.00	-0.71	-100.00
	2	0.21	0.71	0.54	1.25	0.71	-1.04	-83.24	-0.50	-70.56
	3	0.97	0.71	0.74	1.46	0.74	-0.49	-33.70	0.22	30.04
3	1	0.51	0.54	0.48	1.02	0.54	-0.51	-50.03	-0.03	-5.56
	2	0.16	0.54	0.54	1.08	0.54	-0.92	-85.18	-0.38	-70.37
	3	0.76	0.54	0.74	1.28	0.74	-0.52	-40.72	0.02	2.41
4	1	0.80	0.39	0.48	0.87	0.48	-0.08	-8.68	0.31	65.42
	2	0.08	0.39	0.54	0.93	0.54	-0.85	-91.39	-0.46	-85.17
	3	0.14	0.39	0.74	1.13	0.74	-0.99	-87.63	-0.60	-81.13
5	1	0.25	0.53	0.48	1.01	0.53	-0.76	-75.26	-0.28	-52.83
	2	0.84	0.53	0.54	1.07	0.54	-0.23	-21.92	0.30	54.80
	3	0.37	0.53	0.74	1.27	0.74	-0.91	-71.31	-0.38	-50.82
6	1	0.25	0.43	0.48	0.91	0.48	-0.66	-72.55	-0.23	-47.98
	2	0.22	0.43	0.54	0.97	0.54	-0.75	-77.82	-0.32	-60.14
	3	1.22	0.43	0.74	1.17	0.74	0.05	4.09	0.48	64.40
7	1	1.06	0.71	0.48	1.19	0.71	-0.13	-10.67	0.35	50.14
	2	0.39	0.71	0.54	1.25	0.71	-0.86	-69.09	-0.32	-45.47
	3	0.85	0.71	0.74	1.45	0.74	-0.60	-41.30	0.11	14.54
8	1	0.61	0.50	0.48	0.98	0.50	-0.37	-37.47	0.12	23.23
	2	0.43	0.50	0.54	1.03	0.54	-0.60	-58.43	-0.11	-20.28
	3	0.45	0.50	0.74	1.24	0.74	-0.79	-64.03	-0.30	-40.04
9	1	0.90	1.15	0.48	1.63	1.15	-0.74	-45.25	-0.26	-22.44
	2	1.53	1.15	0.54	1.69	1.15	-0.16	-9.65	0.38	32.58
	3	1.23	1.15	0.74	1.90	1.15	-0.67	-35.39	0.07	6.15
10	1	0.73	0.46	0.48	0.94	0.48	-0.21	-22.72	0.25	51.89
	2	0.31	0.46	0.54	1.00	0.54	-0.70	-69.60	-0.23	-43.46
	3	0.49	0.46	0.74	1.21	0.74	-0.72	-59.37	-0.25	-33.97
11	1	0.38	0.42	0.48	0.90	0.48	-0.53	-58.51	-0.11	-21.97
	2	0.38	0.42	0.54	0.96	0.54	-0.59	-61.05	-0.16	-30.48
	3	0.52	0.42	0.74	1.17	0.74	-0.65	-55.38	-0.22	-29.93
12	1	0.68	0.84	0.48	1.32	0.84	-0.65	-48.89	-0.17	-19.64
	2	0.92	0.84	0.54	1.38	0.84	-0.46	-33.30	0.08	9.52
	3	0.93	0.84	0.74	1.58	0.84	-0.66	-41.53	0.09	10.12
13	1	0.31	0.51	0.48	0.99	0.51	-0.68	-68.71	-0.20	-39.22
	2	0.88	0.51	0.54	1.05	0.54	-0.17	-16.14	0.34	63.14
	3	0.34	0.51	0.74	1.25	0.74	-0.91	-72.85	-0.40	-54.18
14	1	0.43	0.84	0.48	1.32	0.84	-0.89	-67.74	-0.41	-49.21
	2	0.47	0.84	0.54	1.38	0.84	-0.91	-65.85	-0.37	-43.83
	3	1.62	0.84	0.74	1.58	0.84	0.04	2.29	0.78	93.02
15	1	0.61	0.77	0.48	1.25	0.77	-0.64	-51.35	-0.16	-21.12
	2	0.81	0.77	0.54	1.31	0.77	-0.50	-38.30	0.04	4.75
	3	0.90	0.77	0.74	1.52	0.77	-0.62	-40.61	0.13	16.38
16	1	0.45	0.60	0.48	1.08	0.60	-0.63	-58.26	-0.15	-24.69
	2	0.40	0.60	0.54	1.14	0.60	-0.74	-65.26	-0.20	-33.89
	3	1.15	0.60	0.74	1.34	0.74	-0.19	-14.15	0.41	54.97
17	1	0.11	0.26	0.48	0.74	0.48	-0.63	-85.21	-0.37	-77.11
	2	0.35	0.26	0.54	0.80	0.54	-0.46	-57.02	-0.19	-36.04
	3	0.34	0.26	0.74	1.01	0.74	-0.67	-66.68	-0.41	-54.86
18	1	0.26	0.47	0.48	0.95	0.48	-0.69	-73.03	-0.23	-46.94
	2	0.39	0.47	0.54	1.00	0.54	-0.61	-61.17	-0.15	-27.70
	3	0.75	0.47	0.74	1.21	0.74	-0.46	-37.87	0.01	1.06
19	1	0.43	0.71	0.48	1.19	0.71	-0.76	-63.98	-0.28	-39.72
	2	0.76	0.71	0.54	1.25	0.71	-0.50	-39.73	0.04	5.85
	3	0.96	0.71	0.74	1.46	0.74	-0.50	-34.38	0.21	28.69
20	1	0.30	0.48	0.48	0.96	0.48	-0.66	-68.70	-0.18	-37.58
	2	0.54	0.48	0.54	1.02	0.54	-0.48	-47.41	0.00	-0.82
	3	0.51	0.48	0.74	1.22	0.74	-0.71	-58.20	-0.23	-31.28
21	1	0.60	0.61	0.48	1.09	0.61	-0.49	-45.19	-0.01	-2.28
	2	0.79	0.61	0.54	1.15	0.61	-0.37	-31.94	0.17	27.85
	3	0.45	0.61	0.74	1.36	0.74	-0.91	-66.82	-0.29	-39.36
22	1	0.45	0.60	0.48	1.08	0.60	-0.63	-58.69	-0.15	-25.42
	2	0.39	0.60	0.54	1.14	0.60	-0.75	-66.11	-0.21	-35.48
	3	0.96	0.60	0.74	1.34	0.74	-0.38	-28.29	0.22	29.36
23	1	0.49	0.68	0.48	1.16	0.68	-0.67	-57.71	-0.19	-27.73
	2	0.88	0.68	0.54	1.22	0.68	-0.34	-27.71	0.20	29.79
	3	0.77	0.68	0.74	1.42	0.74	-0.66	-46.13	0.02	3.09
24	1	0.42	0.58	0.48	1.06	0.58	-0.64	-60.21	-0.16	-26.96
	2	0.45	0.58	0.54	1.11	0.58	-0.66	-59.62	-0.13	-21.74
	3	0.86	0.58	0.74	1.32	0.74	-0.46	-35.08	0.11	15.21

Appendix G. Heterosis of hybrids for grain yield (t/ha) under drought conditions

25	1	0.11	0.25	0.48	0.73	0.48	-0.62	-84.90	-0.37	-77.11
	2	0.07	0.25	0.54	0.79	0.54	-0.72	-91.74	-0.47	-87.95
	3	0.89	0.25	0.74	0.99	0.74	-0.10	-10.11	0.15	19.93
26	1	0.00	0.75	0.48	1.23	0.75	-1.23	-100.00	-0.75	-100.00
	2	0.68	0.75	0.54	1.29	0.75	-0.61	-47.16	-0.07	-9.03
	3	0.82	0.75	0.74	1.49	0.75	-0.67	-45.29	0.07	9.03
27	1	0.94	1.06	0.48	1.54	1.06	-0.60	-39.18	-0.12	-11.52
	2	2.07	1.06	0.54	1.60	1.06	0.47	29.38	1.01	95.42
	3	0.17	1.06	0.74	1.80	1.06	-1.63	-90.55	-0.89	-83.91
28	1	0.09	0.19	0.48	0.67	0.48	-0.58	-86.58	-0.39	-81.27
	2	0.03	0.19	0.54	0.73	0.54	-0.70	-95.89	-0.51	-94.44
	3	0.45	0.19	0.74	0.93	0.74	-0.48	-51.72	-0.29	-39.36
29	1	0.14	0.37	0.48	0.85	0.48	-0.71	-83.49	-0.34	-70.87
	2	0.63	0.37	0.54	0.91	0.54	-0.28	-30.53	0.09	16.80
	3	0.35	0.37	0.74	1.11	0.74	-0.76	-68.46	-0.39	-52.84
30	1	0.24	0.32	0.48	0.80	0.48	-0.56	-70.09	-0.24	-50.06
	2	0.27	0.32	0.54	0.86	0.54	-0.59	-68.64	-0.27	-49.94
	3	0.46	0.32	0.74	1.06	0.74	-0.61	-57.23	-0.29	-38.69
31	1	0.45	0.41	0.48	0.89	0.48	-0.44	-49.47	-0.03	-6.37
	2	0.33	0.41	0.54	0.95	0.54	-0.62	-65.24	-0.21	-38.82
	3	0.45	0.41	0.74	1.15	0.74	-0.70	-60.94	-0.29	-39.36
32	1	0.73	0.68	0.48	1.16	0.68	-0.43	-37.10	0.05	7.35
	2	0.30	0.68	0.54	1.22	0.68	-0.92	-75.40	-0.38	-55.88
	3	1.04	0.68	0.74	1.42	0.74	-0.39	-27.22	0.29	39.47
33	1	0.24	0.78	0.48	1.26	0.78	-1.02	-80.96	-0.54	-69.23
	2	0.66	0.78	0.54	1.32	0.78	-0.66	-50.36	-0.13	-16.03
	3	1.45	0.78	0.74	1.52	0.78	-0.08	-5.07	0.67	85.26
34	1	0.68	0.59	0.48	1.07	0.59	-0.39	-36.48	0.09	15.25
	2	0.50	0.59	0.54	1.13	0.59	-0.63	-55.73	-0.09	-15.25
	3	0.59	0.59	0.74	1.33	0.74	-0.74	-55.71	-0.15	-20.50
35	1	0.41	0.36	0.48	0.84	0.48	-0.43	-51.11	-0.07	-14.69
	2	0.11	0.36	0.54	0.90	0.54	-0.79	-87.74	-0.43	-79.61
	3	0.43	0.36	0.74	1.10	0.74	-0.67	-60.91	-0.31	-42.06
36	1	0.30	0.61	0.48	1.09	0.61	-0.80	-72.95	-0.32	-51.64
	2	0.96	0.61	0.54	1.15	0.61	-0.19	-16.48	0.35	57.38
	3	0.58	0.61	0.74	1.35	0.74	-0.78	-57.47	-0.17	-22.52
37	1	0.78	0.81	0.48	1.29	0.81	-0.52	-40.10	-0.04	-4.71
	2	0.43	0.81	0.54	1.35	0.81	-0.93	-68.58	-0.39	-47.74
	3	1.24	0.81	0.74	1.56	0.81	-0.32	-20.28	0.43	52.47
38	1	0.90	0.47	0.48	0.95	0.48	-0.05	-4.99	0.42	87.27
	2	0.14	0.47	0.54	1.01	0.54	-0.87	-86.58	-0.40	-74.97
	3	0.37	0.47	0.74	1.21	0.74	-0.84	-69.80	-0.38	-50.82
39	1	0.42	0.70	0.48	1.18	0.70	-0.76	-64.42	-0.28	-40.00
	2	0.69	0.70	0.54	1.24	0.70	-0.55	-44.33	-0.01	-1.43
	3	0.85	0.70	0.74	1.44	0.70	-0.59	-41.06	0.15	21.43
40	1	0.34	0.42	0.48	0.90	0.48	-0.56	-62.33	-0.14	-29.26
	2	0.16	0.42	0.54	0.96	0.54	-0.80	-83.36	-0.38	-70.34
	3	0.73	0.42	0.74	1.16	0.74	-0.44	-37.72	-0.02	-2.30
41	1	0.21	0.45	0.48	0.93	0.48	-0.72	-77.51	-0.27	-56.30
	2	0.20	0.45	0.54	0.99	0.54	-0.79	-79.85	-0.34	-62.92
	3	0.95	0.45	0.74	1.20	0.74	-0.25	-20.53	0.21	28.02
42	1	1.11	1.05	0.48	1.53	1.05	-0.42	-27.65	0.06	5.57
	2	0.96	1.05	0.54	1.59	1.05	-0.63	-39.79	-0.09	-8.76
	3	1.08	1.05	0.74	1.79	1.05	-0.71	-39.62	0.03	3.18
43	1	0.99	0.55	0.48	1.03	0.55	-0.04	-4.13	0.44	79.35
	2	0.21	0.55	0.54	1.09	0.55	-0.89	-81.22	-0.35	-62.86
	3	0.68	0.55	0.74	1.29	0.74	-0.61	-47.45	-0.06	-8.37
44	1	0.85	0.95	0.48	1.43	0.95	-0.58	-40.86	-0.10	-10.89
	2	1.00	0.95	0.54	1.49	0.95	-0.49	-33.12	0.05	4.92
	3	1.01	0.95	0.74	1.69	0.95	-0.69	-40.55	0.06	5.98
45	1	0.29	0.36	0.48	0.84	0.48	-0.55	-65.96	-0.20	-40.70
	2	0.37	0.36	0.54	0.90	0.54	-0.53	-59.27	-0.17	-32.33
	3	0.42	0.36	0.74	1.10	0.74	-0.68	-61.78	-0.32	-43.40
46	1	0.16	0.70	0.48	1.18	0.70	-1.03	-86.89	-0.55	-77.91
	2	0.85	0.70	0.54	1.24	0.70	-0.39	-31.51	0.15	21.13
	3	1.10	0.70	0.74	1.44	0.74	-0.34	-23.81	0.36	48.23
47	1	0.14	0.66	0.48	1.14	0.66	-1.00	-87.69	-0.52	-78.68
	2	0.00	0.66	0.54	1.20	0.66	-1.20	-100.00	-0.66	-100.00
	3	0.92	0.66	0.74	1.40	0.74	-0.48	-34.59	0.17	23.30
48	1	0.31	0.45	0.48	0.93	0.48	-0.62	-66.69	-0.17	-35.50
	2	0.19	0.45	0.54	0.99	0.54	-0.80	-80.80	-0.35	-64.78
	3	0.85	0.45	0.74	1.19	0.74	-0.34	-28.70	0.11	14.54
49	1	0.58	0.71	0.48	1.19	0.71	-0.61	-51.42	-0.13	-18.69
	2	0.65	0.71	0.54	1.25	0.71	-0.60	-48.11	-0.06	-8.87
	3	0.91	0.71	0.74	1.46	0.74	-0.55	-37.47	0.17	22.62
50	1	0.22	0.65	0.48	1.13	0.65	-0.92	-81.05	-0.44	-67.13
	2	0.73	0.65	0.54	1.19	0.65	-0.46	-38.83	0.08	11.62

Appendix H. Heterosis of hybrids for grain yield (t/ha) under low nitrogen conditions

Line	Tester	Mean Hybrid	Female	Male	Parent Mean (MP)	Better Parent (BP)	Diff from MP	Heterosis over MP (%)	Diff from BP	Heterosis over BP (%)
1	1	1.85	2.10	2.85	2.47	2.85	-0.62	-25.22	-1.00	-35.08
	2	2.53	2.10	2.91	2.50	2.91	0.02	0.91	-0.38	-13.12
	3	1.92	2.10	2.32	2.21	2.32	-0.29	-13.17	-0.40	-17.39
2	1	2.63	1.84	2.85	2.34	2.85	0.28	12.03	-0.22	-7.88
	2	1.78	1.84	2.91	2.37	2.91	-0.60	-25.15	-1.13	-38.93
	3	1.11	1.84	2.32	2.08	2.32	-0.97	-46.64	-1.21	-52.24
3	1	2.40	2.53	2.85	2.69	2.85	-0.30	-10.99	-0.45	-15.95
	2	3.05	2.53	2.91	2.72	2.91	0.33	11.99	0.14	4.77
	3	2.16	2.53	2.32	2.43	2.53	-0.27	-11.24	-0.38	-14.88
4	1	3.09	2.44	2.85	2.64	2.85	0.45	16.91	0.24	8.44
	2	2.47	2.44	2.91	2.67	2.91	-0.20	-7.54	-0.44	-15.01
	3	1.75	2.44	2.32	2.38	2.44	-0.63	-26.48	-0.69	-28.18
5	1	2.44	2.83	2.85	2.84	2.85	-0.40	-14.03	-0.41	-14.37
	2	3.42	2.83	2.91	2.87	2.91	0.55	19.31	0.51	17.68
	3	2.62	2.83	2.32	2.58	2.83	0.04	1.73	-0.21	-7.31
6	1	2.50	3.11	2.85	2.98	3.11	-0.48	-16.05	-0.61	-19.53
	2	4.16	3.11	2.91	3.01	3.11	1.15	38.37	1.05	33.90
	3	2.66	3.11	2.32	2.72	3.11	-0.06	-2.04	-0.45	-14.38
7	1	2.82	2.72	2.85	2.79	2.85	0.03	1.06	-0.03	-1.21
	2	3.26	2.72	2.91	2.81	2.91	0.45	15.85	0.35	12.17
	3	2.09	2.72	2.32	2.52	2.72	-0.43	-17.16	-0.63	-23.21
8	1	1.65	2.34	2.85	2.59	2.85	-0.95	-36.56	-1.20	-42.27
	2	2.78	2.34	2.91	2.62	2.91	0.16	6.05	-0.13	-4.35
	3	2.59	2.34	2.32	2.33	2.34	0.25	10.93	0.25	10.63
9	1	2.94	2.84	2.85	2.85	2.85	0.09	3.11	0.09	3.00
	2	2.51	2.84	2.91	2.87	2.91	-0.37	-12.86	-0.40	-13.81
	3	3.09	2.84	2.32	2.58	2.84	0.51	19.60	0.25	8.68
10	1	3.64	2.70	2.85	2.77	2.85	0.86	31.00	0.79	27.57
	2	2.22	2.70	2.91	2.80	2.91	-0.58	-20.80	-0.69	-23.61
	3	2.25	2.70	2.32	2.51	2.70	-0.27	-10.63	-0.46	-16.85
11	1	3.14	3.05	2.85	2.95	3.05	0.19	6.37	0.09	2.96
	2	3.70	3.05	2.91	2.98	3.05	0.72	24.34	0.66	21.51
	3	2.30	3.05	2.32	2.68	3.05	-0.38	-14.32	-0.75	-24.47
12	1	3.48	2.67	2.85	2.76	2.85	0.72	26.06	0.63	22.13
	2	2.63	2.67	2.91	2.79	2.91	-0.16	-5.88	-0.28	-9.68
	3	1.91	2.67	2.32	2.50	2.67	-0.59	-23.54	-0.76	-28.51
13	1	3.62	3.11	2.85	2.98	3.11	0.64	21.59	0.52	16.59
	2	3.02	3.11	2.91	3.01	3.11	0.01	0.31	-0.09	-2.90
	3	2.68	3.11	2.32	2.71	3.11	-0.03	-1.27	-0.43	-13.69
14	1	3.44	2.80	2.85	2.82	2.85	0.61	21.60	0.59	20.55
	2	2.57	2.80	2.91	2.85	2.91	-0.28	-9.92	-0.34	-11.57
	3	2.40	2.80	2.32	2.56	2.80	-0.17	-6.52	-0.41	-14.46
15	1	3.07	3.07	2.85	2.96	3.07	0.11	3.70	0.00	-0.06
	2	2.52	3.07	2.91	2.99	3.07	-0.47	-15.86	-0.56	-18.12
	3	3.63	3.07	2.32	2.70	3.07	0.93	34.55	0.56	18.18
16	1	3.93	2.85	2.85	2.85	2.85	1.08	37.91	1.08	37.89
	2	3.36	2.85	2.91	2.88	2.91	0.48	16.57	0.45	15.44
	3	1.27	2.85	2.32	2.59	2.85	-1.32	-51.10	-1.59	-55.61
17	1	2.57	2.56	2.85	2.70	2.85	-0.14	-5.11	-0.28	-9.98
	2	2.37	2.56	2.91	2.73	2.91	-0.37	-13.42	-0.54	-18.63
	3	2.74	2.56	2.32	2.44	2.56	0.30	12.28	0.18	7.17
18	1	3.95	3.08	2.85	2.96	3.08	0.99	33.23	0.87	28.25
	2	2.81	3.08	2.91	2.99	3.08	-0.19	-6.29	-0.28	-8.93
	3	2.49	3.08	2.32	2.70	3.08	-0.22	-8.03	-0.60	-19.32
19	1	2.33	2.47	2.85	2.66	2.85	-0.33	-12.37	-0.52	-18.23
	2	3.26	2.47	2.91	2.69	2.91	0.57	21.13	0.35	12.00
	3	1.82	2.47	2.32	2.40	2.47	-0.58	-24.05	-0.65	-26.27
20	1	3.74	2.86	2.85	2.86	2.86	0.88	30.80	0.87	30.52
	2	2.15	2.86	2.91	2.88	2.91	-0.73	-25.45	-0.76	-26.02
	3	2.70	2.86	2.32	2.59	2.86	0.11	4.13	-0.16	-5.65
21	1	3.45	3.42	2.85	3.13	3.42	0.32	10.11	0.03	0.97
	2	2.76	3.42	2.91	3.16	3.42	-0.41	-12.86	-0.66	-19.37
	3	4.05	3.42	2.32	2.87	3.42	1.17	40.92	0.63	18.39
22	1	3.07	2.74	2.85	2.80	2.85	0.27	9.64	0.22	7.56
	2	3.57	2.74	2.91	2.82	2.91	0.75	26.42	0.66	22.84
	3	1.59	2.74	2.32	2.53	2.74	-0.94	-37.23	-1.15	-42.01
23	1	3.38	3.79	2.85	3.32	3.79	0.06	1.89	-0.41	-10.70
	2	4.40	3.79	2.91	3.35	3.79	1.05	31.51	0.62	16.25
	3	3.58	3.79	2.32	3.05	3.79	0.52	17.04	-0.21	-5.55
24	1	3.56	3.20	2.85	3.02	3.20	0.53	17.63	0.36	11.27
	2	3.08	3.20	2.91	3.05	3.20	0.02	0.80	-0.12	-3.76
	3	2.96	3.20	2.32	2.76	3.20	0.20	7.08	-0.24	-7.51
25	1	2.23	2.38	2.85	2.62	2.85	-0.39	-14.77	-0.62	-21.74
	2	3.46	2.38	2.91	2.64	2.91	0.82	30.82	0.55	19.05
	3	1.46	2.38	2.32	2.35	2.38	-0.89	-37.97	-0.92	-38.74
26	1	1.73	2.02	2.85	2.43	2.85	-0.71	-29.10	-1.12	-39.46
	2	2.34	2.02	2.91	2.46	2.91	-0.12	-4.94	-0.57	-19.49
	3	1.99	2.02	2.32	2.17	2.32	-0.19	-8.54	-0.34	-14.59
27	1	2.88	2.99	2.85	2.92	2.99	-0.05	-1.56	-0.12	-3.90
	2	4.25	2.99	2.91	2.95	2.99	1.30	44.12	1.26	42.06

28	3	1.85	2.99	2.32	2.66	2.99	-0.81	-30.40	-1.14	-38.16
	1	3.34	2.09	2.85	2.47	2.85	0.87	35.24	0.49	17.21
	2	2.51	2.09	2.91	2.50	2.91	0.01	0.27	-0.40	-13.81
	3	0.43	2.09	2.32	2.21	2.32	-1.78	-80.74	-1.90	-81.71
29	1	2.93	2.41	2.85	2.63	2.85	0.30	11.42	0.08	2.83
	2	1.91	2.41	2.91	2.66	2.91	-0.75	-28.33	-1.00	-34.45
	3	2.40	2.41	2.32	2.37	2.41	0.03	1.18	-0.02	-0.62
30	1	3.98	3.09	2.85	2.97	3.09	1.00	33.78	0.88	28.50
	2	2.85	3.09	2.91	3.00	3.09	-0.15	-5.16	-0.25	-8.03
	3	2.46	3.09	2.32	2.71	3.09	-0.25	-9.18	-0.63	-20.47
31	1	2.50	2.92	2.85	2.88	2.92	-0.38	-13.26	-0.42	-14.24
	2	3.97	2.92	2.91	2.91	2.92	1.05	36.22	1.05	36.02
	3	2.28	2.92	2.32	2.62	2.92	-0.34	-12.96	-0.64	-21.78
32	1	3.77	3.22	2.85	3.03	3.22	0.74	24.23	0.55	17.08
	2	3.30	3.22	2.91	3.06	3.22	0.23	7.57	0.07	2.33
	3	2.60	3.22	2.32	2.77	3.22	-0.18	-6.39	-0.63	-19.41
33	1	3.28	2.72	2.85	2.79	2.85	0.49	17.75	0.43	15.11
	2	2.20	2.72	2.91	2.81	2.91	-0.62	-22.00	-0.71	-24.47
	3	2.69	2.72	2.32	2.52	2.72	0.17	6.62	-0.03	-1.16
34	1	2.51	2.66	2.85	2.76	2.85	-0.25	-9.09	-0.34	-12.09
	2	2.38	2.66	2.91	2.78	2.91	-0.40	-14.51	-0.53	-18.11
	3	3.10	2.66	2.32	2.49	2.66	0.61	24.35	0.44	16.47
35	1	3.35	2.90	2.85	2.87	2.90	0.47	16.36	0.45	15.34
	2	2.87	2.90	2.91	2.90	2.91	-0.03	-1.14	-0.04	-1.25
	3	2.49	2.90	2.32	2.61	2.90	-0.13	-4.86	-0.42	-14.31
36	1	2.63	2.77	2.85	2.81	2.85	-0.18	-6.55	-0.22	-7.88
	2	2.79	2.77	2.91	2.84	2.91	-0.05	-1.84	-0.12	-4.17
	3	2.90	2.77	2.32	2.55	2.77	0.35	13.70	0.13	4.58
37	1	3.13	3.13	2.85	2.99	3.13	0.14	4.75	0.00	0.11
	2	3.15	3.13	2.91	3.02	3.13	0.13	4.43	0.02	0.75
	3	3.10	3.13	2.32	2.73	3.13	0.37	13.74	-0.03	-0.85
38	1	1.60	2.68	2.85	2.76	2.85	-1.17	-42.31	-1.25	-44.03
	2	3.49	2.68	2.91	2.79	2.91	0.69	24.77	0.58	19.91
	3	2.96	2.68	2.32	2.50	2.68	0.46	18.30	0.28	10.45
39	1	3.23	3.00	2.85	2.92	3.00	0.30	10.36	0.23	7.68
	2	3.59	3.00	2.91	2.95	3.00	0.63	21.50	0.59	19.70
	3	2.18	3.00	2.32	2.66	3.00	-0.48	-18.22	-0.82	-27.38
40	1	1.33	1.53	2.85	2.19	2.85	-0.87	-39.51	-1.52	-53.50
	2	1.68	1.53	2.91	2.22	2.91	-0.54	-24.52	-1.23	-42.37
	3	1.60	1.53	2.32	1.93	2.32	-0.33	-17.27	-0.73	-31.37
41	1	2.61	2.15	2.85	2.50	2.85	0.11	4.45	-0.24	-8.40
	2	2.11	2.15	2.91	2.53	2.91	-0.42	-16.51	-0.80	-27.40
	3	1.73	2.15	2.32	2.24	2.32	-0.51	-22.86	-0.60	-25.78
42	1	1.56	1.84	2.85	2.34	2.85	-0.78	-33.42	-1.29	-45.25
	2	2.16	1.84	2.91	2.37	2.91	-0.22	-9.13	-0.75	-25.85
	3	1.80	1.84	2.32	2.08	2.32	-0.29	-13.72	-0.53	-22.77
43	1	3.10	3.04	2.85	2.94	3.04	0.16	5.36	0.06	2.14
	2	4.20	3.04	2.91	2.97	3.04	1.23	41.38	1.17	38.39
	3	1.81	3.04	2.32	2.68	3.04	-0.87	-32.64	-1.23	-40.53
44	1	2.91	2.44	2.85	2.64	2.85	0.27	10.06	0.06	2.12
	2	2.66	2.44	2.91	2.67	2.91	-0.01	-0.46	-0.25	-8.47
	3	1.75	2.44	2.32	2.38	2.44	-0.64	-26.72	-0.69	-28.43
45	1	2.33	2.14	2.85	2.49	2.85	-0.16	-6.57	-0.52	-18.23
	2	2.08	2.14	2.91	2.52	2.91	-0.44	-17.54	-0.83	-28.43
	3	2.01	2.14	2.32	2.23	2.32	-0.23	-10.14	-0.32	-13.73
46	1	2.67	2.43	2.85	2.64	2.85	0.03	0.96	-0.18	-6.47
	2	2.46	2.43	2.91	2.67	2.91	-0.21	-7.99	-0.45	-15.53
	3	2.17	2.43	2.32	2.38	2.43	-0.21	-8.71	-0.26	-10.70
47	1	2.07	2.94	2.85	2.89	2.94	-0.82	-28.45	-0.87	-29.51
	2	3.41	2.94	2.91	2.92	2.94	0.48	16.55	0.47	15.95
	3	3.34	2.94	2.32	2.63	2.94	0.70	26.79	0.40	13.56
48	1	3.29	2.60	2.85	2.73	2.85	0.56	20.67	0.44	15.46
	2	3.53	2.60	2.91	2.75	2.91	0.77	27.96	0.62	21.29
	3	1.00	2.60	2.32	2.46	2.60	-1.47	-59.61	-1.61	-61.78
49	1	2.45	2.21	2.85	2.53	2.85	-0.08	-3.35	-0.40	-14.20
	2	1.72	2.21	2.91	2.56	2.91	-0.84	-32.96	-1.19	-40.99
	3	2.47	2.21	2.32	2.27	2.32	0.20	8.95	0.15	6.28
50	1	2.49	3.30	2.85	3.07	3.30	-0.58	-18.97	-0.81	-24.47
	2	4.01	3.30	2.91	3.10	3.30	0.90	29.13	0.71	21.49
	3	3.40	3.30	2.32	2.81	3.30	0.58	20.80	0.10	2.98