GENETIC ANALYSIS OF TOLERANCE TO LOW SOIL NITROGEN IN INTERMEDIATE MATURING MAIZE (*Zea mays* L.) INBRED LINES

By

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DECLARATION

I hereby declare that except for references to works of other researchers, which have been duly cited, this work is my original research and that neither part nor whole has been presented elsewhere for the award of a degree.

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ABSTRACT

Low soil nitrogen (N) is one of the most important constraints to maize production in sub-Saharan Africa (SSA) in general and in particular the Bimodal Humid Forest Zone (BHFZ) of Cameroon. The development and adoption of maize varieties tolerant to low N soils could reduce the need for nitrogen inputs and significantly contribute to sustainable maize production. The objectives of this research were to: i) identify maize production constraints and farmers preferred maize characteristics in the Bimodal Humid Forest Zone of Cameroon; ii) identify maize genotypes tolerant to low N soils; iii) examine the combining abilities of maize inbreds and classify them into heterotic groups and iv) determine the effect of genotype x environment interaction on grain yield and yield stability of maize hybrids across low N and optimal environments. A Participatory Rural Appraisal (PRA) consisting of focus group discussions followed by formal surveys was conducted in six villages of the Central Region in the Bimodal Humid Forest Zone of Cameroon. Thirty nine inbreds originating from IRAD, IITA and CIMMYT were crossed to three heterotic testers (87036, Exp1 24 and 9071) in a line x tester scheme to generate 117 F_1 hybrids. The 117 F_1 hybrids along with 4 checks were evaluated under low N (20 kg ha^{-1}) and optimum N (100 kg ha^{-1} N) at two location viz., Mbalmayo and Nkolbisson, during the minor season of 2012 and minor and major seasons of 2013. Genotype x environment interaction and grain yield stability of 80 hybrids were assessed across 11 environments under low and optimum N using AMMI and GGE biplot analysis. The study revealed that low soil fertility and high cost of fertilizers were among the most important constraints to maize production in the study area. Farmers cited large grain size, soft grain texture, large ear size, high prolificacy, early maturity, short plants, resistance to lodging, resistance to diseases and reduced post-harvest losses as their preferred characteristics in maize varieties. Across environments, CLYN246 x 87036, CLWN201 x Exp1 24, J16-1 x Exp1 24, 1368 x 87036, ATP S6-20-Y-1 x Exp1 24 and Cam inb gp1 17 x 87036 were higher yielding than 87036 x Exp1 24, the commercial hybrid used as check in the study. Among these hybrids, CLWN201 x Exp1 24, J16-1 x Exp1 24 and 1368 x 87036 may be candidates for release. Inbreds CLYN246, ATP S6-20-Y-1 and Cam inb gp1 17 could be used as testers to classify lines into heterotic groups or recombined within groups to develop source populations for new inbred development. For specific areas with low N stress, TL-11-A-1642-5 x Exp1 24, CLWN201 x 87036 and J16-1 x Exp1 24 may be candidates for release while TL-11-A-1642-5 x 87036, TZ-STR-133 x 87036, CLWN201 x Exp1 24 and J16-1 x Exp1 24 could be proposed for release for optimal N conditions. Both additive and non-additive gene action influenced grain yield under low N with predominance of non-additive genetic effects while additive gene action was predominant under optimum conditions. Hybrid development could therefore be employed to exploit non additive gene action under low N. Based on SCA and yield performance of test crosses under low and optimum N, lines were classified into three heterotic groups for each environment; group A (anti-87036), group B (anti-Exp1 24) and group C (anti-9071). Lines from each group will serve as germplasm for development of the second generation of inbreds. Analysis of variance for grain yield revealed highly significant genotype x environment interactions. The GGE biplot analysis divided the study area into three mega environments. One mega-environment included enviroments related with the major season of the year while the two others included environments related to the minor season. Hybrid 1368 x 87036 was identified as the highest yielding hybrid in minor season while TL-11-A-1642-5 x 87036 was the best hybrid for major season. Hybrid TL-11-A-1642-5 x 87036 was the outstanding hybrid, combining high yield and stability and has the potential for commercialization across environments.

DEDICATION

To my husband, Tontsa François, my children, Nathacha, Frank, Karl, Helena and my parents, Apala Benoit and Sangué Marie Hélène.

To the memory of the late Dr.Thé Charles.

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LIST OF ABREVIATIONS

AMMI	Additive Main effect and Multiplicative Interaction
CIMMYT	International Maize and Wheat Improvement Center
CHH	Cameroon Highland hybrid
CLH	Cameroon Low land hybrid
CML	CIMMYT Maize Lines
CMS	Cameroon Maize Selection
FAO	Food and Agriculture Organization
DNA	Deoxyribonucleic acid
FSSRP	Fertilizer Sub-Sector Reform Program
Hh	Household head
IITA	International Institute of Tropical Agriculture
IRAD	Institute of Agricultural Research for Development
Low N	Low soil nitrogen
METs	Multi-environment trials
MINADER	Ministry of Agriculture and Rural Development
NGOs	Non-governmental organizations
OPVs	Open pollinated varieties
SSA	sub-Saharan Africa

CHAPTER ONE

1.0 GENERAL INTRODUCTION

Maize (*Zea mays* L.) is the third largest planted crop in the world after rice and wheat and the second most traded cereal after wheat (FAOSTAT, 2014) . It is a very versatile crop, growing in both temperate and tropical zones, in all edaphic, altitudinal and fertility conditions (IITA, 2009). World maize production is estimated at 872 million tonnes, planted on over 177 million hectares. The largest producer is the United State, which accounts for about 31.4% of the world production (FAOSTAT, 2014). African production represents 7.9% of the world production and the largest African producer is South Africa with nearly 12 million tons, followed by Nigeria with about 9.5 million tonnes (FAOSTAT, 2014).

Maize has a wider range of uses than any other cereal due to its world-wide distribution, high yield, ease of processing, high digestibility and relatively lower price of the grain (Bello *et al.*, 2012). In industrialized countries, maize is largely used as livestock feed and as a raw material for industrial products whereas in developing countries, it is mainly used for human consumption. Worldwide consumption of maize is more than 116 million tons per year, with Africa consuming 30% and sub-Saharan Africa (SSA) 21%. In SSA, maize is a staple food for an estimated 50% of the population. It is an important source of carbohydrate, protein, iron, vitamin B, and minerals (IITA, 2014) and accounts for about 15% of the caloric intake of the population (Badu-Apraku and Akinwale, 2011).

In Cameroon, maize is grown in all the five agro ecological zones, namely: Sudano-Sahelian Zone, High Guinea Savanna, Humid Forest Zone and the Western Highlands with a mono modal rainfall pattern and the Humid Forest Zone with a bimodal rainfall pattern. These agro ecological zones are within an altitude ranging from zero and 4095 meters above sea level. Maize is the most consumed cereal in Cameroon, much more than sorghum, rice and wheat (Etoundi and Dia, 2008). Maize production has increased steadily from 1,050,000 tonnes in 2005 to 1,647,036 tonnes in 2013 (FAOSTAT, 2014). The increase in production has been mainly due to increases in area cultivated (from 492,347 ha in 2005 to 832,400 ha in 2013) rather than yield increase per unit area, with maize grain yield in Cameroon still around 2 t ha^{-1} (FAOSTAT, 2014). The national demand for maize is below production and the country has to import a large quantity of the crop every year to satisfy its needs; for example, in 2011 Cameroon imported 16, 234 tonnes of maize flour (FAOSTAT, 2014)

During the past decade, farmers' involvement in maize production has been increasing, and maize has become a cash crop such as coffee and cocoa, and is an important source of income for farmers (Nguimgo *et al.*, 2003; Hauser *et al.*, 2006). There is also an increasing demand for the crop for use as feed in animal production and in the brewing industry (Etoundi and Dia, 2008). The average yield of maize in developed countries may be up to 8.6 tonnes per hectare while production per hectare in West and Central Africa is still very low, averaging 1.3 tonnes per hectare, resulting in a production gap that must be bridged (IITA, 2009).

The major constraints to maize production in sub-Saharan Africa (SSA) include both biotic and abiotic factors. The main biotic factors are pests and diseases and the parasitic weeds, *Striga hermonthica* (IITA, 2009). The most common abiotic factors are drought, heat, low soil fertility particularly low soil nitrogen, high soil aluminium toxicity, flooding, and salinity (Tuberosa *et al.*, 2005). The low adoption of improved varieties by farmers (Sibiya *et al.*, 2013) and the non-use of appropriate farming techniques (Etoundi and Dia, 2008) are also important factors contributing to low yield.

Low soil nitrogen has been reported as one of the most wide spread problems among small-scale farmers in the tropics (Betràn *et al.*, 2003a; Zaidi *et al.*, 2003). Low soil nitrogen causes an average maize yield losses ranging between 10 – 50% per year in sub- Saharan Africa (Logrono and Lothrop, 1997).

In Cameroon, the price of nitrogen fertilizer has increased steadily since 2005 making it inaccessible to resource-poor small-scale farmers who account for the bulk of the production**.** Attempts to apply N from organic sources have not yielded the desired results because of the high haulage and application costs involved. It has therefore become necessary to explore other avenues that will increase the yield of the crop per unit area under the prevailing low soil N conditions. Many high yielding maize varieties have been developed and are adapted to different agro-ecological zones. The varieties developed include those which are resistant to maize streak virus, tolerant to the parasitic weed, *Striga hermonthica,* and tolerant to Aluminium toxicity in the soil (The *et al.*, 2005; The *et al.*, 2006). However, maize varieties with high yield under low N have not yet been identified in Cameroon. Most of the existing varieties with good yield have been developed to produce optimum yield under high levels of nitrogen, whereas most of the maize in farmers' fields is grown under low N conditions which in part, accounts for the low productivity of maize.

With the low N status of soils in the Bimodal Humid Forest Zone of Cameroon, the rising cost of fertilizers which are prohibitive to the poor resource small scale farmer, it has become imperative to develop maize varieties that could produce acceptable yields under low N if Cameroon is to increase maize production to meet the ever increasing demand.

In Cameroon as in many countries of sub Saharan Africa, most of the released maize varieties are open pollinated varieties with a yield range between 2 to 4 tonnes per hectare, far below the yields of hybrids which have higher yield potential estimated at 8 to 10 tonnes per hectare in developed countries**.** Hybrid varieties which take advantage of heterosis over open pollinated varieties that the farmers use and which will have an added advantage of doing well in low N soils would go a long way in ensuring food security. Despite the development of a number of high yielding improved maize varieties by the National Research Institute of Cameroon, these varieties have been adopted by only a limited number of farmers in the Bimodal Humid Forest Zone of Cameroon (Etoundi and Dia, 2008; Ngo Nonga, 2008a). The low adoption by farmers of improved varieties, especially hybrids despite their yield advantage compared to local varieties also accounts for the low maize yield in Cameroon. Farmer's desired characteristics in maize varieties and their perception of soil fertility have not been well documented in the Bimodal Humid Forest Zone of Cameroon. It is therefore important in developing maize varieties tolerant to low nitrogen to consider farmers constraints to production and incorporate their preferred traits in the breeding strategies in order to have a wide adoption of the developed varieties. The adoption of maize hybrids adapted to low soil N would reduce the quantity of N fertilizer applied by small scale farmers to levels below the recommended rate of 100 kg N ha^{-1} for the humid forest zone of Cameroon (FSSRP, 2011). This would enhance maize production among the predominantly small scale farmers in Cameroon, increase farmers' incomes, and lead to the sustainability of maize production in a safer environment.

Information on the combining ability of inbred lines is crucial for the success of a hybrid programme (Abrha *et al.*, 2013). Genetic studies have been conducted on maize genotypes under low N using different sources of genetic materials (Betràn *et al.*, 2003a; Meseka *et al.*, 2006;

Miti, 2007; De Souza *et al.*, 2008; Pswarayi and Vivek, 2008; Makumbi *et al.*, 2011; Badu-Apraku *et al.*, 2013; Meseka *et al.*, 2013). Furthermore, the development of adapted high yielding hybrids requires that the varieties used as parents are genetically divergent (Acquaah, 2007) and belong to different heterotic groups (Betràn, 2007). To this end, the national breeding program has assessed a number of inbred lines from CIMMYT and IITA for use in improvement of existing inbred lines, development of new lines and hybrids. However, little is known about the heterotic relationship between CIMMYT, IITA and Cameroon maize inbreds particularly under low soil nitrogen. It is therefore important to understand the heterotic relationship between these lines from different origins and genetic backgrounds in order to select outstanding parents for pedigree breeding, backcrossing and marker assisted recurrent selection (MARS). The selected lines could also be used in developing new improved low N tolerant hybrids for release and commercialization. In addition, classification of inbred lines into heterotic groups would facilitate exploitation of heterosis and lead to development of high yielding maize hybrids tolerant to low N soils. Furthermore, due to the poor and unstable environmental conditions in farmer's field which result in low yields compared to yields obtained in research stations, hybrid evaluation in multi-location trials in representative samples of the target environments is required in order to identify high yielding and stable genotypes across environments (Beck *et al.*, 1996; Badu-Apraku *et al.*, 2012; Ndhlela, 2012).

The overall objective of this study was to use the existing germplasm from different origins and genetic backgrounds to develop low N-adapted maize hybrids.

The specific objectives were to:

i. Identify maize production constraints in the humid forest zone of Cameroon and farmers' preferred characteristics in adopting a variety.
ii. Identify high yielding and low N tolerant hybrids adapted to the Bimodal Humid Forest Zone of Cameroon
iii. Estimate the combining abilities of inbred lines and the mode of gene action under low N and to classify the lines into heterotic groups
iv. Analyze genotype x environment (GxE) interaction and stability for grain yield of single cross hybrids.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Climatic requirements of maize

Maize is grown all over the world from latitudes 55° North to 40° South and from sea level to 3800 m altitude. It has a wide range of adaptation to environments, and its growing period ranges from 65 days in the lowland tropics to approximately 12 months in the tropical highlands (Fischer and Palmer, 1984)

Maize can be grown on a wide variety of soils; it performs best on well-drained, well-aerated, loams and silt loams containing adequate organic matter and well supplied with available nutrients but does not yield well on poor sandy soils without sufficient application of fertilizers (Du Plessis, 2003). Maize plant requires moderately high temperatures and adequate, but not excessive, rainfall. On heavy clay soils, deep cultivation and ridging are necessary to improve drainage. Even though the maize plant requires 350 to 450 mm of rain to produce a yield of 3152kg/ha, it does not tolerate water logging and can die if it stands in water for more than two days (Du Plessis, 2003). Maize can be grown successfully on soils with a pH of 5.0 - 7.0 but a moderately high acid environment of pH 6.0 - 7.0 is optimum (Du Plessis, 2003). The optimum temperature for maize growth is between 24-30˚C (Miti, 2007)**.**

For normal growth, maize requires both macronutrients and micronutrients. The macronutrients include Nitrogen (N), phosphorus (P) and potassium (K), while the micronutrients are calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), and boron (B) (Acquaah, 2007). The minimum levels of the three macronutrients required to support maize production in dry soils are 3 % for N, 0.25% for P and 1.9% for K (Mohr and Dickson, 1979). Nitrogen is important in maize production because it promotes vegetative growth and maximizes both kernel initiation and kernel set (Below, 1997). Nitrogen also plays a key role in the establishment and filling of the kernel sink (Below, 1997). The main role of P in maize production is seed development and stalk health while K improves the plant's ability to naturally resist diseases and influences the uptake of several other plant nutrients.

2.2 Importance of nitrogen in maize production

Maize requires N throughout its growth cycle, however N is most important at about four weeks after planting. At this stage, the maize growing point switches from producing leaves to producing the terminal reproductive structure, followed by the initiation of the tassel (Mohr and Dickson, 1979).

Nitrogen is an essential component of all enzymes and it is therefore necessary for plant growth and development. It constitutes about one-sixth of the weight of proteins, which are mainly enzymes (Bänziger *et al.*, 2000). In addition, nitrogen is a basic element of nucleic acids (Bänziger *et al.*, 2000). Nitrogen plays a key role in plant metabolism, especially in protein synthesis during when it has a strong influence on both grain production and protein content (Machado and Fernandes, 2001). It is found in higher amount in leaves, mainly in photosynthetic enzymes, and may account for up to 4% of the dry weight (Bänziger *et al.*, 2000). Nitrogen is therefore an important element for maize production and there is a strong correlation between N uptake, biomass production and grain yield in maize (Bänziger *et al.*, 2000). The N requirement of a maize crop can be related to grain yield as follows: 187 kg.ha^{-1} of N is required to produce

9.5 t ha^{-1} of maize, 98 $kg.ha^{-1}$ of N to produce 5 t ha^{-1} of maize and 40 $kg.ha^{-1}$ of N is needed to produce 2t ha^{-1} of maize (Bänziger *et al.*, 2000).

N deficiency affects different yield-determining factors. It reduces leaf area and leaf stay-green, thus reducing photosynthetic rate and increasing ear abortion. This is because about 50% of the leaf N is directly involved in photosynthesis either as enzymes or as chlorophyll. When N becomes scarce, plants remobilize N from older tissues (leaves, stalk) to younger tissues (leaves, grains), leading to early senescence of the older, lower leaf tissues (Bänziger *et al.*, 2000).

The effect of N stress on yield depends on the timing of the stress in the growing plant parts. If stress occurs during flowering, it will increase kernel abortion. Nitrogen stress before flowering reduces leaf area development, photosynthetic rate and number of potential kernel ovules. Severe N stress delays both shedding of pollen and emergence of silks. The delay in silking is relatively more severe, therefore increasing the anthesis-silking interval (Bänziger *et al.*, 2000). Nitrogen stress also influences root growth. Under low N, plants favor root growth over shoot growth, and the root/shoot ratio increases even though the total amount of roots is usually less for plants grown under N stress than under normal N (Bänziger *et al.*, 2000).

2.3 Management of low N stress

Maize is highly sensitive to deficiencies in plant nutrients, especially nitrogen, thus it requires high amounts of fertilizers to produce high yields. This increases production cost (Emede and Alika, 2012).

The main strategy for maintaining or restoring soil nutrients and increasing crop yields is the application of mineral fertilizers such as nitrogen (N) (Hirel *et al.*, 2011)**.** The N used in commercial fertilizers is particularly soluble and can easily be taken up and assimilated by plants. The simplicity of storage and handling of these fertilizers make them easy to apply when plants need most. Animal manure is an important source of nutrients supply, especially when there is densely populated livestock nearby (Hirel *et al.*, 2011).

The non-availability and high cost of fertilizers limit maize productivity in most developing countries where the majority of smallholder farmers lack resources for purchasing inputs (Bello *et al.*, 2012). Because of this, fertilizer application on crops averaged 25 kg/ha in developing countries in 2003 and has decreased over the past 10 years (Bello *et al.*, 2012).

Two basic approaches have been proposed to develop maize production in a sustainable manner in regions with low N fertility. These include the development of innovative agronomic practices that utilize N from organic matter or from biological fixation in an efficient manner to supplement N fertilization (Bello *et al.*, 2012) and the selection for low N tolerance in maize varieties (Smith *et al.*, 1994). The later approach is the best strategy for improving the productivity of maize under sub-optimal N fertility (Bello *et al.*, 2012). The low N tolerant cultivars are superior in the utilization of available N, either due to enhanced N- uptake capacity or more efficient use of absorbed N for grain production (Lafitte and Edmeades, 1994).

2.4 Genetic basis of maize tolerance to low soil nitrogen

An understanding of the genetic basis for maize development and yield under low N conditions is required to accelerate and improve selection efficiency for low N environments (Bänziger and Lafitte, 1997). Combining ability determines the usefulness of the inbred lines for hybrid maize breeding. The concepts of general and specific combining ability were introduced by Sprague and Tatum (1942). Hallauer and Miranda (1988) defined general combining ability (GCA) as the mean performance of a line in all its crosses, expressed as a deviation from the mean of all crosses. It is the average contribution an inbred makes to hybrid performance in a series of hybrid combinations in comparison to other inbreds in the same series of hybrid combinations and specific combining ability (SCA) is the contribution of an inbred to hybrid performance in a cross with a specific other inbred in relation to its contributions in crosses with an array of other inbreds. SCA can also be defined as the specific ability of two inbred lines to complement each other to produce superior hybrid performance. GCA effects may be used to estimate gene action of traits. In statistical terms, GCA effects indicate primarily additive gene action. Specific combining ability is associated with non-additive genetic effects which are not predictable but are ephemeral and therefore hard to predict with statistical models (Falconer and Mackay, 1996). A high GCA effect for a particular trait in a parent indicates the presence of additive gene effects for the trait in the concerned parent. It would be expected that when parents possessing high GCA effects were crossed, a large proportion of progenies would have high values for the trait concerned, facilitating selection for that trait (Falconer, 1981). Effects of GCA can be used to select superior genotypes under low N conditions. High GCA effects under low N may reflect the presence of the desired trait for low N tolerance.

Combining ability analysis is important in identifying the best parents or parental combinations for a hybridization program (Tamilarasi *et al.*, 2010). Various biometrical approaches are available to assess the breeding value of the parents and to assess the genetics of the traits under transfer. Diallel analysis is used to estimate GCA and SCA effects and their implications in breeding (Griffing, 1956; Gardner and Eberhart, 1966; Baker, 1978). Griffing (1956) proposed an analysis for diallel mating systems that estimate the general and specific combining abilities of lines and hybrids. Line x tester analysis (Kempthrone, 1957) is another approach often employed to understand the genetic basis of a given character and combining ability of parents and hybrids (Tamilarasi *et al.*, 2010).

Gene action under low-N conditions were inconclusive (Ajala *et al.*, 2010). Betràn *et al.* (2003a) reported low GCA effects for grain yield under low N conditions and crossover interactions of GCA effects under low and optimal conditions. In the study of Makumbi *et al.*(2011), gene action controlling grain yield varied with type of stress, with non-additive gene appearing to be more important than additive gene action under low N stress. Similar results were obtained by Meseka *et al*. (2006), Ndhlela (2012) and Meseka *et al.* (2013). On the contrary, other studies indicated that additive gene action was more important in the control of grain yield under low-N while non-additive gene effect was more important under high-N. For example, Below *et al.* (1997) used a diallel under temperate environment and found that both SCA and GCA mean square were significant for all traits under both N levels. They concluded that based on magnitude of difference between GCA compared to SCA, the majority of the genetic effect was associated with GCA, indicative of additive effects. Similar results were obtained by Kling *et al.* (1997), Mosiza (2005) , Miti *et al* (2010), Badu-Apraku *et al.* (2013) and Ifie (2013). De Souza *et al.* (2008) also studied the genetic control of grain yield and nitrogen use efficiency and its primary components. They reported that additive and non-additive genetic effects were responsible for the genetic control of nitrogen use efficiency and grain yield under high N and additive effects were more important while only additive gene action was significant for nitrogen uptake efficiency for maize grown in low N soils.

The contradictory results obtained by researchers might be due to the N stress level (testing environments) under which the genotypes were tested and or genotypic differences among sets of genotypes included in the studies (Mosiza, 2005).

Because of these contradictory results, more research is necessary on the genetic control of maize tolerance to low N in order to determine the appropriate breeding strategy to use for the development of low N tolerant hybrids adapted to the tropics.

2.5 Breeding strategies for developing low N tolerant maize varieties

2.5.1 Maize selection for low N tolerance

Maize genotypes differ widely with regard to N nutrition, especially low N tolerance and nitrogen use efficiency (Bänziger and Lafitte, 1997; Akintoye *et al.*, 1999). This variation in nitrogen use efficiency indicates that this trait may be genetically determined and could be improved by breeding (Mi *et al.*, 2005).

An appropriate breeding strategy could be used to develop genotypes that tolerate low N stress and produce high grain yield under both low soil N and optimal conditions. However, few studies have been conducted because it has often been assumed that there is no interaction between N levels and cultivars for grain yield (Mi *et al.*, 2005).

According to Bänziger *et al.* (2000), breeding methodologies in the tropics have been strongly influenced by maize breeding in temperate areas. In temperate environments, maize is grown under relatively stress free conditions and yields obtained at the farm levels are comparable to those obtained from experiment stations. In the tropics maize is frequently stressed in farmers' fields and yields are far below those obtained on breeding stations. Therefore, selection under high yielding conditions may not be suitable to increase yields in farmers' fields (Bänziger *et al.*, 2000).

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

Using three different types of environments described as: recommended agronomic management with high rainfall condition, low N stress and managed drought stress, Bänziger *et al.* (2004) produced 41 CIMMYT hybrids and compared their performance with 42 hybrids from private seed companies in several environments across east and southern Africa. Hybrids from the CIMMYT stress breeding program showed consistent advantage over commercial checks and hybrids from private companies at all yield levels. Eberhart-Russell stability analysis estimated 40% yield advantage at the one ton level, which decreased to 2.5% at 10 t level (Bänziger *et al.*, 2004).

Alleles related to stress tolerance are present in most elite maize populations at a relatively low frequency; therefore, selection under controlled, low N would be as an effective means of developing varieties capable of tolerating low N (Vasal *et al.*, 1997; Tollenaar and Lee, 2002). Since yield is controlled by a large number of minor genes, its improvement under low N environments will depend on how the respective genes respond to the stress (Miti, 2007).

Bänziger and Lafitte (1997) proposed direct selection (i.e. selection under conditions where the stress factor occurs uniformly and predictably as the more appropriate method to maximize selection gains under low N. This method was often superior to indirect selection in targeting stress environments. Presterl *et al.* (2002) developed hybrids under low and high N conditions and reported that the average yields of the hybrids developed at low N conditions were 11.5% higher in low N conditions than those selected under high N conditions. There was no significant difference in yield between the two hybrid types under high N conditions. In addition, the N-efficient hybrids showed significantly higher N uptake at low N levels than the hybrids selected under high N. No differences in N-utilization efficiency were observed (Presterl *et al.*, 2002).

Lafitte and Edmeades (1995) and Bänziger *et al.*, (1999) observed that recurrent selection under drought has a spillover effect on performance under low N conditions. Lafitte and Banziger (1997) reported gains in grain yield of about 3.4% per year under low N conditions when selecting for drought tolerance. They attributed this to reduced ear abortion and delayed leaf senescence, which are improved when developing drought tolerance. From this study, an increase in grain yield was achieved under low N while, under high N, grain yield was reduced after a single cycle of selection among half-sib families of a tropical maize population.

Using full-sib family selection to develop maize cultivars tolerant to low N under selection conditions of low and high N, (Omoigui *et al.*, 2006) obtained genetic gains in grain yield of 2.3% and 1.9%, under low and high N after one cycle of selection, respectively. They also recorded an increase in stay green by 17% and 4.7% after cycle-1 under low and high N, respectively. These results suggest that mechanisms conditioning grain yield under low N, differed from those under high N conditions (Omoigui *et al.*, 2006).

2.5.2 Sources of germplasm

Reports from several studies have indicated that useful genetic potential exists in maize for the improvement of nitrogen use efficiency (Heuberger *et al.*, 1995; Kling *et al.*, 1997) and promising genetic material with good nitrogen uptake and utilization efficiency has been identified from these studies and used as parents to develop populations adapted to West and Central Africa (Ajala *et al.*, 2007; Ajala *et al.*, 2010).

In a comparative evaluation study of landraces and improved varieties under low N, Lafitte *et al.* (1997) reported that improved varieties out-yielded landraces but landraces were superior in grain N concentration. In the same study, improved varieties were not consistently superior to landraces in N recovery, above ground biomass or in the fraction of N partitioned to the grain under low N, which would reflect their efficiency in the use of N.

Using S_1 selection for tolerance to low N among ninety-six maize landraces, Miti *et al.* (2010) identified some maize landraces that tolerated the stress caused by low N more than improved maize varieties and concluded that there was adequate genotypic variation for low N tolerance among maize landraces which could be improved by selection.

Improvement of drought tolerance in a maize population (Tuxpino Sequia), resulted in improved performance under low N conditions (Zambezi and Mwambula, 1997). Betràn *et al.* (2003a) highlighted the need to use drought tolerant maize inbred lines as parents of single-cross hybrids to improve grain yield under both drought and low N stresses. Meseka *et al.* (2006) also reported that screening drought tolerant maize inbred lines under low N was important to enhance opportunities for identifying parents of single cross hybrids for low N environments. Most of the above mentioned studies on maize tolerance to low N were carried out using germplasm developed at CIMMYT or IITA.

2.5.3 Secondary traits in selection for low N tolerance in maize

A secondary trait is a trait for which the breeder can select to achieve the progress expected from selecting for an original desired trait (Falconer and Mackay, 1996). This is called indirect selection, also defined as selection applied to some character other than the one it is desired to improve (Falconer and Mackay, 1996).

Breeders' primary interest is in grain yield. However, other secondary traits may be used to assess low N tolerance in maize because the secondary traits can improve the precision with which low N tolerant genotypes are identified, compared to measuring only grain yield under low N stress. This is because, under stress, the heritability of grain yield usually decreases, whereas the heritability of some secondary traits remains high, while at the same time the genetic correlation between grain yield and those traits increases sharply (Bolaños and Edmeades, 1996; Bänziger and Lafitte, 1997). Secondary traits can measure the degree to which a crop is stressed under low N, or, if observed before or at flowering, they can be used for selecting desirable parents, (Bänziger *et al.*, 2000). Moreover, If observed before maturity secondary traits can be used for preliminary selection when there is not sufficient time between two consecutive growing seasons (Bänziger *et al.*, 2000).

Edmeades *et al.,* (1997) established that an ideal secondary trait should be genetically associated with grain yield under stress, highly heritable, genetically variable, cheap and fast to measure, stable within the measurement period, not associated with a yield loss under unstressed conditions. A secondary trait should be observed at or before flowering so that undesirable parents are not crossed. Finally, it should be a reliable estimator of yield potential before final harvest. According to Bänziger *et al.* (2000), a secondary trait should not be only related to drought or low N tolerance, but the use of this trait together with grain yield in selection should provide greater breeding progress than progress obtained using grain yield alone. Thus, not only must secondary traits be identified, but their value in breeding must be proven (Bänziger *et al.*, 2000).

Plant breeding for nitrogen use efficiency, which is a combination of the efficiency of uptake, translocation and utilization of N (Moll *et al.*, 1982), could be accelerated in maize by the selection of secondary traits that possess high heritability and positive correlation with productivity (Bänziger and Lafitte, 1997; Bänziger *et al.*, 2000). Bänziger and Lafitte (1997) showed that the use of secondary traits plus yield improved selection gains for maize yield under low N by 20% compared to selection for yield alone , and the gains increased as N deficiency intensified (Bruce *et al.*, 2002).

Since the 1990s, breeding for low N tolerant maize hybrids for farmers in developing countries has been an objective of CIMMYT (Edmeades *et al.*, 1997). The selection criteria identified by CIMMYT for maize tolerance to low-N include grain yield at high and low N, plant height under low N, ear leaf area , number of ears and kernels per plant (Lafitte and Edmeades, 1994). In maize, phenotypic and genotypic correlations were highly significant between grain yield, kernel number and kernel weight under low N (Bertin and Gallais, 2000). Genotypes with a short anthesis-silking interval and a high number of ears per plant are efficient in remobilizing N from the stover to the grain, particularly during the early stage of embryo development thereby reducing embryo or ear abortion (Gallais and Coque, 2005).

Anthesis-silking interval has moderately high heritability and is correlated with grain yield under low N conditions (Bänziger and Lafitte, 1997). However, anthesis-silking interval only explained

25-35% of variation in grain yield and could not be used alone (Edmeades *et al.*, 1997). Vasal *et al.* (1997) observed that in selecting for tolerance to low N, anthesis-silking interval and number of ears per plant were effective and this was in accordance with the findings of Lafitte and Bänziger (1997), who reported that in addition to these, leaf senescence was also important. Bänziger *et al.* (2000) reported that the grain yield, number of ears per plant, anthesis-silking interval and leaf senescence were important in identifying superior genotypes under low N.

Miti *et al.* (2010) evaluated grain yield, number of ears per plant, anthesis-silking interval, leaf senescence, leaf rolling, tassel size and grain texture in S_1 plants from 96 land races for their relevance in selecting genotypes tolerant to low N and reported that secondary traits should be used to supplement grain yield to identify superior genotypes under low N conditions. They suggested that grain yield, tassel size and number of ears per plant should be used in selection indices to identify genotypes that tolerate low N. The use of secondary traits in a selection index had previously been suggested to be appropriate in identifying genotypes tolerant to low N (Bänziger *et al.*, 2000). By using a selection index, selection for several traits can be made simultaneously and breeders' decisions are based on the relative weights they give to each trait (Hallauer *et al.*, 2010). Badu-Apraku *et al.* (2011a) reported that, under low N, the most reliable traits were days to anthesis, days to silking, stay green characteristic, anthesis silking interval, plant height, number of ears per plant, ear aspect and plant aspect, but concluded that progress in selecting for improved grain yield is possible using only the number of ears per plant, ear aspect, plant aspect and anthesis silking interval.

2.6 Heterosis

The term heterosis was coined by Shull (1952). Heterosis is the vigor manifested in hybrids and represents the superiority in performance of hybrids compared with their parents (Hallauer *et al.*, 2010). Hybrid vigor in maize is manifested in the offspring of inbred lines with high specific combining ability (Hallauer *et al.*, 2010). Heterosis is important in maize breeding and is dependent on expression of over dominance and epistasis. The manifestation of heterosis usually depends on genetic divergence of the two parental varieties, and genetic divergence of the parental varieties is inferred from the heterotic patterns manifested in a series of variety crosses (Hallauer *et al.*, 2010). Heterosis may be defined in two basic ways. Hallauer *et al.* (2010), proposed methods to measure high-parent heterosis and mid-parent heterosis of a hybrid relative to is parents: High-parent heterosis is the performance of a hybrid relative to the performance of its best parent expressed in percentages while mid-parent heterosis is the performance of a hybrid relative to the average performance of its parents expressed in percentages. In maize, heterosis can be maximized by crossing inbred lines belonging to different heterotic groups (Makumbi, 2005). Many heterotic groups have been developed by maize breeders and inbred lines that are complimentary to other inbred lines can be considered as being in opposite heterotic groups. For example, heterotic group A and B designate broad classes in maize with diverse genetic base that are complimentary and result in expression of heterosis after crossing (Abrha *et al.*, 2013). Crossing maize varieties from these complementary groups will result in expression of heterosis. On the other hand, synthetic varieties are developed from inbred lines belonging to the same heterotic group. It is therefore important to have knowledge of the heterotic groups of inbred lines before they can be used for variety development (Makumbi, 2005; Abrha *et al.*, 2013).

2.7 Classification of inbred lines into heterotic groups

A heterotic group may be defined as a group of related or unrelated genotypes from the same or different populations which display a similar combining ability when crossed with genotypes from other germplasm groups (Acquaah, 2007). Knowledge of the heterotic groups and patterns is important in plant breeding as it helps breeders to utilize germplam in a more efficient and consistent manner through exploitation of complementary lines for maximizing the outcomes of a hybrid breeding program. More concretely, establishment of heterotic patterns among varieties is important for the selection of inbred lines as potential parents in hybrids (Hallauer and Miranda, 1988). Badu-Apraku *et al.* (2013) also highlighted the importance of classifying the parental lines used in a breeding program into heterotic groups as this could help to determine the usefulness of these lines for the development of high yielding hybrids and synthetics.

A number of procedures may be used to establish heterotic groups and patterns. These include pedigree analysis, geographic isolation inference, and measurement of heterosis and combining ability analysis. Many researchers have used diallel analysis to obtain preliminary information on heterotic pattern (Acquaah, 2007). Modern approaches based on biochemical assays or DNA marker data have been very useful to assess genetic diversity and genetic divergence but these approaches are of limited usefulness for predicting good heterotic combinations (Hallauer *et al.*, 2010). To establish heterotic groups and patterns, breeders use an elite inbred as a tester to select new inbred lines developed from crosses of two inbred lines that are complementary to the tester.

Hybrids between the new inbreds and the tester that show superior performance identify the new inbreds that are advanced as hybrid parents. Several methods have been proposed to classify inbred lines into heterotic groups (Vasal *et al.*, 1992; Menkir *et al.*, 2004; Fan *et al.*, 2009; Badu-Apraku *et al.*, 2013).

Heterotic patterns have been studied in various species. For certain crops, breeders have defined standard patterns that can guide the production of hybrids. In tropical regions, some heterotic patterns are the "Eto-composite'' x "Tuxpeno'' and "Suwan I x Tuxpeno" (Acquaah, 2007).

2.8 Genotype x environment (GE) interaction effects and grain yield stability

2.8.1 Genotype x environment (GE) interaction

Genetic x environment interactions (GE) are of major importance in developing improved genotypes. Performance trials have to be conducted in multiple environments because of the presence of this GE; and for the same reason, the analysis of genotype by environment data must start with the examination of the magnitude and nature of GE (Yan and Tinker, 2006).

When genotypes are compared over a series of environments, the relative ranking of these genotypes usually shows differential rankings (Khalil *et al.*, 2011). In other words, the existence of genotype x environment interaction may mean that the best genotype in one environment is not the best in another environment (Falconer and Mackay, 1996). Genotypes x environment interactions are a challenge to plant breeders because they cause difficulties in selecting genotypes to be grown in diverse environment (Khalil *et al.*, 2011).

Because of the high genotype x environment interactions, stress experiments often produce rankings that differ significantly from one environment to another, making it difficult to identify the best germplasm (Bänziger *et al.*, 2000). The existence of GE may indicate that the best genotype under one level of stress caused by low N or other stress factors such as drought is not the best genotype in another level of stress (Falconer, 1981). When G x E interaction effects are non-significant, means of evaluated varieties across environments are adequate indicators of genotypic performance across the environments. In this situation, the varieties are said to be stable across the environments (Miti, 2007). Significant GE indicates that selections from one environment may often perform differently in another and the variety is not stable across the environments (Miti, 2007)**.** Therefore, information on GE may help in determining a breeding strategy. When GE exists, it is necessary to determine whether there are important crossovers, i.e., rank changes of the genotypes in different environments, such that different winners are picked up in different environments (Yan and Tinker, 2006). When there is no change in rank of genotypes over environments, there is non-crossover type of interaction effects, and genotypes with superior means can be recommended for all the environments (Yan and Tinker, 2006).

Breeders can also use information on G x E to choose appropriate locations for selection (Yan and Tinker, 2006). The G x E interaction in multi-location trials makes it difficult to identify superior genotypes for a single location. This is because the magnitude of genotype by location interaction is often greater than genotype by year interaction (Badu-Apraku *et al.*, 2003).

Gallais and Coque, (2005) reported significant genotype x N interaction effects for grain yield. They attributed this to genotype x N interaction effects for kernel number, and concluded that reducing kernel abortion just after fertilization could increase tolerance to low N. Significant genotype x N interaction effects for grain yield indicate that N may influence grain yield achieved by genotypes differentially. Therefore, efficiency of selecting superior genotypes for both high and low N environments is low. Genotype x N interactions have been shown in studies of Bertin and Gallais (2000), Presterl *et al.* (2003) and Gallais and Coque, (2005). These interactions imply that the same genotype will not necessarily be adapted to both high and low

N-input. However the correlation between yield at high and low N-input appeared to be generally high.

Mashark *et al.* (2007) reported that genotypes x environment interaction effects have been widely reported in maize in West and Central Africa. They suggested the use of stability analyses to identify the most high yielding and stable genotype when G x E interaction is present.

2.8.2 Yield stability analysis

Farmers cultivate maize under contrasting environmental conditions and one of the important factors to consider while developing varieties that will have wide adoption is grain yield stability (Miti, 2007). Grain yield stability of a variety can be defined as it's repeatability in performance over various environments. This stability may be static when grain yield of a variety does not change regardless of environmental conditions, or it can be dynamic, when grain yield of a genotype changes in a predictable manner across a wide range of environmental conditions (Tollenaar and Lee, 2002). A stable genotype possesses an unchanged or least changed performance regardless of any variation of the environmental conditions (Rahman *et al.*, 2010).

The success of a variety depends as much on its stable performance over varied environments as on its inherent yield ability. The desirable hybrid is one that would be adapted to a wide range of growing conditions in a given production area, with above average yields and low variances across environments (Kenga, 2001). Farmers need cultivars that are reliable and consistent across a wide array of stress conditions and that have high yield potential that may be expressed when conditions become more favorable (Kenga, 2001). Plant breeder's aim should be to produce adapted cultivars capable of withstanding unpredictable transient environmental variations. In addition, for the developed varieties to be widely accepted throughout the region by farmers, the varieties should show evidence of enhanced stability (Kenga, 2001).

Once G x E interaction is identified as significant, it is important for the breeder to assess the response of varieties to different environments as well as their overall stability. Many stability analysis models are available including joint regression analysis, multivariate analysis including additive main effects and multiplicative interactions (AMMI), genotype plus genotype by environment interactions (GGE), and biplot analysis (Ndhlela, 2012). However the most widely used method by plant breeders are AMMI and GGE biplot analyses (Ndhlela, 2012). Badu-Apraku *et al.* (2012) also indicated that among the several methods available for the analysis and interpretation of multi-environment trials (MET) data, the most powerful statistical tools for the analysis of METs data are the additive main effects and multiplicative interaction (AMMI) model (Gauch, 1988; Zobel *et al.*, 1988; Gauch and Zobel., 1997) and the GGE biplot proposed by Yan *et al.* (2000).

2.8.2.1 Additive main effects and multiplicative interaction

The additive main effects and multiplicative interaction (AMMI) combines analysis of variance and principal components analysis into a unified approach. AMMI is more appropriate in the initial statistical analysis of yield trials because it provides an analytical tool for the diagnosis of other models as sub cases, especially when these are better for particular data sets (Gauch, 1988). Moreover, AMMI clarifies the genotype x environment interaction and gives a summary of patterns and relationships of genotypes and environments (Zobel *et al.*, 1988; Crossa, 1990). AMMI is used to improve the accuracy of yield estimates. Crossa (1990) and Zobel *et al.* (1988) reported that with the improved accuracy of yield estimates, gains that are equivalent to increasing the number of replicates by a factor of two to five have been obtained. Such gains may be used to reduce testing costs by reducing the number of replications, including more treatments in the experiments, or improving efficiency in selecting the best genotypes (Zobel *et al.*, 1988; Crossa, 1990).

Since AMMI model combines the analysis of variance for the genotype and environment main effects with principal components analysis of the genotype environment interaction, it has proven to be useful for understanding complex GEI. Moreover, the results can be graphed in a useful biplot that shows both main and interaction effects for both the genotypes and environments (Alberts, 2004). There are different AMMI graphs but the AMMI1 biplot (Zobel et al., 1988) is the most well known (Yan *et al.*, 2007). On the AMMI1 graph, mean performance and the stability (IPC1) of the genotypes are visualized simultaneously. However, this graph cannot accurately display the performance of a given genotype in a given environment and a different AMMI1 graph (Gauch and Zobel., 1997) is needed for visualizing the which-won-where pattern (Yan *et al.*, 2007). According to the same authors**,** the AMMI1 biplot is less useful to breeders than the GGE biplot because it always explains less G+GE than the GGE biplot and its shape is completely subjective because the axes are in diff erent units (original unit for the abscissa and square root of the original unit for the ordinate).

2.8.2.2 Genotype and genotype by environment interaction biplot analysis

There are two main sources of variation important in cultivar assessment. These include genotypic main effect (G) and genotype by environment interaction effect (G x E). The GGE biplot displays the GGE of multi environmental trial data and is constructed by plotting the first two principal components (PC1 and PC2). These two components are also referred to as primary and secondary effects, respectively. The PC1 and PC2 values are derived from singular value decomposition (SVD) of the environment-centered data. The GGE biplot method is effective for identifying the best performing cultivar in a given environment and the most suitable environment for each cultivar. It compairs any pair of cultivars in individual environments, identifies the best cultivars for each environment and differenciates mega-environments. The GGE biplot method also provides information on the yield and stability of the genotypes, and the discriminating ability and representativeness of the environments (Yan and Tinker, 2006).

Badu-Apraku *et al.* (2012) reported that one of the major advantages of the GGE biplot over the AMMI graph is that of mega-environment identification. Three megaenvironments were identified by the GGE biplot in their study whereas the AMMI graph could not identify any mega-environment. Another advantage of the GGE biplot over the AMMI analysis is that the discriminating power and representativeness view of the former was an effective tool for test-environment evaluation, and facilitated the identification of a minimum set of discriminating and representative core testing sites (Yan *et al.*, 2007). The GGE biplot identified the ideal environment and ranked the environments based on their discriminating power and representativeness. In contrast, the AMMI analysis could not identify an ideal environment or rank the environments.

2.9. Adoption of improved maize varieties

The ultimate objective of every breeder is that varieties developed reach farmers. Many factors affect the farmers' varietal adoption decision among which are socioeconomic and agro-ecological variables, sources of farm information, and farmers' attitude towards the improved maize varieties (Kafle, 2010). Etoundi and Dia (2008) reported that the choice of a variety depends on several criteria which are not only linked to characteristics related to the variety such as cycle, color, taste and yield, but also factors such as production constraints which include low soil fertility, non-availability and high cost of organic and or inorganic fertilizers, inappropriate farming practices, weed pressure, pest damages, and diseases.

Several studies reported that farmers are willing to grow hybrids if the cost of seed and other inputs are affordable and their consumption preferences are considered (Sibiya *et al.*, 2013). The same authors also reported that opportunities exist for improving farmers' local varieties, and maize breeders can take advantage of these preferred traits to incorporate them into existing high yielding varieties.

Farmers' perception of a new technology is important for its adoption; the technology may be appropriate, but subjective perceptions may limit the adoption process (Miti, 2007). This author therefore indicated that it is important to obtain farmers' perceptions on the suitability of any technology being developed in order to strengthen the focus of plant breeding and direct the strategy used to of develop the technology. Thus, effective maize breeding programs should be based on clear identification of farmers' perceived constraints and their preferences for cultivars (Derera, 2005).

From more than 20 maize varieties released in Cameroon only a few are multiplied and used by farmers (Etoundi and Dia, 2008). Consequently most agricultural households usually plant local varieties of maize. The majority of farmers using local varieties are small-scale farmers. In the Humid Forest Zone of Cameroon, farmers grow local maize for their own consumption, but grow improved varieties for commercialization (Etoundi and Dia, 2008).

Sibiya *et al.* (2013) indicated that the use of local maize by farmers for consumption might be due to its superiority in taste, processing and storage. Even though farmers know that there is a yield advantage of growing improved varieties, they are interested in some characteristics in the local maize varieties, and continue to grow them. According to the authors, another reason why farmers usually grow unimproved varieties is that they cannot afford additional inputs such as fertilizers. In addition, the improved varieties developed sometimes lack their specific preferences while local varieties used by small-scale farmers usually reflect their values and preferences. Therefore, breeders need to understand the circumstances of small-scale farmers and their preferences in order to develop appropriate varieties suitable for their environment and meeting their preferences (Miti, 2007). This can be done through information obtained from participatory rural appraisal (PRA).

CHAPTER THREE

3.0 PRODUCTION CONSTRAINTS AND FARMERS' PREFERRED CHARACTERISTICS IN MAIZE VARIETIES IN THE BIMODAL HUMID FOREST ZONE OF CAMEROON AND THE IMPLICATIONS FOR PLANT BREEDING

3.1 Introduction

Despite the increasing demand for grain due to population growth and the diversification of maize uses in West and Central Africa, maize yields have stagnated around 1.5 t ha^{-1} (Kenga *et al.*, 2007; IITA, 2009). The low yield obtained in sub-Saharan Africa is caused, in part, by the low adoption rate of improved varieties by farmers and the poor adaptation of some improved varieties to changing environmental conditions (Nkamleu, 2004; World Bank, 2008).

Improving maize production is one of the most important strategies to meet the growing food demand and improve food security in developing countries (Kafle, 2010).This can be done by increasing maize production per unit of land through the development and diffusion of improved maize cultivars with high yield potential (Kafle, 2010). However, despite the development of improved varieties in most of the sub-Saharan Africa's countries, the majority of smallholder farmers still rely on unimproved open-pollinated varieties (OPVs) for their plantings (Aquino *et al.*, 2001).

The low adoption rate of improved maize varieties may be due to the fact that these varieties are not always available at affordable price to farmers. Moreover, the varieties may not be adapted to particular soil conditions in the farmers' fields. While developing improved varieties, breeders have focused more on increasing yields under optimal agronomical well managed conditions (Reeves and Cassaday, 2002). Most often, farmers do not perceive advantages in growing improved varieties because these varieties do not always meet their needs (Bänziger and Diallo, 2002). This might be because the breeders are often unaware of farmers' needs (Sibiya *et al.*, 2013). Therefore, for effective breeding, farmer's preferences for varieties should be clearly identified through researcher-farmer interaction and collaboration (Sibiya *et al.*, 2013).

The National Research Institute in Cameroon has developed a number of improved maize varieties. These include open pollinated and hybrid varieties. However these improved high yielding varieties are grown by a limited number of farmers. Earlier studies indicated that the rate of utilization and regular renewal of seeds of improved varieties was still slow (less than 55%) in the southern part of Cameroon (Ngo Nonga, 2008a). Etoundi and Dia (2008) also reported low adoption of improved maize varieties in the specific zone of the Bimodal Humid Forest of Cameroon. The low adoption by farmers of improved varieties, especially hybrids, despite their yield advantage compared to the open pollinated and local varieties, could account for the low maize yield in Cameroon (2t.ha^{-1}). Among the major reasons given by the farmers are the high cost of seeds, the high demand for fertilizers by improved varieties and the non-availability or the high cost of these mineral fertilizers (Ngo Nonga, 2008a). Moreover, the maize varieties developed don't always meet farmers' preferences or are not well adapted to their specific environments. Farmers' preferences for maize traits and their perception on soil fertility have not been well documented in the Bimodal Humid Forest Zone. It is therefore important to find out from farmers their constraints and preferences on maize characteristics and select for these traits in the maize breeding program. This strategy could enhance the adoption of improved maize varieties by farmers, especially varieties developed for their specific environments.

The objective of the study was to identify constraints to maize production at the farmer level and assess their preferences for maize varieties which could be incorporated into a varietal development strategy.

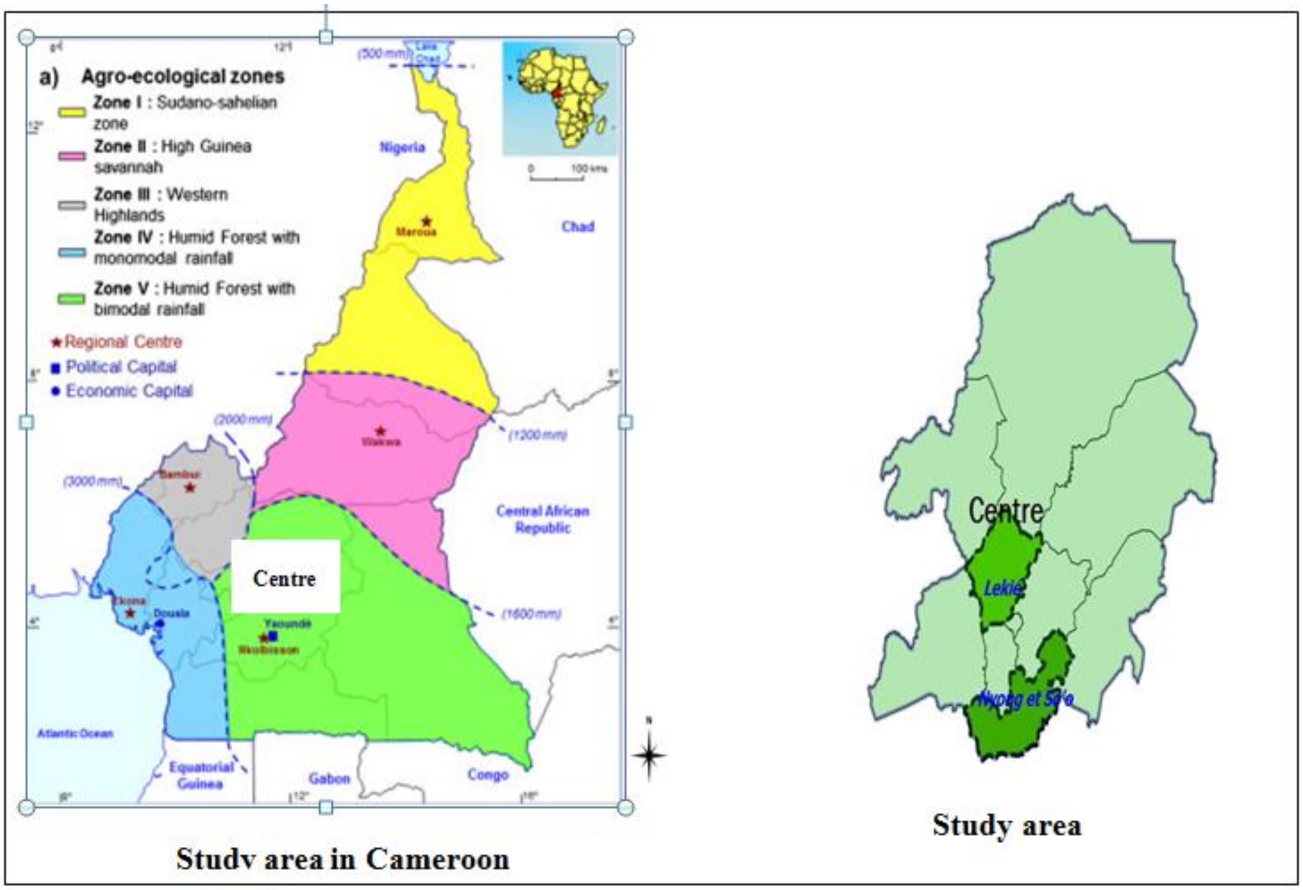
3.2 Materials and methods

3.2.1 Study area

The study was carried out in the Centre Region, in the Bimodal Humid Forest Zone (Fig. 3.1). The Bimodal Humid Forest Zone extend over three regions, the Central, South and Eastern Regions between $2^{o}00$ E and $4^{o}00$ N and $10^{o}31$ E and $16^{o}12$ N (Degrande *et al.*, 2012). The Bimodal Humid Forest zone has mid-altitude plateau 300-600 m above sea level with a Sub-Equatorial Congo-Guinea climate characterized by four seasons: A short rainy season, from March to June; a short dry spell from July to August; a long rainy season, from September to November and a long dry season, from December to February (Degrande *et al.*, 2012). The average rainfall varies between 1500 and 2000 mm over 10 months period and the temperature is rather constant (23^{o} -27^{o}) (Degrande *et al.*, 2012).

From the socio economic point of view, the Bimodal Humid Forest Zone is characterized by low population density apart from areas around Yaoundé and the Lekié Division. Land is mostly inherited and farmers are mainly small scale farmers. Shifting cultivation is the main agricultural practice (Moudingo, 2007; Njessa, 2007; Kemajou, 2008) and the main crops cultivated are banana, plantain, cocoyam, cassava, sweet potato, yam, maize, groundnut, pineapple, cocoa, oil palm, rubber, vegetables and robusta coffee grown in a mixed cropping system. Small scale animal husbandry and aquaculture are the main animal production activities (Degrande *et al.*, 2012).

Six predominantly maize growing villages namely, Zamengoe, Nkong, Nkol-ekié, Zamengoe, Nkolnguet, Abang and Avebe were selected for the study based on their maize output using data from the Ministry of Agriculture and Rural Development. Zamengoe, Nkong and Nkol-ekié are located within the Lekié Division while Nkolnguet, Abang and Avebe are located within the Nyong et So'o Division (Fig.3.1). These six villages are all rural in setting, in close proximity to the city Yaoundé where demand for maize especially fresh maize is increasingly high.



Study area in Cameroon

Study area

Figure 3.1 Location map of the study area

3.2.2 Sampling procedure

In all the six villages selected, the participatory rural appraisal (PRA) was restricted to farmers of over 18 years old since they are the group actively engaged in agriculture. The PRA consisted of Focus Groups Discussions (FGD) and a structured survey.

Selection of farmers for the focus group discussion was done in consultation with a facilitator who was an extension agent with the Ministry of Agriculture in the Division, and a resident of the Division where the survey was conducted. In each village a group of 10 to 12 key informants including farmers and individuals with extensive knowledge of the village, the cropping system and history, the local conditions and problems of the entire zone was formed. The selected farmers consisted of males and females who cultivated many crops including maize and had a reputation for good workmanship. The group included farmers with varying farm land holdings.

In order to obtain detailed information on specific issues during the FGD, a structured survey was carried out in the six villages where FGD were organized. One hundred and forty individual farmers selected from households were interviewed using a structured questionnaire (Appendix 3.1). The number of households randomly selected in relation to population per village is shown in Table 3.1.

Table 3.1 Geographic coordinates of Nyong et So'o and Lekié Division, population of the villages and number of households selected in each village

Division	Latitude and longitude	Village	Population	Number of households Selected
Nyong et So'o	3°51'67" N, 11°50'00"E	Abang	150	10
		Avebe	311	25
		Nkolnguet	850	25
Lekié	4°12'00" N, 11°24'00"E	Nkong	884	15
		Zamengoe	1800	35
		Nkol-ekié	1700	30
TOTAL			**5695**	**140**

Source of population data : Carnet du poste agricole, (MINADER, 2012).

The research team comprised the plant breeder, two agricultural economists and a facilitator, the extension agent from the Ministry of Agriculture and Rural Development.

3.2.3 Data collection

Primary data was collected through a structured survey and participatory methodologies. The check list used in the Focus Group Discussion (FGD) covered broad issues on the cropping environment and general farmer perceptions on released cultivars. The issues covered livelihood and food security strategies, farming system, access to market, cultivar analysis, production constraints and cultivar selection criteria. Debate on issues raised from the check list was organized and the responses collected.

A structured questionnaire was administered to serve as a control to check and compare information obtained during the FGD. It was administered to the farmers by trained enumerators selected from technicians of the Institute of Agricultural Research for Development (IRAD) and personnel of the Ministry of Agriculture and Rural Development in Lekié and Nyong et So'o division.

A modified questionnaire of Miti (2007) targeted at maize farmers was used (appendix 3.1). Specifically, data were collected on: (1) farmer specific characteristics such as age, education, gender, size of family, farming experience on maize cultivation, family labor availability, membership of an association, contact with extension service; (2) farm specific characteristics such as size of the farm, access to credit, distance to input and grain markets; and (3) Variety specific attributes such as cultivar maturity cycle, yield, prolificacy, pest and disease resistance, taste, storage and tolerance to abiotic stresses. The study also investigated small-scale farmer's perceptions on released cultivars with respect to type, suitability, frequency of cultivar release, seed delivery, adaptability to different soils, as well as the plant characteristics preferred by farmers in collecting seed from their local maize to replant.

Secondary data were obtained from the Ministry of Agriculture annual reports and the literature on the physical features, agro ecology and maize production systems of the study area.

3.2.4 Data analysis

Data were analyzed using SPSS (Statistical Package for Social Science) release 15.0. Descriptive statistics, involving the use of means and frequency counts to describe the study variables, were presented using tables and charts. Both a combined analysis and site (village) specific analysis of data were done. Chi-square test of differences between means and proportions was used to compare data between villages. Pair wise correlations were performed between some variables which were related.

3.3 Results

3.3.1 Demographic characteristics of households

The formal surveys revealed that majority (61.2%) of households in the selected villages were headed by male (Table 3.2). Many of the farmers (62.1%) interviewed across the six villages were married and their age was between 45 and 60 years. Some of the household heads had primary (45.0%) and secondary (46.4%) education. Fifty two percent of the household heads had lived in the village for more than ten years practicing small-scale farming. Twenty seven percent of household heads, mainly farmers from the Nyong et So’o division belong to an association. Only 22.9% of the farmers have regular contact with extension service (Table 3.2).

Table 3.2 Demographic characteristics of households (% farmers)

	Nyong et So'o			Lekié				
	Abang	**Avebe**	**Nkolnguet**	**Nkol-ekié**	**Nkong**	**Zamengoe**	**Overall**	**P-Value**
Sex of Hh								
Male	60.0	88.0	80.0	58.6	46.7	37.1	61.2	0.001
Female	40.0	12.0	20.0	41.4	53.3	62.9	38.8	
Age of Hh								
<30 years	0.0	4.0	4.0	10.0	0.0	20.0	8.6	0.104
30-45 years	30.0	44.0	24.0	23.3	60.0	37.1	35.0	
45-60 years	50.0	40.0	64.0	43.3	33.3	34.3	43.6	
> 60 years	20.0	12.0	8.0	23.3	6.7	8.6	12.9	
Marital status								
Single	10.0	12.0	20.0	23.3	26.7	34.3	22.9	0.297
Married	70.0	80.0	76.0	50.0	53.3	51.4	62.1	
Divorced	10.0	0.0	4.0	6.7	0.0	2.9	3.6	
Widow	10.0	8.0	0.0	20.0	20.0	11.4	11.4	
Educational level of Hh								
No formal education	10.0	8.0	0.0	16.7	0.0	5.7	7.1	0.002*
Primary school	60.0	64.0	68.0	20.0	40.0	34.3	45.0	
Secondary school	30.0	20.0	32.0	63.3	60.0	60.0	46.4	
High school	0.0	8.0	0.0	0.0	0.0	0.0	1.4	
Number of years of stay in the village								
< 5 years	10.0	12.0	0.0	16.7	20.0	28.6	15.7	0.006*
5-10 years	30.0	64.0	32.0	30.0	20.0	17.1	32.1	
> 10 years	60.0	24.0	68.0	53.3	60.0	54.3	52.1	
Hh belongs to an association								
Yes	70.0	40.0	52.0	16.7	13.3	5.7	27.9	0.000*
No	30.0	60.0	48.0	83.3	86.7	94.3	72.1	
Hh had regular contact with extension	10.0	20.0	26.7	23.3	12.0	34.3	22.9	

*****denotes that the villages differed significantly at $p \leq 0.05$; Hh = Household head.

3.3.2 Access to resources

Almost all the farmers interviewed (99.3%) had agriculture as their main occupation. The average farm size across the villages varies from 1 to 5 ha. Only 15.8% of farmers had more than 5 ha (Table 3.3). Family labor was adequate for only 20% of the households. The majority of farmers (84.9%) have no difficulties in accessing their farms which are within 5 km from their houses. Only 17.3% of farmers can easily access market for agricultural inputs at a distance within 5 km (Table 3.3).

About 60.6% of farmers interviewed reported that their households were food secure. Farmers cited lack of labor (60.5%), lack of improved seed (40.0%), difficulty in weeding (39.4%), lack of fertilizer (36.3%), high cost of fertilizer (25.2%) and post harvest losses (24.4%) as the main constraints to crop production. Lack of land (54.2%) was only mentioned as constraint in Nkolnguet (Table 3.3). In all, 73.4% had adequate land for farming. In terms of credit accessibility, with the exception of Abang where 20% of the farmers could easily access credit, the other five villages generally had difficulty. No farmer in the Nkong village had used fertilizer in 2012 while between 3.7 and 43.5% of farmers in the other five villages had. Majority of these were mainly farmers of the Nyong et So'o division (Table 3.3). Farmers from the Lekié villages had used pesticides in 2012 and 2013 seasons (46.7% - 66.7%). In the Nyong et So'o division 33.3% to 43.5% of farmers used fertilizers while only 3.7% to 13.3% applied fertilizer in the Lekié division. In all the divisions, the percentage of farmers who used basal fertilizer was higher (10.41%) than those who applied top dressing fertilizer (8.3%). In all the six villages, no farmer had access to tractor (Table 3.3).

Table 3.3 Households access (% farmers) to services in the study area

Characteristics	Nyong et So'o			Lekié			Overall	P-Value
	Abang	Avebe	Nkolnguet	Nkol-ekié	Nkong	Zamengoe		
Main activity of Hh is agriculture	100.0	100.0	96.0	100.0	100.0	100.0	99.3	NA
Family labor is adequate	20.0	8.0	32.0	14.3	42.9	15.2	20.0	0.072*
Farm size < 1 ha	20.0	36.0	0.0	72.4	86.7	80.0	52.5	0.000*
Farm size 1 - 5 ha	60.0	64.0	28.0	20.7	13.3	20.0	31.7	
Farm size > 5 ha	20.0	0.0	72.0	6.9	0.0	0.0	15.8	
Distance from house to farm < 5km	90.0	88.0	52.0	86.2	93.3	100.0	84.9	0.000*
Distance from house to farm 5 - 20 km	10.0	12.0	48.0	10.3	6.7	0.0	14.4	
Distance from house to input source < 5km	0.0	4.0	0.0	6.9	6.7	57.1	17.3	0.000*
Distance from house to input source 5 - 20 km	100.0	96.0	32.0	6.9	93.3	42.9	52.5	
Distance from house to input source 20 - 50km	0.0	0.0	52.0	86.2	0.0	0.0	27.3	
The household is food secure	100.0	100.0	92.0	29.6	33.3	34.3	60.6	0.000
Major production constraints								
Lack of labor	80.0	100.0	12.0	54.5	44.4	73.9	60.5	0.000*
Lack of land	40.0	0.0	88.0	0.0	0.0	20.0	54.2	0.000*
Lack of improved seed	14.3	0.0	84.0	50.0	35.7	28.1	40.0	0.000*
Difficulty in weeding	50.0	100.0	8.0	22.7	0.0	26.7	39.4	0.000*
Lack of fertilizer	37.5	84.0	20.0	9.1	28.6	6.7	36.3	0.000*
High cost of fertilizer	11.1	0.0	68.0	22.2	27.3	14.8	25.2	0.000*
Insects damage (post harvest losses)	28.6	0.0	24.0	19.2	50.0	23.5	24.4	0.000*
Household access to services and inputs								
Household access to credit	20.0	4.0	0.0	0.0	0.0	2.9	2.9	0.027*
Household applied fertilizer in 2012	33.3	43.5	36.0	3.7	0.0	13.3	21.1	0.001*
Use of basal fertilizer (50-100kg ha^{-1}) in 2012	1.38	4.86	2.7	0	0	1.38	10.41	
Use of top dressing fertilizer (50-100kg ha^{-1}) in 2012	0.7	4.86	1.4	0.7	0.0	0.7	8.33	
Household has controlled pest and diseases in 2012	30.0	0.0	20.0	61.5	46.7	66.7	39.6	0.000
Access to tractor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

*denotes that the villages differed significantly at $p \leq 0.05$; Hh = household head

Pair wise correlation between yield and some household characteristics showed a positive correlation (r=0.44*) between high yield obtained and food security of the household (Table 3.4). Food security is defined here as the ability of the household to have enough food from one year to the other. Membership of the household head in an association was also positively correlated (r=0.27*) with food security while in contrast, female leadership was negatively correlated (-0.184*) with the food security of the household (Table 3.4).

Table 3.4 Pair wise correlation of some household characteristics with grain yield in 2012 and food security

	Grain yield in 2012 (t ha^{-1})		Sex of Hh	Age of Hh		Education		Hh belongs to a farmers group
	High (>4)	Low (<1)	Female Hh	<30 yrs	>60 yrs	No formal education	High school	
High grain yield in 2012 (>4 t ha^{-1})								
Low grain yield (<1 t ha^{-1})	-0.717*							
Female Hh	-0.173	0.084						
Age of Hh <30 yrs	0.012	-0.096	0.018					
Age of Hh >60 yrs	-0.156	-0.042	-0.044	-0.118				
No formal education	-0.082	0.127	0.121	0.014	0.225*			
High school	0.130	-0.093	-0.096	-0.037	-0.046	-0.033		
Hh belonging to an association	0.183	-0.132	-0.157	-0.133	0.142	-0.049	0.059	
Household is food secure	0.448*	-0.355*	-0.184*	-0.120	-0.059	-0.118	0.098	0.277*

*denote significant correlation between variables at $P \leq 0.05$; Hh = Household head

3.3.3 General crop production aspects and maize utilization

The livelihood of households in the area was centered on the availability of land for food crop and livestock production, and marketing. Agriculture was the major occupation for almost all the households across the six villages. The agricultural practice in all the villages was mixed cropping and maize was among the dominant crops grown especially in the Lekié Division (Table 3.5). Forty six percent of farmers ranked maize as the dominant crop grown, followed by cassava (33.9%), cocoa (20.8%), plantain (14.4%), groundnuts (6.6%) and cocoyam (1%) (Fig.3.2). Many of the farmers interviewed (53.3%) were small scale maize growers with farm size of less than 1 ha. About 47% of farmers had maize farms between 1 and 5 ha (Table 3.5).

Maize was grown mainly for human consumption in 97.1% of households (Table 3.5). However, some farmers also used maize for animal feed or as source of income by selling the surplus. Maize was an important source of income for an average of 88.6% of the farmers. Majority of farmers (69.5%) planted maize during the two cropping seasons of the year (Table 3.5).

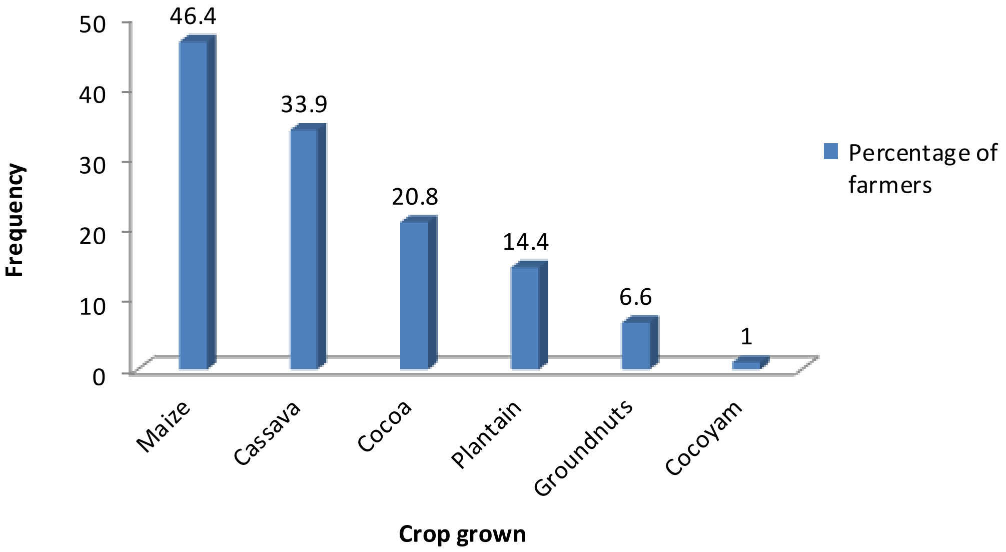


Figure 3.2 Major crops grown by farmers in study area

Maize production was hampered by many constraints among which are: inadequate labor, insufficient land, poor soil fertility, unavailability of improved seeds, difficulty in weeding, high cost and unavailability of fertilizer and post harvest losses as the major constraints in their area (Table 3.5 and Table 3.6).

Time for planting maize by farmers varied and only 36.8% of farmers planted their maize always on time. The main reasons for farmers delaying the planting of maize were the non-availability of seeds and labor.

3.3.4 Management of soil fertility

In general, during the 2012/2013 growing season, use of inorganic fertilizer was very low in the six villages with farmers of Nkong not using any soil amendment at all. Only between 3.3 and 13.3% of the farmers in the other five villages applied inorganic fertilizers. Apart from

Zamengoe where 10% of the farmers used organic fertilizers, the percentage of farmers using the organic amendment was very low, and Nkong, Avebe and Abang did not apply any. Soil fertility in the maize fields was maintained mainly through fallowing (Table 3.6).

During the focus group discussions, the farmers indicated that selection of soils for maize cultivation was done based on fertility. Yellowing of maize leaves was indicative of low soil fertility in addition to small size of stalks and ears, low yields and the lack of lush vegetation in the field. At Nkolnguet farmers used the presence of grasses such as *Imperata cylindrica* as an index of low soil fertility.

Table 3.5 Five major constraints to maize production as ranked by farmers during the focus group discussions.

Constraints	**Nyong et So'o**			**Lekié**		
	Abang	**Avebe**	**Nkolnguet**	**Nkol-ekié**	**Nkong**	**Zamengoe**
Difficulty of weeding		1				
Unavailability of improved seed	1	2		5	2	
Lack or high cost of fertilizer	4	5		5	3	
Insects damage	5		2	3	4	2
Birds and rodents			4	4		4
Low soil fertility	3	4	3	1	1	1
Ignorance of growing techniques	2	3				3
Lack of market for maize		5				
Difficulty of grain conservation			5		5	5
Climate change			1			

1= first major constraint

Table 3.6 Uses of maize, maize production factors and constraints (%farmers)

Characteristics	Nyong et So’o			Lekié			Over all	P-Value
	Abang	Avebe	Nkolnguet	Nkol-ekié	Nkong	Zamengoe		
Maize as major crop grown	0.0	44.0	8.0	46.4	46.7	88.6	46.7	0.000*
Mixed cropping as the household farming system	60	85	60	88	80	100	78.83	
Uses of maize								
Human consumption	90.0	100.0	100.0	97.1	100.0	91.4	100.0	0.119
Source of income	100.0	100.0	96.0	88.6	80.0	71.4	93.3	0.003*
Animal consumption	40.0	8.0	24.0	13.6	13.3	8.6	6.7	0.053
Number of cropping seasons in 2012/2013								
One	30.0	44.0	4.2	28.9	42.9	26.7	32.0	0.041*
Two	70.0	56.0	87.5	69.5	57.1	73.3	68.0	
Area cultivated with maize < 1ha	40.0	40.0	16.0	53.0	64.3	80.6	66.7	0.000*
Area cultivated with maize 1-5ha	60.0	60.0	84.0	47.0	35.7	19.4	33.3	
Major constraints to maize production								
Lack of labor	70.0	100.0	0.0	51.3	25.0	58.3	48.0	0.000*
Lack of land	60.0	0.0	88.0	51.8	0.0	33.3	12.5	0.000*
Low soil fertility	50.0	83.3	32.0	46.9	28.6	18.8	50.0	0.000*
Unavailability of improved seeds	22.2	0.0	88.0	42.9	46.7	31.0	53.8	0.000*
Difficulty in weeding	50.0	100.0	4.0	41.0	16.7	12.5	38.9	0.000*
Unavailability of fertilizers or high cost of fertilizers	20.0	4.5	28.0	30.0	66.7	37.0	41.2	0.000*
Post harvest losses	14.3	0.0	16.0	24.7	18.2	36.4	31.0	0.000*
Planting period								
planting always on time	0.0	0.0	0.0	36.8	57.1	87.9	43.3	0.000*
planting sometimes on time	80.0	84.0	100.0	57.4	35.7	12.1	53.3	
Main reason for planting late								
Seed not available	60.0	68.0	100.0	90.0	93.3	100.0	96.7	0.000*
Lack of labour	60.0	72.0	100.0	89.3	80.0	100.0	96.7	0.000*
Management of soil fertility in maize field								
Use of chemical fertilizers	11.1	10.5	12.0	8.6	0.0	13.3	3.3	0.540
Use of organic fertilizers	0.0	0.0	4.0	3.9	0.0	10.0	3.3	
Fallow	88.9	89.5	84.0	87.5	100.0	76.7	93.3	

*denotes that the villages differed significantly at $p \leq 0.05$.

Pair wise correlation between yield and some production characteristics of households showed a positive correlation (r=0.360*) between high yields obtained in maize fields during the growing seasons 2012/2013 and application of fertilizers (Table 3.7). In contrast, there was a negative correlation (r = -0.677*) between high grain yield and application of low amount of top dressing fertilizer (less than 50 ha^{-1}).The correlation between high yield and the use of improved maize varieties was positive (r=0.58*). The correlation between short distance from house to input source (less than 5 km) and high level of fertilizer (100kg.ha^{-1}) in general was positive (r=0.504*). The short distance from house to input source was also positively correlated (r=0.220*) with the high level of application of organic fertilizer in maize fields, control of pest and diseases (0.199*) and with planting maize on time (r=0.334*).

Table 3.7 Pair wise correlation of some household characteristics with grain yield, use of fertilizer, management of soil fertility and time of planting

	Grain yield t ha^{-1}		Distance to input source	Household applied fertilizer in 2012				In 2012, household had	
	High (>4)	Low (<1)	<5km	chemical fertilizer	Basal >100kg ha^{-1}	Top dressing <50 kg ha^{-1}	Top dressing >100 kg ha^{-1}	controled pest and diseases	used improved varieties
Distance to input source <5km	0.065	-0.175							
Household had applied fertilizer in 2012	0.360*	-0.234*	-0.076						
Basal >100 kg ha^{-1}	0.203	-0.203	0.504*	.-					
Top dressing <50 kg ha^{-1}	-0.677*	0.677*	-0.158	.-	-0.158				
Top dressing >100 kg ha^{-1}	0.233	-0.233	0.316	.-	1	-0.200			
chemical fertilizers	0.192	-0.109	-0.072	0.0504*	0.268	-0.101	0.471		
organic fertilizers	-0.004	-0.034	0.220*	0.057	0.544*	-	-		
Control of pest and diseases	-0.218*	0.199*	0.199*	-0.032	-0.942	0.112	-0.239	1	
Planting of improved varieties	0.582*	-0.584*	0.096	0.346*	0.098	0.108	0.108	-0.262*	
Planting always on time	-0.120	-0.140	0.334*	-0.232*	0.092	-0.108	-0.108	0.318*	-0.057

*denote significant correlation between variables at $P \leq 0.05$.

3.3.5 Types of maize varieties grown and sources of seeds.

All the respondents were well informed of the existence of improved maize varieties and the majority (65%) of them usually plants these varieties (Fig.3.3) while twenty four percent of farmers planted unimproved maize varieties.

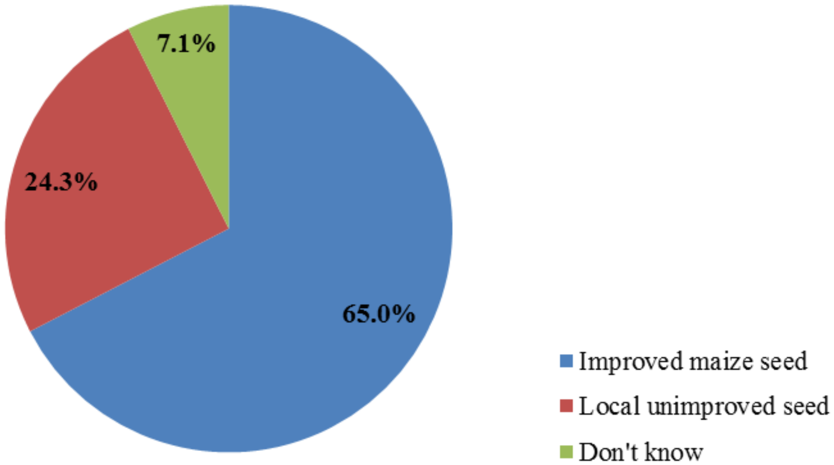


Figure 3.3 Percentage of farmers growing different types of maize varieties

Among the improved varieties grown by the farmers interviewed, the most used were open pollinated varieties (Table 3.8). Most of the respondents, particularly those in the Nyong et So’o Division used CMS8704 as their planting material. Only 14.6% of farmers used seeds of hybrids such as CLH103, CHH101 and CHH300. These farmers were found only in the Lekié Division.

Among the respondents who usually plant improved maize varieties, 27.4% usually buy seeds from input shops and 22.2% of farmers, mostly from Nkolnguet, in the Nyong et So’o division had taken the seeds from seeds of improved varieties they have harvested the previous season (Table 3.8). Only 12.6% of the farmers had ever received seeds from the Government or NGOs and these were farmers from Avebe in the Nyong et So’o Division.

All the farmers in Avebe mentioned the long distance to seed source as a reason for not using improved varieties whereas at Nkol-ekié and Zamengoe, distance to seed source was as a problem for only 45 to 50% of the farmers interviewed (Table 3.8). At Abang, Nkolnguet and Nkong, distance was not a reason for not using improved varieties. Apart from farmers at Nkolnguet, all the other farmers complained of the absence of seed sources in their locality. Many farmers complained about the high cost of seeds of improved varieties and these were mainly farmers from Abang Avebe and Nkolnguet villages all in the Nyong et So'o division (Table 3.8).

All the farmers in Nkol-ekié and in Nkong, in the Lekié Division regarded the cultural practices associated with the use of improved varieties as impediments to adoption. Although 50% of farmers in the Zamengoe and Nkol-ekié villages did not see non-availability of fertilizer as a factor militating against the use of improved varieties, their counterparts in the Nkong village within the same division considered it as an impediment to the use of improved varieties. They thought that improved varieties are more demanding in their fertilizer requirements than the local ones. Non-availability of fertilizer was a factor related to the inability to use improved varieties for less than 50% of farmers in the Nyong et So'o division.

Table 3.8 Maize varieties grown by farmers, sources of seeds and major problems encountered when using improved varieties (% farmers)

Characteristics	Nyong et So'o			Lekié			Overall	P-Value
	Abang	Avebe	Nkolnguet	Nkol-ekié	Nkong	Zamengoe		
Improved varieties usually grown by farmers								
CMS 8704 (OPV)	100.0	100.0	95.8	8.3	66.7	28.0	67.7	0.000*
CMS 8501(OPV)	0.0	84.0	0.0	0.0	0.0	24.0	28.1	0.000*
CLH103 (Hybrid)	0.0	0.0	0.0	16.7	0.0	8.0	4.2	0.147
CHH101(Hybrid)	0.0	0.0	0.0	8.3	33.3	20.0	7.3	0.020*
CHC202 (OPV)	0.0	0.0	0.0	8.3	0.0	12.0	4.2	0.226
CHH300 (Hybrid)	0.0	0.0	0.0	0.0	33.3	8.0	3.1	0.022*
Source of maize seed in 2012/2013								
Own saved improved seed	40.0	8.3	60.0	13.3	20.0	6.5	22.2	0.000*
Own saved local seed	30.0	12.5	4.0	26.7	33.3	9.7	17.0	
Bought local seed	0.0	4.2	0.0	16.7	20.0	9.7	8.9	
Bought improved seeds	30.0	12.5	8.0	33.3	6.7	58.1	27.4	
Improved seeds provided by relatives or friends	0.0	0.0	28.0	10.0	20.0	9.7	11.9	
Relief seed provided by government or NGOs	0.0	62.5	0.0	0.0	0.0	6.5	12.6	
Most critical problems encountered with improved varieties								
Long distance to seed source	0.0	100.0	0.0	50.0	0.0	45.5	26.7	0.000*
Absence of seed source	33.3	66.7	0.0	64.3	50.0	33.3	31.0	0.008*
High cost of seeds	77.8	79.2	54.2	13.3	33.3	21.1	48.5	0.000*
Difficult cultural practices associated with improved varieties	16.7	60.0	16.7	100.0	100.0	33.3	27.9	0.523
on availability of fertilizers	37.5	47.1	8.3	50.0	0.0	50.0	31.3	0.005*
High cost of fertilizers	62.5	29.2	33.3	28.6	66.7	44.4	37.3	0.162
Diseases	0.0	0.0	4.2	0.0	100.0	43.8	18.5	0.000*
Post-harvest losses	80.0	0.0	50.0	0.0	0.0	0.0	42.9	0.042*

*denotes that the villages differed significantly at $p \leq 0.05$ (based on Chi square).OPV= Open pollinated variety

3.3.6 Impression of households on improved maize distributed in the area

Majority of farmers were of the view that much work had not been done on the distribution of improved varieties and timely supply of seeds to farmers (Table 3.9). Only 20% of farmers in Abang and Zamengoe were of the view that the seeds were compatible to their needs and within their means.

Generally, in Abang and Avebe in the Nyong et So'o Division, the improved varieties were not adapted to the soils of the region. Between 35% to 60% of farmers interviewed in the the Lekié Division and in Nkolnguet, in the Nyong et So'o responded that the improved varieties were adapted to their soils (Table 3.9). A lower percentage of the farmers interviewed (20%-33.3%) were of the view that the improved varieties were adapted to the environment.

With their specific experience in growing improved maize varieties during the growing seasons of the year 2012, 52.8% of the farmers, mostly from villages of the Nyong et So'o division, felt that the improved maize varieties they grew produced acceptable yields. For 21.7% of farmers, the improved varieties were highly tolerant to low soil fertility while 27.1% of farmers found them tolerant to water stress. However, 37.9% of farmers reported high levels of attack by pests and 40.7% reported high levels of infection by diseases (Table 3.9). Majority of farmers (96.6%) were interested in growing improved maize varieties.

Table 3.9 Best maize varieties grown by farmers in 2012-2013 and farmers' opinion of improved maize varieties distributed in the study area (% farmers)

	Nyong et So'o			Lekié				
	Abang	**Avebe**	**Nkolnguet**	**Nkol-ekié**	**Nkong**	**Zamengoe**	**Overall**	**P-Value**
Best maize varieties grown (2012-2013)								
CMS 8704 (OPV)	100.0	100.0	100.0	49.1	0.0	3.7	5.0	0.000*
Local Maize (OPV)	0.0	0.0	0.0	28.9	84.6	18.5	85.0	
CHH101(Hybrid)	0.0	0.0	0.0	9.6	0.0	40.7	0.0	
CMS 8501 (OPV)	0.0	0.0	0.0	1.8	0.0	7.4	0.0	
CLH103 (Hybrid)	0.0	0.0	0.0	1.8	0.0	0.0	10.0	
CHC202 (OPV)	0.0	0.0	0.0	0.9	0.0	3.7	0.0	
Opinions of households on improved maize distributed in the area								
Good compatibility with farmers needs	20.0	0.0	4.2	10.2	0.0	20.0	5.0	0.288
Availability of desired varieties on time	0.0	0.0	0.0	2.3	0.0	3.7	5.0	0.525
Good provision of improved maize seed in the area	0.0	0.0	0.0	1.1	0.0	3.3	0.0	0.022*
Adaptability of improved varieties to soil of the area	0.0	4.8	41.7	33.0	60.0	41.4	35.0	0.016*
Adaptability to climatic conditions of the area	20.0	0.0	37.5	25.7	33.3	20.0	45.0	0.016*
Performance of improved maize variety with experience in maize production in 2012-2013)								
High level of yield	100.0	100.0	0.0	52.8	6.7	64.7	16.7	0.000*
High level of crop attack by pests	11.1	0.0	12.0	37.9	85.7	44.1	63.3	0.000*
High level of crop infection by diseases	0.0	0.0	4.0	40.7	57.1	44.1	66.7	0.000*
High level of tolerance to low soil fertility	0.0	0.0	4.0	21.7	50.0	14.7	56.7	0.000*
High level of tolerance to water stress	20.0	0.0	24.0	27.1	57.1	9.1	36.7	0.031*
Farmers interested in growing improved varieties	80	100	100	100	100	100	96.6	

*denotes that the villages differed significantly at $p \leq 0.05$ (based on Chi square).OPV= Open pollinated variety

3.3.8 Reasons for adoption of local varieties

About 58% of the farmers interviewed did not use seeds of improved maize varieties during the growing seasons of 2012/2013 because of the non-availability of seed at the time of sowing (Fig. 3.4). Farmers preferred using local seeds due to a number of reasons which include cheaper cost, ability to be recycled and the fact that local varieties are more suitable for processing and preparing local delicacies. The demand for improved varieties for preparation of food is low making marketing of the produce within the villages difficult.

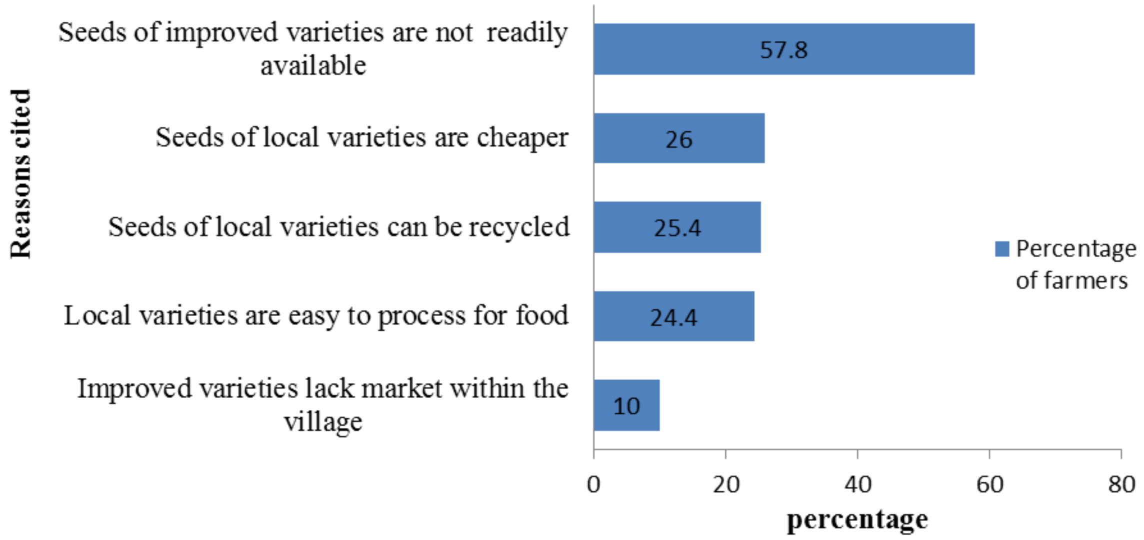


Figure 3.4 Reasons cited by farmers for growing local maize cultivars

3.3.9 Selection of maize varieties by farmers

About 66.7% of farmers who used saved seeds selected seeds for the next planting at harvest. However the selection criteria are diverse and in some cases varied among the villages. The main selection criterion used in Avebe, Nkol-ekié and Nkong was good plant aspect whereas in Abang it was both good plant aspect and large ear size and in Nkolnguet large ear size was the criterion (Table 3.10). In addition to the main criterion, farmers at Avebe considered pest and disease resistance. At Nkong the next most important criteria used are pest and disease resistance and plant height and to a lesser extent, large grain size. Farmers in Nkolnguet also considered prolificacy and large grain size in selecting varieties for the ensuing season's planting. The second most important criterion used at Nkol-ekié is plant height. In Zamengoe farmers used only resistance to lodging and early maturity as the criteria in their selection of maize varieties (Table 3.10).

Table 3.10 Time of selection of local maize seeds by farmers and selection criteria (% farmers)

	Nyong et So'o			Lekié			Overall	P-Value
	Abang	Avebe	Nkolnguet	Nkol-ekié	Nkong	Zamengoe		
Time of local seed selection								
At harvest	100.0	100.0	91.7	16.7	46.7	50.0	66.7	0.000*
At bagging	0.0	0.0	0.0	37.5	33.3	16.7	14.8	
At sowing	0.0	0.0	0.0	12.5	6.7	0.0	3.7	
No special selection	0.0	0.0	8.3	33.3	13.3	33.3	14.8	
Most important criteria used to select local variety								
Good plant aspect	71.4	100.0	27.8	84.6	100.0	0.0	75.4	0.000*
Large ear size	80.0	0.0	65.0	0.0	0.0	0.0	25.8	0.000*
Prolificacy (more ears/plant)	33.3	0.0	0.0	0.0	0.0	0.0	8.3	0.195
Grain texture (soft endosperm)	0.0	0.0	0.0	16.7	0.0	0.0	6.7	0.448
Second most important criteria used to select local variety								
Disease/pest resistance	66.7	100.0	0.0	0.0	100.0	0.0	93.3	0.050
Plant height	0.0	0.0	0.0	0.0	100.0	75.0	66.7	0.060
Prolificacy (more ears/plant)	33.3	0.0	100.0	0.0	0.0	33.3	66.7	0.050*
Large grain size	100.0	0.0	100.0	0.0	66.7	28.6	42.9	0.014*
Resistance to lodging	0.0	0.0	0.0	50.0	33.3	0.0	40.0	0.709
Early maturity	0.0	0.0	0.0	50.0	0.0	0.0	28.6	0.350

***** Denotes that villages are significantly different at 5%

3.4. Discussion

Almost all the farmers interviewed had farming as their main occupation and the majority was small scale farmers. The livelihood of households in the study area was focused on food crops, animal production and marketing. Crop production was the first option for the majority of farmers. The predominant cropping system was mixed cropping with maize as the dominant crop. Mixed cropping as a major cropping system of the southern part of Cameroon has been reported earlier by Ngo Nonga (2008a). Most farmers have difficulties in accessing production factors such as labor, fertilizers, seeds and credits. This might be due to the fact that majority of farmers do not belong to an Association. The low percentage of household heads belonging to an association was earlier reported by Mala (2009) who indicated that only 38.7% of farmers belonged to farmer Associations in Mbalmayo, in the Nyong et So'o division. Ngo Nonga (2008a) also reported less than 7% of farmers producing maize as belonging to farmer Associations in the southern part of Cameroon.

The higher percentage of farmers having access to credit was found in Abang in the Nyong et So'o division, this was related to their membership of farmers Associations since most of the funding organizations prefer to fund farmer groups rather than individuals.

The low percentage of farmers belonging to farmer Associations could also explain the non-regular contact with extension services. This is because extension staffs usually prefer working with group of farmers rather than with individual farmers. Farmers who were not members of any Association were either not informed of their existence or were not satisfied with the organization and management of such groups. This was similar to the findings of Ngo Nonga (2008b).

Despite these difficulties in accessing credit, many households, especially of the Nyong et So'o division were food secure. In the Lekié division, food security was not assured and this could be due to smaller farm size (less than 1 ha). Food security was positively correlated with high yields of maize (r =0.448*) indicating that farmers who obtained high yields in their maize fields may be able to feed their family throughout the year. This is due to the fact that products from agriculture provided for both domestic consumption and income generation. Incomes from farm products help to buy what is not produced by the household. Food security could also be due to the presence of two cropping seasons per year. Most farmers produced maize during these two seasons and this is made possible by the rainfall pattern of the area as indicated by Etoundi and Dia (2008). All the six villages had no access to tractor and this probably limited the land area cultivated by individual farmers.

The major constraints faced by farmers in maize production included lack of labor, low soil fertility, unavailability and high cost of seeds of improved varieties, difficulty in weeding, high cost and unavailability of fertilizer, and post-harvest losses. These constraints have earlier been reported in the humid forest zone of Cameroon (Ngoko *et al.*, 2002; Nguimgo *et al.*, 2003).

In the present study, there was a positive correlation (r=0.36*) between high yields obtained in maize fields during the growing seasons of 2012/2013 and fertilizer application. Only few farmers were able to apply fertilizers in their maize field, either chemical or organic. Most farmers who used fertilizers applied more of the basal fertilizer compared to top dressing fertilizer, usually at a lower rate than recommended. This may explain the negative correlation between high yield and application of low level (less than 50 kg ha^{-1}) of top dressing fertilizer. The very low use of fertilizers was mainly due to the high cost of fertilizers. Unlike in the past years when the government provided subsidies on farm inputs, the situation has changed and farmers must bear all the production costs. Moreover, farmers do not have access to credit to allow them to buy the necessary inputs.

Short distance from house to input source was positively correlated with high level of application of fertilizers, use of seeds of improved varieties, control of pest and diseases and planting on time. This means that the greater the distance to agrishops or markets where farmers acquire inputs, the more difficult it is to have inputs available in the farm on time. This may be attributed to the difficulty in transportation as a result of bad roads and high transport fares. The distance from house to input source also impacted on fertilizer availability and consequently its application by smallholder farmers. Access to input markets was one of the major problems, especially in Nkol-ekie which is very far from the main road and difficult to access due to poor road condition during certain periods of the year. These results could explain the positive correlation obtained between short distance from home (less than 5km) to the input source and the first application of fertilizer by households. There was a positive correlation (r=0.58*) between high yield and the use of improved maize varieties, because the most important trait targeted by breeders while developing these varieties is yield.

The method used by farmers to manage soil fertility in maize fields was mostly bush fallow. This result is similar to the report of (Ngo Nonga, 2008a). Fallow is frequent in the forest zone where there is enough land. In spite of alternatives such as rotation or mixed cropping with legume crops to improve soil fertility in the Bimodal Humid Forest of Cameroon (Nguimgo *et al.*, 2003; The *et al.*, 2012), farmers are not using them probably because these techniques have not been sufficiently disseminated.

The majority of farmers in the Lekié and Nyong et So'o divisions planted improved maize varieties. This is probably due to the earlier work by the extension services and other projects executed by the national research institute or the Ministry of Agriculture in the Bimodal Humid Forest Zone. Among the improved varieties grown by the farmers, CMS 8704 was the most popular. The preference of CMS 8704 to local varieties by farmers of the humid forest zone of central Cameroon was earlier reported by Aroga *et al.* (2001). CMS 8704 is an open pollinated variety developed by the national research institute. According to farmers, the yellow maize is the most suitable for commercialization and poultry feed. The high adoption of this variety could be due to its yellow color. Farmers who planted improved varieties were satisfied with high yields and many other characteristics compared to local varieties. However others complained about the high cost of seeds of these varieties and indicated that improved varieties are not compatible with their means and needs. This explains why they preferred to grow local varieties. The most critical problems encountered when using improved maize varieties are the high cost of seeds or the long distance to /or the absence of seed sources, the inability of some farmers to apply the recommended agronomic practices such as appropriate planting date and time of fertilization, or dose of fertilizer. All these could justify the positive correlation between the short distance from house to input source with use of seeds of improved varieties and planting on time. In addition, some farmers indicated that improved varieties cannot be recycled. More over, farmers pointed out that improved varieties are not suitable for processing and cooking some of their their local meals because of the flinty texture of the grains. All these factors associated with the use of improved maize varieties were impediments to the adoption of improved varieties.

Few farmers planted hybrids. These were farmers of the Lekié Division where a project funded by the West and Central African Council for Agricultural Research and Development

(CORAF/WECARD) was carried out by the national research institute on on-farm evaluation of maize varieties (both OPVs and Hybrids) developed by IRAD. Other farmers were not aware of the existence of hybrids or did not know the difference between these hybrids and open pollinated varieties (OPV). Farmers who had experience in using hybrids preferred them because of their higher yields compared to the OPVs and are willing to grow hybrids if the seeds are available and affordable and possess the desired characteristics. Farmers cited good plant aspect, large grain size, soft grain texture, large ear size, high prolificacy, early maturity, short plant height, resistance to lodging, resistance to pests and diseases, and reduced post-harvest losses as their preferred characteristics in maize varieties. Therefore, Farmers selected seeds for their subsequent planting based on these preferred plant, grain and ear characteristics. The selection done by farmers is not always effective because some of these characteristics are not highly heritable and therefore not always reflected in their harvest the following season. Moreover, other characteristics might be negatively correlated to desired traits. An example is the case of long cob size which is positively correlated to plant height. Therefore in selecting for long ears, farmers obtain very tall plants which are susceptible to lodging. That is why, in most fields where farmers use their own saved seeds, maize plants are very tall. Another example is the correlation between the soft grain texture and good storability. Moreover, in maintaining their varieties, farmers don’t always follow the appropriate requirements in terms of isolation distance from other maize fields. Consequently, farmers harvest a mixture of many varieties and this prevents them from obtaining the desired characteristics. It is therefore appropriate for breeders to work with farmers in the process of varietal development as suggested by Sperling *et al.* (2001). This would allow breeders to identify farmer’s preferences in order to incorporate them into the improved varieties developed for their specific area. Sibiya *et al.* (2013) also suggested that breeding opportunities exist for improving farmers' local varieties, and maize breeders can take advantage of the preferred traits to incorporate them into existing high yielding varieties. These may lead to an increased and more stable productivity and a faster release and adoption of varieties (Sperling *et al.*, 2001).

3.5 Conclusions

This study examined farmers' perceptions on maize cultivars, production constraints and preferences for cultivars adapted to the Bimodal Humid Forest Zone of Cameroon and their implication for breeding. The results showed that maize is one of the most important staple crops grown in the bimodal humid Forest Zone of Cameroon. It is grown mostly by small scale farmers who have difficulties in accessing agricultural inputs. Maize production constraints included lack of labor, low soil fertility, unavailability and high cost of seeds of improved varieties, difficulty in weeding, high cost and unavailability of fertilizer, and post-harvest losses. Low soil fertility and high cost of fertilizers were among the most important constraints cited by farmers. Nitrogen is one of the critical elements for maize growth, and farmers of the study area were not able to apply the necessary amount of fertilizer in their maize fields, especially the top dressing nitrogen fertilizer. It is therefore important for breeders to develop maize varieties better adapted to poor soils of the study area, especially maize varieties capable of producing acceptable yield under low N conditions. The use of such varieties by farmers would increase maize yields in their fields, reduce the cost of maize production and encourage farmers to increase cultivated land area. These would lead to an increase of maize production of the Bimodal Humid Forest Zone.

Many farmers of the study area planted improved maize varieties including hybrids and were satisfied with the high yields and other characteristics compared to local varieties. This suggests that more farmers should be encouraged to grow improved maize varieties, especially hybrids which will give better yields than open pollinated varieties.

Farmers listed large grain size, soft grain texture, large ear size, high prolificacy, early maturity, short plant height, resistance to lodging, resistance to pests and reduced post-harvest losses as their preferred characteristics in maize varieties. These traits should be taken into account while developing maize varieties for farmers in this area.

Due to the interest of some farmers in maize hybrids, high yielding maize hybrids adapted to low N should be developed and promoted. The use of such varieties by farmers would lead to an increase of yield per unit land area and therefore maize production of the area. The hybrids should possess farmers preferred traits for improved adoption.

Even though farmers are encouraged to grow improved maize varieties which are higher yielding than the local varieties, the local germplasm should be maintained in order to preserve the genetic diversity since some local varieties possess some inherent ability to tolerate stresses and are better adapted to the area.

CHAPTER FOUR

4.0 HYBRID PERFORMANCE, COMBINING ABILITY AND HETEROTIC GROUPING OF MAIZE INBRED LINES UNDER LOW AND OPTIMUM SOIL NITROGEN CONDITIONS

4.1 Introduction

Maize (*Zea mays* L.) is one of the most important and widely grown cereal crops in West and Central Africa. However, its grain yield is low, especially under small-scale farmers' conditions where many stresses are present. In Cameroon, despite the increase in maize production from 966,000 tonnes in 2004 to 1,647,036 tonnes in 2013 (FAOSTAT, 2014), there is a deficit between domestic demand and supply. Failure of the national production to meet the needs of Cameroonian households may be attributed to the effects of various biotic and abiotic constraints including low soil fertility, soil acidity, poor crop management practices, low adoption of improved varieties, and pest and disease damages (Ngoko *et al.*, 2002; Nguimgo *et al.*, 2003; The *et al.*, 2013).

Low soil fertility, particularly soil nitrogen deficiency, is a serious concern of maize farmers in Cameroon (Hauser and Nolte, 2002; Ngoko *et al.*, 2002; Nguimgo *et al.*, 2003; The *et al.*, 2013). The problem is worsened by the lack of availability and/or high prices of mineral fertilizers in the country. In addition to these, continuous cropping over decades with no measures in place to regenerate the soil productivity has contributed to decreased soil fertility and consequently, the low level of maize production in Cameroon. New maize varieties with high nitrogen uptake efficiency and low soil nitrogen requirements are therefore needed in the country.

An appropriate strategy to develop low N tolerant hybrids requires (i) an understanding of maize crop's behavior under low N stress, (ii) the development and/or the introduction of maize inbreds that carry low N tolerance genes, (iii) the use of appropriate N stress management and secondary traits that have high heritability and are strongly correlated to yield under N stress, and (iv) the use of improved statistical designs to ensure good selection progress (Bänziger *et al.*, 2004). Hybrid evaluation in multi-location trials in representative samples of the target environments is also required (Beck *et al.*, 1996) as well as information about heritability, genetic and environmental variances, and mode of gene action controlling low N tolerance in maize in order to advance progress in selection.

Most maize varieties released in Cameroon are open pollinated (OPVs) with grain yield ranging from 2 to 4 t ha $^{-1}$, far below the yield potential of hybrids that can go up to 10 t ha $^{-1}$. Available hybrids are not widely grown by farmers (Ngo Nonga *et al.*, 2008a). The development of maize hybrids with high yield potential is therefore necessary to boost the national maize production from its current level. The new hybrids should combine acceptable grain yield levels and good adaptation to the various factors militating against increased maize production in Cameroon

For a successful maize hybrid program, there is a need for knowledge on combining abilities and heterotic groups and patterns of available inbreds (Abrha *et al.*, 2013). The Cameroonian National Maize Breeding Program, in collaboration with the International Institute of Tropical Agriculture (IITA), has developed maize inbred lines adapted to the different agro-ecological zones of Cameroon and to different stresses such as acid soils, drought and Striga except low soil nitrogen for which very little work has been done. The program has introduced other inbreds from IITA, CIMMYT and some African breeding programs. Therefore, there is need to examine the combining ability and heterosis for grain yield and agronomic traits of the available inbreds under low soil nitrogen and optimal growing conditions.

The objectives of the present study were to (i) identify high yielding maize hybrids under low N and optimal growing conditions, (ii) determine the combining abilities and gene action controlling low N tolerance in intermediate maturing maize inbred lines and (iii) classify the lines into heterotic groups.

4.2 Materials and methods

4.2.1 Germplasm

Forty two intermediate to late maturing inbred lines (39 lines and 3 testers) were used in the study. These included inbred lines from IRAD Cameroon, IITA, CIMMYT and lines from other African maize breeding programs (Table 4.1). Of the 39 inbred lines, six were tolerant to low N, four to drought, five to acid soils and four to aluminium toxicity.

The thirty nine inbred lines were crossed to three testers (87036, Exp1 24 and 9071), in a line by tester scheme to obtain 117 hybrids. In addition to the 117 hybrids, 3 hybrids (87036 x Exp1 24, 9071 x Exp_1 24, 87036 x 9071) from crosses among the 3 testers and hybrid 88069 x Cam inb $\text{gp}_1$17 were included as checks resulting in a total of 121 entries. The entry 87036 x Exp1 24 is a high yielding hybrid released in Cameroon and adapted to the Humid Forest Zone. This hybrid was obtained from a cross between tropical lowland and mid-altitude inbred. Exp_1 24 x 9071 is also a high yielding hybrid, derived from a cross of a tropical lowland x temperate converted inbred.

Table 4.1 Origin, grain color and main characteristics of maize inbred lines, testers and hybrid checks used in the study

No	Lines	Origin	Color	Main characteristics
1	Cla 17	CIMMYT	Y	Tolerant to acid soils. Heterotic to Cla 18
2	9450	IITA	Y	Converted from B73 and tolerant to low N
3	1368	IITA	W	Extracted from pop 21
4	M 131	IRAD	W	Mid altitude adaptation and tolerant to low N.
5	88094	IRAD	W	Mid altitude adaptation and tolerant to low N.
6	J18-1	WACCI	W	Tolerant to drought
7	88069	IRAD	Y	Mid altitude converted to lowland adaptation.
8	Entrada 29	CIMMYT	W	Tolerant to Aluminium.
9	CML 358	CIMMYT	Y	Tolerant to Aluminium.
10	Entrada 3	CIMMYT	W	Tolerant to Aluminium.
11	CML 254	CIMMYT	W	Tolerant to Aluminium.
12	5012	IITA	W	Temperate converted to tropical adaptation.
13	Cam inb gp1 17	IRAD	Y	Tolerant to acid soil
14	9848	IITA	Y	Temperate converted to tropical adaptation.
15	CLA 18	CIMMYT	Y	Tolerant to Al acid soil.
16	ATP S9 30 Y-1	IRAD	Y	Extracted from acid tolerant maize population.
17	ATP S5 26 Y-1	IRAD	Y	Extracted from acid tolerant maize population.
18	KU1414	IITA	Y	Tolerant to low N
19	5057	IITA	W	Temperate line converted: Susceptible to drought, striga.
20	ATP S6 20 Y-1	IRAD	Y	Extracted from acid tolerant maize population.
21	ATP S8 30 Y-3	IRAD	Y	Extracted from acid tolerant maize population.
22	TZMI 102	IITA	W	
23	J16-1	CIMMYT	W	Tolerant to drought
24	CLYN246	CIMMYT	Y	Tolerant to low N
25	CML395	CIMMYT	W	Susceptible to low N
26	CML494	CIMMYT	W	Susceptible to low N
27	CML165	CIMMYT	Y	Susceptible to low N
28	CLQRCWQ26	CIMMYT	W	Susceptible to low N
29	CML451	CIMMYT	W	Susceptible to low N
30	V-351-1/6	CIMMYT	W	Drought tolerant
31	V-481-73	CIMMYT	W	Drought tolerant
32	TZ-STR-133	IITA	W	
33	TL-11-A-1642-5	CIMMYT	W	
34	Ku 1409	IITA	Y	Tolerant to low N and downy mildiew. From Swan pop
35	ATP S6-20-Y-1	IRAD	Y	Extracted from acid tolerant maize population.
36	CLWN201	CIMMYT	W	Tolerant to low N

W = white
Y = yellow

Table 4.1 Origin, grain color and main characteristics of maize inbred lines, testers and hybrid checks used in the study (cont'd)

No	Lines	Origin	Color	Main characteristics
37	CML444	CIMMYT	W	Tolerant to low N
38	CML343	CIMMYT		Tolerant to low N
39	4001STR	IITA	Y	Tolerant to low N, extracted from population 28
	Testers			
40	87036	IRAD	W	Mid altitude line converted to low-land
41	Exp1 24	IRAD	W	Tuxpeno background. Good combiner.
42	9071	IITA	W	Converted from N28 and good combiner
	Hybrid checks			
1	87036 x Exp1 24		W	
2	Exp1 24 x 9071		W	
3	87036 x 9071		W	
	Line checks			
1	9001	IITA	W	Tolerant to low N
2	CML264	CIMMYT	W	Tolerant to low N
3	TZSTR 132	IITA	W	
4	C316-10		W	
5	C316-7		W	
6	V481-73/2	WACCI	W	
7	K9351-10-3		Y	Tolerant to Striga

W = white
Y = yellow

4.2.2 Experimental sites

The study was conducted in two locations of the Humid Forest Zone with bimodal rainfall namely Nkolbisson and Mbalmayo. Nkolbisson is located at 11°36 East and 3° 44 North, 5 km from the main capital city 'Yaoundé'. The altitude is 650 m above sea level. The annual rainfall is 1560 mm with bimodal distribution. The average daily temperature is 23.5°C. The soil is sandy clay. The main cropping system is maize/groundnut/cassava in sole cropping or mix cropping (The *et al.*, 2013).

Mbalmayo is located at 11°30' East and 3°31' North, 45 km from Yaoundé. The altitude is 641 m above sea level. The mean annual rainfall varies from 1017 to 1990 mm with bimodal distribution. The mean monthly temperature varies from 22°C to 25°C. The soil is sandy clay. The agricultural practice is based on shifting cultivation techniques. The main crops are cassava and cocoyam grown as sole crops or in association with groundnut or maize. Other cultivated crops include banana, melon, plantain and vegetables (Tchienkoua, 1996).

4.2.3 Site preparation and soil analysis

In Mbalmayo and Nkolbisson, low N plots were established by soil depletion of available nitrogen. This was achieved by planting maize uniformly in the field at a very high density without any fertilizer application. At maturity, all plants were harvested and the stover removed from the field to prevent the organic matter from decaying to release N to the soil as suggested by Bänziger *et al.* (2000).This activity was repeated at Mbalmayo for three growing seasons from 2010 to 2011 and at Nkolbisson for six growing seasons from 2008 to 2012.

In order to assess the level of soil nitrogen in each experimental site, composite soil samples were collected from the two locations before each cropping season. The soil samples were analyzed for selected chemical properties at the soil laboratory of IITA Cameroon. The soil total nitrogen content at Mbalmayo was 0.07% and 0.13% for the 10 cm and 20 cm depth (Table 4.2). These values were within the range of 0.05 to 0.15% which is considered as low (Bruce and Rayment, 1982). The N values in both sites in 2013 ranged from 0.06 to 0.15% which were also low (Table 4.2). The Carbon nitrogen ratio (C/N) at Mbalmayo was lower (9.90) than the C/N ratio at Nkolbisson (15.9).

The soil pH at Mbalmayo was 5.97 which is moderately acidic, while at Nkolbisson the pH was 4.54 which is strongly acidic. The soil organic matter at Mbalmayo (1.30) was lower compared to that at Nkolbisson (1.87). The soil available phosphate and the exchangeable cations (K, Na, Ca and Mg) were moderate for maize production in this area.

Table 4.2 Soil characteristics at Mbalmayo and Nkolbisson before the evaluation trials in 2012 and nitrogen level in 2013

Chemical characteristics	**Mbalmayo**		**Nkolbisson**	
	0-10cm	**10-20cm**	**0-10cm**	**10-20cm**
Exchangeable Ca^{2+} (cmol kg^{-1})	5.92	2.58	1.53	0.88
Exchangeable Mg^{2+} (cmol kg^{-1})	1.15	0.63	0.77	0.46
Exchangeable K^{+} (cmol kg^{-1})	0.11	0.06	0.38	0.24
Cation Exchange Capacity (cmol kg^{-1})	nd*	nd*	10.55	9.37
Organic Carbon %	1.30	0.58	1.87	1.51
C/N	9.90	8.03	15.90	12.94
Bray Phosphorus (mg kg^{-1})	2.11	0.99	13.85	3.10
pH 1:1 (H_2O)	5.97	5.04	4.54	4.36
Total Nitrogen %				
In 2012	0.13	0.07	0.12	0.12
In 2013	0.11	0.15	0.06	0.11

4.2.4 Experimental design and stress management

The experiments were conducted in 2012 and 2013 during three cropping seasons at Mbalmayo and two seasons at Nkolbisson. At Mbalmayo, the experiment consisted of one hybrid trial and one inbred trial planted next to each other. At Nkolbisson, only the hybrid trial was planted. The hybrid trial consisted of 117 F_1 hybrids and 4 hybrid checks while the inbred line trial consisted of 42 lines and 7 checks.

The 121 F_1 hybrids were evaluated during two years and in three cropping seasons under optimum N level (100 kg ha^{-1}) and low N (20 kg ha^{-1}), and the inbred lines were evaluated separately under the same conditions. At each N level, the 121 hybrids were arranged in an 11 x 11 lattice design with two replications while the inbreds were arranged in a 7 x 7 lattice design with two replications. At Mbalmayo, the experimental unit consisted of a single row of 5m while at Nkolbisson it was a single row of 4m. The spacing between rows was 0.75m and 0.5m between hills within a row. Three seeds were planted in a hill and thinned to 2 plants after emergence, for a final density of 53,330 plants per hectare.

Split fertilization was done on each plot. On the low N plot, the first application consisted of a mixture of 10 kg ha^{-1} of N, 24 kg ha^{-1} of P_2O_5 per hectare in the form of Tricalcium phosphate and 14 kg ha^{-1} of K_2O per hectare as Potassium chloride, 10 days after planting. The second dose consisted of 10 kg ha^{-1} N in the form of Urea applied 30 days after planting. On the optimum N plot, Tricalcium phosphate and Potassium chloride were also used. The first application consisted of a mixture of 35 kg ha^{-1} of N, 24 kg ha^{-1} of P_2O_5 and 14 kg ha^{-1} of K_2O per hectare, applied 10 days after planting while the second dose was 65 kg ha^{-1} of N per hectare, applied 30 days after planting. The same fertilizers were used. The trials were kept weed free throughout each growing season by spraying herbicides in the form of 750 g/kg of Atrazine and 40 g/kg of Nicosulfuron at the early stages of maize growth, and later by hand weeding.

4.2.5 Data collection

Data were recorded based on CIMMYT guide for trial management (CIMMYT, 1985). The main data collected were:

Days to anthesis (DTA) and Days to silking (DTS) were obtained as ‘number of days after planting, when 50% of plants were shedding pollen and silking, respectively. The anthesis silking interval (ASI) was calculated as silking date minus anthesis date.

Leaf chlorophyll content was determined in four randomly selected plants from each experimental unit and two measurements were obtained per plant on the ear leaf, using a portable Minolta chlorophyll meter (SPAD-502, MINOLTA) one week after silking.

Ear leaf area was determined after silking from the leaf immediately below the upper ear on four randomly selected plants in each plot, and was obtained by multiplying maximum leaf width by leaf length by 0.75 (Giauffret *et al.*, 1997).

Leaf senescence was scored at 10 weeks after planting on a scale from 0 to 10, by dividing the percentage of the estimated total leaf area below the ear that is dead by 10. A score of 1 = 10% dead leaf area and 10 = 100% dead leaf area (Bänziger *et al.*, 2000) was used.

Plant and ear height (cm) were measured as the distance from the base of the plant to the height of the first tassel branch and the node bearing the upper ear, respectively.

At harvest, the prolificacy, defined as the number of ears per plant, was computed as the proportion of total number of ears divided by the number of plants harvested in each experimental unit.

Ear aspect was scored on a scale of 1 to 5, where 1 corresponded to clean, uniform, large, and well-filled ears and 5 was the rotten, variable, small, and partially filled ears. At maturity, each row was harvested separately and ear weight was determined for each plot. Grains were shelled from five ears randomly selected from each plot to measure the percent grain moisture at harvest using the "Dickey John" moisture tester. Grain yield adjusted to 15% grain moisture was calculated in kg ha^{-1} for every entry from the data of fresh ear weight per plot using the following formula.

$$\text{Grain yield (kg ha}^{-1}\text{)} = \frac{\text{Fresh ear weight (kg/plot)} \times (100\text{-MC}) \times 0.8 \times 10{,}000}{(100\text{-}15) \times \text{Area harvested/plot}}$$

Where:

MC = moisture content in grains at harvest (%)

0.8 = Shelling co-efficient

1 hectare = 10,000 m^2

15 % = moisture content required in maize grain at storage

4.2.6 Statistical analysis

The data were analyzed using general linear model (GLM) procedure in SAS (SAS Institute**,** version 9.2, 2008). Entry means adjusted for block effects were analyzed according to the lattice design (Cochran and Cox, 1960).

Each environment was defined as year x season x site x nitrogen treatment.The Combined analysis of variance (ANOVA) and the ANOVA for each environment were computed with PROC GLM procedure in SAS using the RANDOM statement with the TEST option. Environment effects were treated as random and genotypes as fixed effects. The effects of environment on all the measured traits were evaluated through different interaction estimates.

The first step of analysis was the combined ANOVA across environments for all the 121 F_1 hybrids evaluated (including checks) and all the measured traits. The combined analysis was followed by ANOVA across low N environments and across optimal environments for traits which exhibited significant genotype x environments interaction.

The mathematical model underlying the analysis of variance for each experiment was as follows:

$$Y_{gjk} = \mu + G_g + R_j + B_K + \varepsilon_{gjK}$$

Y_{gjK} is the observation on the g^{th} genotype of the k^{th} block in the jth replication;

μ is the general mean;

G_g is the effect of the g^{th} genotype

B_k is the block effect within the j^{th} replication

ε_{gjk} is the residual variation contributed by the j^{th} replication for the g^{th} genotype

The mathematical model for analysis of variances of the combined data is:

$$Yijkg = \mu + Ei + Rj(i) + Bk(ij) + Gg + EGig + \varepsilon ijkg$$

Where:

Yijkg is the response of the gth genotype grown in the Block k in replicate j of the environment i,

μ is the grand mean;

Ei is the main effect of environment;

Rj(i) is the effect of replicate nested within environment effect;

Bk(ij) is the effect of block nested within replicate j by environment i;

Gg is the effect of the genotype;

EGig is the interaction effect between genotype and environment;

and εijkg is the error term.

i = 1,2,…..10; j = 1,2; k= 1,2….11 and g = 1,2,……121.

Mean separation was done with Tukey's test in order to identify outstanding hybrids in each environmεent and across environments.

The selection of tolerant genotypes was done using the low N selection index proposed by Bänziger *et al.* (2000):

$$\mathbf{I_N = 5.0\ YN + 2.0EPP - 2.0LS - 1.0ASI}$$

where, YN is yield of low N plots; EPP is number of ears per plant in low N plots; LS is leaf senescence in low N plots and ASI is anthesis-silking interval.

The selection index combined the standardized means of grain yield, number of ears per plant, leaf senescence and anthesis silking interval. Each of these traits was standardized using a mean of zero and standard deviation of one to minimize the effects of different scales. A positive value of the low N tolerance index is an indicator of tolerance of line to low N while a negative value is an indicator of susceptibility to low N (Meseka *et al.*, 2006; Ifie, 2013; Meseka *et al.*, 2013).

Line x tester analysis

Following the analysis of variance, a line x tester analysis (Kempthrone, 1957) was done for crosses excluding the checks for low N environments, optimum and across environments. This was done for traits that showed significant differences among crosses in order to partition the mean squares due to crosses into lines, testers and line by tester interaction effects, for each environment (model 1) and for combined data (model 2).

The line by tester analysis was done with PROC GLM procedure in SAS using a RANDOM statement with the TEST option (SAS, 2008). The crosses component of variation was partitioned into variation due to line, tester and line x tester interaction. The F tests for line, tester and line x tester mean squares were computed using the mean squares for their respective interaction with environment. The mean square attributable to environment x line x tester was tested using the pooled error mean squares.

The main effects of line and tester represent the general combining ability (GCA) effects while the line x tester interaction represents specific combining ability (SCA) effects.

Model 1: model for line x tester analysis in each environment

$$Y_{ijk} = \mu + R_m + B_k + l_i + t_j + (l \times t)_{ij} + e_{ijk}$$

Model 2: model for line x tester analysis across environments

$$Y_{eijkm} = \mu + E_e + R_m + B_k + l_i + t_j + (l \times t)_{ij} + (l \times E)_{ie} + (t \times E)_{je} + (l \times t \times E)_{ije} + \varepsilon_{eijkm}$$

Where,

Y_{eijkm} is the response of the of the i x jth progeny of the Kth block of the mth replication of the eth environment;

μ is the experimental mean;

Ee is the main effect of Environment;

R_m is the effect of the mth replication;

Bk is the effect of the kth block within the mth replication;

l_i is the effect of the ith line;

t_j is the effect of the jth tester;

$(l \times t)_{ij}$ is the interaction effect of the cross between ith line and jth tester and;

$(l \times E)_{ie}$ is the interaction effect between line and the Environment;

$(t \times E)_{je}$ is the interaction effect between tester and the Environment;

$(l \times t \times E)_{ije}$ is the interaction effect between line and tester and the Environment;

ε_{eijkm} is the error effect associated with the *eijkm*th observation;

Estimation of general combining ability and specific combining ability effects

Estimate of general combining ability (GCA) effects for lines, testers and specific combining ability (SCA) effects for lines x testers (hybrid) were also estimated based on the above models.

Combining ability effects were estimated using the formulae:

GCA effects of lines= xi../rt – x…/rlt

GCA effects of testers= x.j./rl – x…/rlt

SCA effects of hybrids = xij./r-xi../rt – x.j./rl + x…/rlt

where

x… = total of all hybrids over replications

xi..= total of ith line over t testers and r replications

x.j. = total of jth tester over l lines and r replications

xij, = total of the hybrid between ith line and jth tester over r replications.

The relative importance of GCA effects versus SCA effects on progeny performance was calculated as the ratio between sum of square due to GCA and total genotypic sum of squares (GCA and SCA sum of square) (Beck *et al.*, 1990; Pswarayi and Vivek, 2008).

Classification of inbred lines into heterotic groups was done using SCA effects for grain yield and testcross mean grain yield as suggested by (Menkir *et al.*, 2004) with modification. Lines with positive SCA with a tester and mean grain yield higher than the yield of the best check were assigned to the group opposite to that tester's heterotic group while lines with negative SCA when crossed with a tester were classified into the same heterotic group as the tester. The best check was 87036 x Exp1 24, a hybrid from the cross between two of the three testers.

Simple linear correlation coefficients were calculated at each nitrogen level to determine relationships between grain yield and all the measured traits.

Broad sense heritability (H^2) of the measured traits was estimated at each N level using the formula:

$$H^2 = \sigma^2_G / (\sigma^2_E/re + \sigma^2_{GE}/e + \sigma^2_G)$$

where σ^2_G is variance for genotype, σ^2_E is error variance, σ^2_{GE} is variance for genotype x environment interaction, r is number of replications, and e is number of environments (Fehr, 1991).

Mid-parent heterosis (MPH) and Better parent heterosis (BPH) for grain yield were calculated using adjusted means of the hybrids and inbred lines from hybrids and inbred evaluation trials only in Mbalmayo where both hybrid trial and inbred lines trial were planted in adjacent plots. The formula used was:

$$MPH = [(F1-MP)/MP] \times 100$$

Where F1 is the mean of the F1 hybrid performance and

MP = (P1 +P2)/2 where P1 and P2 are the means of the two inbred parents, respectively.

BPH was calculated as BPH = [(F1-BP)/BP] x 100, where,

F1 = the mean of the hybrid,

BP = the mean of the best parent,

MPH and BPH were averaged across low N environments and across optimum environments.

In order to estimate hybrids superiority over the check, standard heterosis for grain yield was calculated using adjusted means of the hybrids and mean of the best check, 87036 x Exp1 24 which is one of the commercial hybrids. The means used were means across all low N environments in Mbalamyo. The formula used was:

Standard heterosis = [(Hybrid – Check)/Check] x 100, (Singh and Singh, 1994).

4.3. Results

4.3.1 Analysis of variance and hybrid performance

4.3.1.1 Analysis of variance and hybrid performance under low N environments

Highly significant differences ($p<0.01$) were observed among the hybrids for all traits except number of ears per plant which was only significant ($p<0.05$) (Table 4.3). The differences among low N environments were significant ($p<0.05$) for grain yield and ear leaf chlorophyll content and highly significant for days to silking, anthesis silking interval, leaf area and plant height (Table 4.3). The difference among low N environments was not significant for leaf senescence, ears per plant and ear aspect. The interaction between hybrids and environments was highly significant for all traits.

Across low N environments, broad sense heritability varied from 22% for leaf senescence to 59% for days to silking (Table 4.3). Heritability estimates for grain yield was 32%.

Across low N environments, grain yield ranged from 1539 kg ha^{-1} for CML 358 x 9071 to 3771 kg ha^{-1} for TL-11-A-1642-5 x Exp1 24, with a mean of 2721 kg ha^{-1} (Table 4.4). Days to silking ranged from 63 to 72 with a mean of 67 days. Anthesis-silking interval ranged from 1.9 days to 4.9 days with a mean of 3.2 days. Short anthesis silking interval was observed among the 20 best hybrids while larger interval was observed among the poorest hybrids. Leaf area varied from 404.9 to 626.6 cm^2 with a mean of 525.6 cm^2. Leaf chorophyll content varied from 31.5% to 46.2%, with a mean of 40.8% and higher values were observed among the 20 best hybrids. Means for plant height was 163.5 cm, ranging from 135 cm to 182.9 cm and ear aspect ranged from 2.4 to 4.1 with a mean of 3.1 (Table 4.4). Across low N stress environment, six hybrids yielded more than 3500 $kg.ha^{-1}$and were more than 10% higher yielding than the best check, these are TL-11-A-1642-5 x Exp1 24 (3771 kg ha^{-1}), CLWN201 x 87036 (3609 kg ha^{-1}), ATP S6 20 Y-2 x Exp1 24 (3557 kg ha^{-1}), J16-1 x Exp1 24 (3516 kg ha^{-1}), ATP S9 30 Y-1 x Exp1 24 (3514 kg ha^{-1}) and CLYN246 x 87036 (3512 kg ha^{-1}) (Table 4.4). None of the four hybrid checks was among the 20 best hybrids under low N.

Low N tolerant index ranged from -5.7 for 9450 x 9071 to 6.2 for TL-11-A-1642-5 x Exp1 24. Based on low N selection index, 15 of the 20 high yielding hybrids selected were also ranked among the 20 most tolerant based on the index. TL-11-A-1642-5 x Exp1 24 and ATP S6 20 Y-2 x Exp1 24 had the same position based on grain yield (first and third respectively).

Table 4.3 Mean squares for grain yield and other agronomic traits of hybrids evaluated under low N environments at Mbalmayo and Nkolbisson in 2012 and 2013

Source of variation	Df	YIELD ($kgha^{-1}$)	DTS (days)	ASI (days)	LAREA (cm^2)	SPAD (%)	SEN (1-9)	PHT (cm)	EPP	EA (1-5)
Env	4	120610253.6*	2610.91**	156.89**	991661.7**	12763.1*	69.10ns	138175.3**	0.43ns	2.21ns
Rep (Env)	5	18954223.1**	71.28*	5.24ns	59589.4ns	2158.68**	28.29**	1861.11ns	0.15**	3.13*
Block (Rep x Env)	100	1994390.9**	19.31**	2.62**	20918.8**	79.50**	1.47**	681.22	1.09ns	0.68**
Hybrids	120	1899873.4**	23.60**	2.72**	14272.18**	62.69**	1.02**	836.83**	1.31*	0.94**
Hybrids*Env	480	1293549.0**	9.59**	1.90**	9643.81**	33.76**	0.80**	417.99**	1.52**	0.46**
Pooled error	500	729665	7.27	1.5	5921.28	23.15	0.6	236.97	0.03	0.29
H^2		0.32	0.59	0.30	0.32	0.46	0.22	0.50	-	0.51

*, **, Significant at 0.05 and 0.01probability levels, respectively; ns = not significant; DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPAD = leaf chlorophyll content; SEN=leaf senescence PHT=plant height; EPP=ears per plant; EA=ear aspect, YIELD=grain yield; H^2 = Broad sense heritability.

Table 4.4 Grain yield and other agronomic traits of the selected best 20 hybrids and checks across low N environments at Mbalmayo and Nkolbisson in 2012 and 2013

Hybrids	YIELD (kgha^{-1})	DTS (days)	ASI (days)	LAREA (cm^2)	SPAD (%)	SEN (1-10)	PHT (cm)	EPP	EA (1-5)	(%)Yield red.	Low N index	Rank index
TL-11-A-1642-5 x Exp1 24	3771	66.7	2.6	531.8	41.5	2.9	155.8	1.1	2.4	30.4	6.2	1
CLWN201 x 87036	3609	66.1	4.2	504.4	41.6	3.8	175.6	1.1	2.35	33.5	2.1	24
ATP S6 20 Y-2 x Exp1 24	3556	64.5	2.9	589.3	41.9	3.2	158.7	1.1	2.7	31.0	3.9	3
J16-1 x Exp1 24	3516	65.7	3.8	601.4	39.9	3.2	162.7	1.1	2.6	41.9	3.6	6
ATP S9 30 Y-1 x Exp1 24	3514	66.4	3.1	585.4	44.2	3.7	167.1	1.1	2.5	22.0	2.5	16
CLYN246 x 87036	3512	65	2.7	602.0	41.4	3.8	173.7	1.2	2.7	46.7	5.0	2
ATP S9 30 Y-1 x 87036	3464	66.6	2.7	536.3	41.9	3.7	179.7	1.2	3.0	33.3	3.9	5
CLWN201 x Exp1 24	3415	65.3	2.5	491.7	41.1	3.5	153.9	1.1	2.8	44.5	3.3	9
ATP S6-20-Y-1 x Exp1 24	3365	64	2.7	556.5	34.3	3.4	162.9	1.0	2.9	40.6	2.4	17
Entrada 29 x Exp1 24	3321	66.2	3.3	594.6	42.9	2.9	174.2	1.1	2.5	34.4	3.9	4
CML165 x 87036	3320	66.5	3.1	585.7	44.4	3.6	175.0	1.1	2.6	36.8	2.4	18
1368 x 87036	3316	66.7	3.5	574.8	41.1	3.5	173.8	1.1	2.7	44.0	2.1	25
CML343 x 87036	3306	68.5	2.6	568.7	43.4	3.3	172	1.1	3.0	40.6	2.8	12
4001STR x 87036	3291	66.5	3.2	543.5	43.3	3.6	163.7	1.1	2.8	41.1	2.6	15
CLQRCWQ26 x 87036	3289	64.7	2.9	558.7	38.5	3.6	169.8	1.1	2.7	39.6	2.1	23
CML 444 x Exp1 24	3275	71.7	2.6	529.3	40.3	3.7	160.8	1.1	3.1	35.0	2.9	11
V-481-73 x Exp1 24	3256	68.9	3.6	559.7	44.1	2.6	165.1	1.1	2.6	27.3	3.3	8
CML343 x Exp1 24	3242	68.2	3.6	527.0	40.8	3.3	160.6	1.0	2.8	32.5	1.8	28
Cam inb gp1 17 x 87036	3228	66	3.7	556.3	37.1	3.4	169.9	1.0	2.7	43.8	1.2	36
CML343 x 9071	3224	69	2.5	509.9	41.9	3.6	171.1	1.2	2.8	41.7	3.4	7
Best checks												
87036 x Exp1 24	2866	69.9	3.7	521.4	43.0	3.5	175.1	1.1	2.8		0.1	
Exp1 24 x 9071	2337	67.3	2.7	548.5	37.7	3.9	160.6	1.1	3.1		-1.6	
Mean	**2721**	**66.98**	**3.18**	**525.6**	**40.8**	**3.5**	**163.5**	**1.1**	**3.1**			
Min	**1539**	**62.50**	**1.9**	**404.9**	**31.5**	**2.6**	**135.0**	**0.9**	**2.4**		**-5.8**	
Max	**3771**	**71.70**	**4.9**	**626.6**	**46.2**	**4.4**	**182.9**	**1.3**	**4.1**		**6.2**	
Lsd (0.05)	**1687**	**5.32**	**2.42**	**152.1**	**9.5**	**1.5**	**30.4**	**0.3**	**1.1**			

DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPAD = leaf chlorophyll content; SEN=leaf senescence PHT=plant height; EPP=ears per plant; EA=ear aspect, YIELD=grain yield, Yield red.= yield reduction; Rank index=rank based on index.

4.3.1.2 Analysis of variance and hybrid mean performance under optimal environments

Differences among optimum environments were significant ($p<0.05$) for plant height but highly significant ($p<0.01$) for other traits (Table 4.5). Differences among hybrids were significant for anthesis to silking interval and ears per plant but highly significant ($p<0.01$) for days to silking, leaf area, leaf chloropyll content, plant height and ear aspect. The interaction between hybrids and environments was significant for all traits except anthesis silking interval (Table 4.5).

Broad sense heritability across optimal environments varied from 25% for number of ears per plant to 60% for grain yield (Table 4.5).

Under optimum environments, mean yield varied from 3027 kg ha^{-1} for J18-1x 9071 to 6589 kg ha^{-1} for TL-11-A-1642-5 x 87036, with an overall mean of 4887 kg ha^{-1} (Table 4.8). Days to 50% silking ranged from 61 to 60 days with a mean of 62 days. Mean anthesis silking interval varied from 1.6 to 3.1 days with a mean of 2.3 days (Table 4.6).

The top five hybrids yielded above 6000 kg ha^{-1} under optimum environments (Table 4.6). The highest yielding checks were 87036 x Exp1 24 (5169 kg ha^{-1}) and Exp1 24 x 9071 (5262 kg ha^{-1}) but these hybrids were not among the 20 best hybrids selected in the optimal environments.

Table 4.5 Mean squares for grain yield and other agronomic traits of hybrids evaluated under optimal environments at Mbalmayo and Nkolbisson in 2012 and 2013

Source of variation	df	YIELD ($kgha^{-1}$)	DTS (days)	ASI (days)	LAREA (cm^2)	SPAD (%)	PHT (cm)	EPP	EA (1-5)
Env	4	119107647.2**	162.91**	15.46**	1334687.99**	730.34**	164171.82*	0.46ns	3.74**
Rep (Env)	5	26332548.7**	68.39**	0.64ns	90669.38**	197.92*	27138.47**	0.11ns	2.41**
Block(Rep x Env)	100	2064134.4**	9.38**	0.60ns	14834.01**	48.94**	776.82**	0.04**	0.45**
Hybrids	120	4770711.5**	19.76**	0.78*	23684.96**	49.09**	1006.39**	0.04*	0.95**
Hybrids*Env	480	1909551.4**	10.5**	0.57ns	13831.34**	30.82**	497.46**	0.03**	0.43**
Pooled error	500	1281168	6.11	0.56	7935.25	24.69	305.79	0.03	0.22
H^2		0.60	0.47	0.27	0.42	0.37	0.51	0.25	0.55

*, **, Significant at 0.05 and 0.01probability levels, respectively; ns = not significant; DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPAD = leaf chlorophyll content; PHT=plant height; EPP=ears per plant; EA=ear aspect, YIELD=grain yield; H^2 = broad sense heritability.

Table 4.6 Grain yield and other agronomic traits of the best 20 hybrids and checks under optimum environments at Mbalmayo and Nkolbisson in 2012 and 2013

Hybrids	**YIELD ($kgha^{-1}$)**	**DTS (days)**	**ASI (days)**	**LAREA (cm^2)**	**SPAD (%)**	**PHT (cm)**	**EPP**	**EA (1-5)**
TL-11-A-1642-5 x 87036	6588.8	65.2	1.7	650.9	51.1	193.6	1.1	2.4
CLYN246 x 87036	6585.0	63.4	2.2	740.3	54.2	197.7	1.1	2.05
TZ-STR-133 x 87036	6393.3	62.5	2.5	582.7	51.6	194.0	1.1	2.4
CLWN201 x Exp1 24	6152.3	63.1	2	617.8	49.5	174.2	1.1	2.05
J16-1 x Exp1 24	6048.7	63	2.2	653.0	47.8	175.0	1.1	2.1
CLQRCWQ26 x Exp1 24	5968.8	64.9	2.3	606.8	47.0	174.4	1.1	2.1
1368 x 87036	5923.7	64.3	2	625.9	48.6	195.3	1.1	2.1
CLA 18 x Exp1 24	5909.7	64.2	2	635.9	48.6	168.8	1.0	2.05
4001STR x 9071	5792.1	63	2.2	645.8	48.7	177.8	1.1	2.45
J16-1 x 87036	5780.5	63.7	1.9	654.3	51.0	181.7	1.1	2.3
CML395 x Exp1 24	5772.5	66.3	2.1	656.1	45.7	177.1	0.9	2.35
ATP S6-20-Y-1 x 87036	5765.9	63.6	1.6	671.1	52.6	198.0	1.00	1.9
Cam inb gp1 17 x 87036	5741.05	64.6	2.9	614.1	55.9	196.3	1.06	1.85
CML451 x 87036	5729.1	66.3	2.7	617.0	47.8	187.5	0.99	2.45
CLYN246 x Exp1 24	5708.8	63.4	2.1	677.9	50.5	175.9	1.13	2.15
CML 358 x 87036	5699.0	65.6	2.3	644.9	46.8	197.1	1.08	2.4
CLA 18 x 87036	5694.1	64.2	2.2	663.1	54.1	199.7	1.12	2.15
88069 x 9071	5687.9	62.3	2.4	709.5	53.6	188.7	1.03	2.4
ATP S5 31 Y-2 x 87036	5682.3	63.5	2.3	639.7	51.1	180.5	1.22	2.4
ATP S6-20-Y-1 x Exp1 24	5665.4	63.6	2.1	668.9	47.3	178.1	1.09	2.3
Best checks								
87036 x Exp1 24	5169.4	64.6	2.5	655.2	49.7	185.6	1.13	2.35
Exp1 24 x 9071	5262.2	68.2	2.1	680.2	47.7	176.2	1.16	2.9
Mean	**4887.2**	**64.7**	**2.3**	**630.6**	**50.0**	**182.3**	**1.07**	**2.5**
Min	**3026.5**	**61.2**	**1.6**	**472.7**	**43.0**	**153.2**	**0.92**	**1.9**
Max	**6588.8**	**69.4**	**3.1**	**772.1**	**55.9**	**210.1**	**1.24**	**3.5**
Lsd (0.05)	**2236.6**	**4.9**	**1.5**	**176.0**	**9.8**	**34.6**	**0.32**	**0.9**

DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPAD = leaf chlorophyll content; PHT=plant height; EPP=ears per plant; EA=ear aspect, YIELD=grain yield.

4.3.1.3 Analysis of variance and hybrid performance across environments

Across the ten environments, highly significant differences ($p<0.01$) were observed among the hybrids for all the measured traits (Table 4.7). Differences between environments were also highly significant ($p<0.01$) for all traits. Hybrid x environment interaction was highly significant for all traits.This suggests that relative performance of the hybrids were not consistent across environments.

Grain yield of hybrids ranged from 2328 kg ha^{-1} to 5049 kg ha^{-1}, with a mean of 3804 kg ha^{-1} (Table 4.8). Days to silking ranged from 62.5 to 69.4 days with a mean of 65.9 days, and anthesis silking interval varied from 2.2 to 3.9 days with a mean of 2.7 days. The mean value of hybrids for leaf area was 578.2 cm^{2}; mean for leaf chlorophyll concentration was 45.4%; mean plant height was 173.1 cm. Means for number of ears per plant and ear aspect were 1.1 and 2.8 respectively (Table 4.8).

Five hybrids yielded more than 4600 kg ha^{-1} and were more than 10% superior to the best check. These are CLYN246 x 87036 (5049 kg ha^{-1}), TL-11-A-1642-5 x 87036 (4887 kg ha$^{-1)}$, CLWN201 x Exp1 24 (4784 kg ha^{-1}), J16-1 x Exp1 24 (4783 kg ha^{-1}) and 1368 x 87036 (4620 kg ha^{-1}) (Table 4.8).

Table 4.7 Mean squares of grain yield and other agronomic traits of hybrids evaluated across environments at Mbalmayo and Nkolbisson in 2012 and 2013

Source of variation	Df	YIELD (kgha^{-1})	DTS (days)	ASI (days)	LAREA (cm^2)	SPAD (%)	PHT(cm)	EPP	EA (1-5)
Env	9	421826605**	1572.49**	133.37**	1775554.16**	11634.39**	158195.18**	0.40*	23.22**
Rep (Env)	10	22643366**	69.83**	2.95ns	75129.41**	1178.31**	14499.79**	0.13**	2.77**
Block(Rep x Env)	200	2029263**	14.35**	1.61**	17876.44**	64.22**	729.02**	0.04**	0.56**
Hybrids	120	5390074**	33.69**	1.95**	26687.76**	78.46**	1477.59**	0.04**	1.64**
Hybrids*Env	1080	1565879**	9.94**	1.27**	11685.55**	32.42**	447.50**	0.04**	0.42**
Pooled error	1000	1005416	6.69	1.03	6828.26	23.92	271.38	0.03	0.26

*, **, Significant at 0.05 and 0.01probability levels, respectively; ns = not significant; DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPD = leaf chlorophyll content; SEN=leaf senescence PHT=plant height; EPP=ears per plant; EA=ear aspect, YIELD=grain yield.

Table 4.8 Grain yield and other agronomic traits of the best 20 hybrids across environments at Mbalmayo and Nkolbisson in 2012 and 2013

Hybrids	**YIELD (kgha^{-1})**	**DTS (days)**	**ASI (days)**	**LAREA (cm^2)**	**SPAD (%)**	**PHT (cm)**	**EPP**	**EA (1-5)**	**%yield reduction**
CLYN246 x 87036	5049	64.2	2.5	671.2	47.8	185.7	1.1	2.35	46.8
TL-11-A-1642-5 x 87036	4887	66.6	2.3	575.1	46.1	179.4	1.2	2.68	51.7
CLWN201 x Exp1 24	4784	64.2	2.3	554.8	45.3	164.0	1.1	2.4	44.5
J16-1 x Exp1 24	4783	64.35	3	627.2	43.9	168.5	1.1	2.33	41.9
1368 x 87036	4620	65.5	2.8	600.4	44.9	184.6	1.1	2.38	44.0
CLQRCWQ26 x Exp1 24	4596	66.25	2.6	598.5	42.7	168.1	1.1	2.53	46.0
TL-11-A-1642-5 x Exp1 24	4595	65.75	2.5	562.2	44.5	158.6	1.1	2.55	30.4
TZ-STR-133 x 87036	4529	62.5	2.8	540.6	47.9	182.8	1.0	2.7	58.3
CLWN201 x 87036	4519	64	3.1	559.4	46.9	179.2	1.1	2.28	33.5
ATP S6-20-Y-1 x Exp1 24	4515	63.8	2.4	612.7	40.8	170.5	1.1	2.6	40.6
CLA 18 x Exp1 24	4493	66.15	2.4	583.3	45.6	164.0	1.1	2.38	47.9
ATP S6-20-Y-1 x 87036	4490	65.7	2.6	594.8	48.9	178.0	1.0	2.33	44.3
Cam inb gp1 17 x 87036	4484	65.3	3.3	585.2	46.5	183.1	1.0	2.25	43.8
J16-1 x 87036	4444	64.9	2.7	595.1	47.6	176.8	1.1	2.5	46.3
4001STR x 87036	4438	65.3	2.8	621.5	48.2	177.9	1.1	2.53	41.1
CML343 x 87036	4436	67.3	2.4	670.4	48.3	183.1	1.1	2.53	40.6
CLA 18 x 87036	4413	65.8	2.9	609.8	48.0	183.2	1.1	2.43	45.0
CML395 x Exp1 24	4411	68.2	2.5	590.2	41.3	170.7	1.0	2.73	47.2
CML451 x 87036	4410	66.4	3	577.0	44.4	180.3	1.0	2.58	46.1
CML343 x 9071	4378	67.8	2.6	601.0	44.4	180.3	1.1	2.55	41.7
Best Checks									
87036 x Exp1 24	4018.	67.3	3.1	588.3	46.4	180.4	1.1	2.55	44.5
Exp1 24 x 9071	3799	67.8	2.4	614.4	42.7	168.2	1.1	3	55.6
Mean	**3804**	**65.9**	**2.7**	**578.2**	**45.4**	**173.1**	**1.1**	**2.8**	**44.3**
Min	**2328**	**62.5**	**2.2**	**457.2**	**38.2**	**148.3**	**1.0**	**2.3**	**21.5**
Max	**5049**	**69.4**	**3.9**	**671.2**	**50**	**193.3**	**1.2**	**3.7**	**58.6**
Lsd	**1396**	**3.6**	**1.4**	**115.9**	**6.8**	**22.9**	**0.2**	**0.7**	

DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPAD = leaf chlorophyll content; PHT=plant height; EPP=ears per plant; EA=ear aspect, YIELD=grain yield.

4.3.2 Combining ability

4.3.2.1 Combining ability under low N

Under low N environments, there were significant differences among hybrids for all traits except number of ears per plant (Table 4.9). Line x tester analysis revealed highly significant ($p<0.01$) line GCA mean squares for all traits (Table 4.9). Means squares of tester GCA were significantly different for all traits except days to silking and anthesis silking interval. There were highly significant differences in SCA mean squares for all traits except leaf senescence and plant height (Table 4.9).

Crosses x environment interaction was significant for all traits ($p<0.01$), suggesting that hybrids did not perform consistently across environments. Environment x line GCA interaction was highly significant for all the traits except for days to silking while environment x GCA tester interaction was significant for grain yield, leaf area and highly significant for, days to silking, leaf chlorophyll content and plant height (Table 4.9). Environment x SCA interaction was highly significant ($p<0.01$) for grain yield, leaf area, plant height and ear aspect but was only significant ($p<0.05$) for days to silking.

Under low N, the relative contribution of SCA to the total sum of squares of square of crosses (%SS SCA) was higher compared to the contribution of GCA (%SS GCA) for grain yield, anthesis silking interval, leaf area and leaf chlorophyll content, while contribution of SCA was lower than GCA for days to silking, plant height and ear aspect (Table 4.9).

4.3.2.2 Combining ability under optimum conditions

Under optimal environments, there were significant differences among hybrids for all traits except number of ears per plant (Table 4.10). Line x tester analysis revealed significant ($p<0.05$) line GCA mean squares for anthesis silking interval and highly significant ($p<0.01$) line GCA mean squares for all the other measured traits. Tester GCA mean square was significant for all traits except anthesis silking interval (Table 4.10). SCA mean squares were significant for grain yield, days to silking, leaf area and ear aspect. Environment x Line GCA interaction was significant for all traits except anthesis silking interval and leaf chlorophyll content while environment x tester GCA interaction was significant for all measured traits except anthesis silking interval and leaf area (Table 4.10). SCA x environment interaction was significant only for days to silking and ear aspect. The relative contribution of GCA to the sums of squares of crosses was higher than the contribution of SCA for all traits, except anthesis silking interval (Table 4.10).

Table 4.9 Line x tester analysis for grain yield and other agronomic traits across low N environments at Mbalmayo and Nkolbisson in 2012 and 2013, and relative contribution of GCA and SCA sum of squares to the total genotypic sum of squares

Source of variation	df	YIELD (kg.ha^{-1})	DTS (days)	ASI (days)	LAREA (cm^{2})	SPAD (%)	SEN (1-9)	PHT (cm)	EA (1-5)
Env	4	115584228.4*	2565.56**	150.00**	916162.69**	12249.75*	64.57ns	130530.30**	2.24ns
Crosses	116	1604070.5**	21.31**	2.46**	13004.16**	61.88**	1.06**	660.13**	0.84**
Env *Crosses	464	1281639.8**	9.30*	1.91*	9364.79**	31.93*	0.75*	395.42**	0.47**
Line (GCA)	38	2033201.1**	38.82**	3.40**	17208.56**	67.92**	1.32**	629.38**	1.06**
Tester (GCA)	2	6836645.8**	0.94ns	4.11ns	16265.33ns	305.68**	10.93**	13490.22**	3.44**
Line*Tester (SCA)	76	1227344**	11.58**	2.08*	11138.17**	48.92**	0.71ns	317.82ns	0.64**
Env*Line (GCA)	152	1586891.9**	8.83ns	2.18**	9477.26**	37.02**	0.79*	365.82*	0.62**
Env*Tester (GCA)	8	1824558.9*	24.08**	1.15ns	15949.62*	59.08**	1.03ns	1509.20**	0.48ns
Env*Line* Tester (SCA)	304	1095883.3**	9.16*	1.74ns	8863.19**	27.85ns	0.72ns	365.70**	0.39**
Error	689	770917	7.56	1.53	6477.74	25.99	0.62	283.15	0.3
% SS GCA (Line)		41.52	64.95	44.38	43.35	35.96	40.99	31.23	41.26
% SS GCA (Tester)		7.35	0.11	2.88	2.16	8.52	17.84	35.23	7.03
% SS SCA (Line x Tester)		51.13	35.48	55.34	56.12	51.8	43.92	31.54	49.4

*, **, Significant at 0.05 and 0.01probability levels, respectively; ns = not significant; DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPAD = leaf chlorophyll content; SEN=leaf senescence PHT=plant height; EA=ear aspect, YIELD=grain yield; %SS GCA=.relative contribution of GCA to the total genotypic sum of squares.

Table 4.10 Line x tester analysis for grain yield and other agronomic traits across optimum environments at Mbalmayo and Nkolbisson in 2012 and 2013 and relative contribution of GCA and SCA to the total genotypic sum of squares

Source of variation	df	YIELD (kg.ha^{-1})	DTS (days)	ASI (days)	LAREA (cm^{2})	SPAD (%)	PHT (cm)	EA (1-5)
Env	4	113613785.2*	152.37ns	14.48**	1253297.66**	707.94ns	158316.66*	4.12**
Crosses	116	4235566.4**	18.05**	0.72ns	18531.24**	41.88**	877.13**	0.87**
Env *Crosses	464	1840627.2**	10.11**	0.59ns	13091.60ns	30.38*	461.43**	0.040**
Line (GCA)	38	5735295**	31.32**	0.92*	27262.50**	50.34**	864.85**	1.10**
Tester (GCA)	2	27425796**	52.36**	0.95ns	33483.60*	608.21**	17622.32**	4.5**
Line*Tester (SCA)	76	2766032.3**	9.89**	0.61ns	13372.88*	22.97ns	401.10ns	0.67**
Env*Line (GCA)	152	2297712.1**	11.97**	0.57ns	16689.71**	30.84ns	492.73**	0.39**
Env*Tester (GCA)	8	3273204.3*	12.61**	0.94ns	9156.18ns	104.76**	1552.15**	0.58*
Env*Line*Tester (SCA)	304	1502318.4ns	8.68**	0.59ns	11064.99ns	28.46ns	403.81ns	0.40**
Error	689	1292975	6.13	0.57	9877.4	26.3	360.33	0.24
% SS GCA (Lines)		44.36	56.68	42.15	48.19	39.38	32.30	41.24
% SS GCA (Testers)		11.16	4.98	2.31	3.12	25.04	34.64	8.88
% SS SCA (Line x Tester)		44.48	38.34	55.54	48.69	35.58	33.06	49.88

*, **, Significant at 0.05 and 0.01probability levels, respectively; ns = not significant; DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPAD = leaf chlorophyll content; PHT=plant height; EA=ear aspect, YIELD=grain yield; %SS GCA=.relative contribution of GCA to the total genotypic sum of squares.

4.3.2.3 General combining ability effects

The GCA effects of the inbred lines for grain yield, days to silking, leaf area, plant height, ear height and ear aspect under low N environments are presented in Table 4.11. Six lines had positive and significant GCA for grain yield. These were CML 343 (522.26), ATP S6 20-Y1 (504.46), CLWN201 (483.80), 1368 (468.23), ATP S9 30 Y-1 (436.48) and CLQRCWQ26 (396.45). CML 343 had the highest GCA effect for grain yield. The desired line GCA value for days to silking and anthesis to silking interval would be negative, therefore, the best lines for days to silking were V 351-1/6 and CLA 17 with a GCA effect of -3.2 and -2.5 respectively. The same lines V351-1/6 and CLA 17 had the best GCA effects for anthesis silking interval (-0.8 and -0.6 respectively). The two best combiners in terms of leaf area, with positive and significant GCA effects were CLQRCWQ26 (44) and ATP S5 31-Y-2 (36). The lines ATP S9 30 Y-1 (9.3) and 5012 (8.1) had the highest GCA effects for plant height.

The lines CLWN 201, CLYN246 and ATP S6 20 Y-2 were the best general combiners for ear aspect, with a GCA effect of -0.2.

Two out of the three testers had positive GCA for grain yield under low N (Table 4.11). These are 87036 (72.19) and (59.95). The tester 9071 had a negative GCA value. For days to silking, only tester 9071 had a negative GCA (-0.07). Testers 87036 and Exp1 24 had negative GCA (-0.02 and -0.11 respectively) for anthesis silking interval, indicating a good general combining ability for this trait under low N. The testers 87036 and Exp1 24 also had positive GCA for ear leaf area indicating good combining ability for this trait while 9071 GCA was negative. For leaf chlorophyll content, 87036 had the best GCA (0.81) while for leaf senescence EXP1 24 was the tester with best GCA (-0.18). For plant height the tester 87036 had the best GCA (6.75). The testers 87036 (-0.06) and Exp1 24 (-0.06) both had a good GCA for ear aspect.

The GCA effects of inbreds for the measured traits under optimal environments are presented in Table 4.12. The six best lines with positive and significant GCA for grain yield were CLYN246 (982.75), J16-1 (728.75), CLWN201 (720.74), TL-11-A-1642-5 (675.86), CLQRCWQ26 (640.10) and 1368 (546.51). Three of these were also among the best general combiners for grain yield under low N (Table 4.12). These are CLWN201, 1368 and CLQRCWQ26. CLA 17 and CLWN 201 had the best negative GCA effects for days to silking and anthesis to silking interval of -2.76 and -2.20 respectively. In terms of anthesis silking interval, ATPS6 20 Y-1 (-0.32) and CML 494 (-0.29) were the best inbreds. The two best general combiners for leaf area were CML343 (94.05) and CLYN246 (59.62). The lines with best GCA effects for plant height were 5012 (9.49) and KU1409 (10.40) while the best lines with positive and significant GCA effects for ear aspect were Cam inb gp1 17 (-0.37) and CML 343 (-0.36).

GCA effects of testers under optimal environments are presented in Table 4.12. Two out of the three testers had positive and significant GCA effects for grain yield under optimal environments. These were 87036 (262.49) and Exp1 24 (21.36). The tester 9071 had a significantly negative GCA effect for grain yield. Testers 87036 and 9071 had negative GCA effect for days to silking (-0.14 and -0.30, respectively). The inbred 87036 had negative GCA effect (-0.06) indicating its good general combining ability for this trait. 87036 was the only tester with positive GCA effect (11.18) for ear leaf area whereas 87036 and 9071 had positive GCA effects (1.21 and 0.12) for leaf chlorophyll content. Inbred 87036 was the only tester with positive GCA effect for plant height (8.65) and also had the best GCA effect (-0.11) for ear aspect.

Table 4.11 General combining ability effects of lines and testers for grain yield and other agronomic traits under low N environments

Lines	Yield (kg.ha^{-1})	DTS (days)	ASI (days)	LAREA (cm^2)	SPAD (%)	SEN (1-9)	PHT (cm)	EA (1-5)
Cla 17	-235.01	-2.46**	-0.58*	-18.71	-0.92	-0.11	0.71	0.08
9450	-865.88**	0.64	0.76**	-41.15*	-2.17	0.19	-2.17	0.23*
1368	468.23*	-0.99	-0.01	21.83	-0.14	0.17	0.45	-0.30**
M 131	-471.41*	0.77	0.09	-6.40	0.26	0.37*	1.29	0.20
88094	-262.54	1.21*	0.26	21.39	-2.84*	0.27	-12.93**	0.13
J18-1	-355.27	2.54**	-0.04	-44.19**	-1.99	0.40*	-0.44	0.71**
88069	275.61	-0.59	-0.01	-0.09	0.23	-0.35	-2.37	-0.27*
Entrada 29	-215.15	1.41*	0.62**	19.27	1.03	-0.16	1.65	0.15
CML 358	-321.81	-0.33	0.19	-34.39*	-2.90*	-0.01	-3.32	0.13
Entrada 3	-158.03	-1.06	-0.14	-45.01**	0.00	0.06	-1.11	0.06
CML 254	19.99	0.97	-0.18	28.50	-0.99	0.22	1.05	-0.04
5012	-103.65	1.07	0.16	-8.25	-0.16	-0.16	8.10*	0.01
Cam inb gp1 17	253.52	-0.43	0.42	23.11	-1.31	-0.11	-1.52	-0.22*
9848	-436.20*	-1.13*	0.19	-11.79	-1.58	0.42*	-2.23	0.31**
CLA 18	208.75	0.97	-0.14	22.53	1.26	0.17	0.71	-0.25*
ATP S9 30 Y-1	436.48*	0.01	-0.24	32.59*	1.61	0.11	9.31**	-0.14
ATP S5 31 Y-2	106.39	-0.79	-0.38	35.98*	-1.23	0.09	0.32	-0.09
KU1414	-123.14	1.27*	0.16	-6.11	2.37	-0.21	3.79	-0.04
5057	-334.54	1.44**	0.32	-22.48	-1.21	0.34	-2.26	0.25*
ATP S6 20 Y-2	185.23	-1.26*	-0.08	16.17	3.00*	-0.21	2.76	-0.20
ATP S8 30 Y-3	-62.55	-1.09	-0.21	-0.65	-0.21	0.02	-1.17	-0.04
CLWN201	483.80**	-1.43*	0.02	-32.79*	-0.63	0.14	-4.28	-0.20
TZMI 102	-88.74	-0.93	-0.44	-36.37*	3.55**	-0.38*	-0.37	0.08
J16-1	326.14	-0.49	0.39	34.05*	0.60	-0.08	0.14	-0.22*
CLYN246	300.65	-1.33*	-0.24	9.64	1.07	-0.24	-2.65	-0.20
CML395	-283.85	2.24**	0.29	-19.82	-1.63	0.17	2.59	0.23*
CML494	-299.82	1.27*	-0.41	20.10	-0.77	-0.03	-3.42	0.25*
CML165	-46.53	-0.46	-0.01	23.81	1.91	0.19	-3.83	-0.12
CLQRCWQ26	396.45*	-0.66	-0.01	43.97**	-2.49	-0.23	1.59	-0.12
CML451	85.04	0.47	-0.24	26.71	0.09	-0.56**	3.66	0.05
V-351-1/6	-165.15	-3.23**	-0.81**	-23.68	0.97	-0.23	-16.34**	-0.09
V-481-73	-293.94	0.87	0.42	31.85	2.40	-0.31	7.90*	-0.01
TZ-STR-133	121.22	-1.16*	-0.18	-6.05	1.30	0.40*	5.22	0.11

*, **, Significant at 0.05 and 0.01 probability levels, respectively; ns = not significant; DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPAD = leaf chlorophyll content; SEN=leaf senescence PHT=plant height; EA=ear aspect, YIELD=grain yield

Table 4.11 General combining ability effects of lines and testers for grain yield and other agronomic traits under low N environments (Cont'd)

Lines	**Yield ($kg.ha^{-1}$)**	**DTS (days)**	**ASI (days)**	**LAREA (cm^2)**	**SPAD (%)**	**SEN (1-9)**	**PHT (cm)**	**EA (1-5)**
TL-11-A-1642-5	326.73	1.07	-0.41	-17.10	0.24	-0.13	0.27	-0.14
Ku1409	15.45	-0.69	0.16	-9.71	0.75	0.05	5.53	-0.01
ATP S6-20-Y-1	504.46**	-1.03	0.12	24.47	1.02	-0.08	-0.22	-0.29**
CML343	522.26**	1.64*	-0.28	9.58	1.23	-0.16	4.49	-0.24*
CML 444	11.67	2.91**	0.36	-51.57**	-1.71	0.05	1.79	0.26*
4001STR	75.15	-1.19*	0.06	-9.23	0.04	-0.04	-2.70	-0.07
Testers								
87036	72.19	0.02	-0.02	3.21	0.81*	0.08	6.75**	-0.06*
Exp1 24	59.95	0.05	-0.11	1.19	-1.03**	-0.18**	-4.13**	-0.06*
9071	-132.13**	-0.07	0.13	-4.41	0.22	0.10*	-2.63**	0.12**
SE lines	**184.11**	**0.56**	**0.24**	**16.35**	**1.32**	**0.18**	**3.34**	**0.03**
SE testers	**51.06**	**0.16**	**0.07**	**4.53**	**0.32**	**0.05**	**0.93**	**0.01**

*, **, Significant at 0.05 and 0.01 probability levels, respectively, and ns, not significant; SE = standard error; DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPAD = leaf chlorophyll content; SEN=leaf senescence PHT=plant height; EA=ear aspect, YIELD=grain yield.

Table 4.12 General combining ability effects of lines and testers for grain yield and other agronomic traits under optimal environments

Lines	Yield (kg ha^{-1})	DTS (days)	ASI (days)	LAREA (cm2)	SPAD (%)	PHT (cm)	EA (1-5)
Cla 17	-197.43*	-2.76**	-0.05	-43.12*	-1.31	-0.51	0.09
9450	-880.92*	0.60	-0.12	5.36	-1.52	6.79	0.28**
1368	546.51*	-0.33	0.01	35.62	-1.03	1.56	-0.19
M 131	-867.08**	0.17	0.34*	-8.09	-1.02	-4.36	0.31**
88094	-569.49*	0.24	-0.05	13.38	-2.95**	-0.79	0.04
J18-1	-650.35**	0.80	0.08	-55.79**	-2.44*	3.05	0.51**
88069	367.32	-0.76	-0.05	17.35	1.50	4.18	-0.20*
Entrada 29	-501.27*	0.97*	-0.12	4.94	0.44	-2.22	0.13
CML 358	-146.94	0.87	0.01	-4.29	-3.41**	-1.31	-0.02
Entrada 3	-470.78*	0.30	0.01	2.93	-0.46	1.36	0.09
CML 254	84.29	0.40	0.01	23.47	0.55	-5.66	-0.12
5012	-341.08	0.37	-0.12	22.61	0.00	9.49*	-0.19
Cam inb gp1 17	259.45	0.50	0.25	13.83	1.54	6.04	-0.37**
9848	-329.05	-1.30**	0.15	15.33	1.37	0.64	0.13
CLA 18	217.99	-0.16	-0.25	3.87	0.82	0.70	-0.21*
ATP S9 30 Y-1	-431.89	0.34	-0.15	-11.40	0.30	-0.57	0.36**
ATP S5 31 Y-2	308.32	-0.66	-0.09	-2.16	1.45	-2.23	0.01
KU1414	274.74	0.70	0.21	1.37	2.43*	-2.52	-0.16
5057	-235.70	0.10	0.25	-5.61	1.12	-3.97	0.08
ATP S6 20 Y-2	-84.51	0.17	-0.22	-1.07	1.79	5.46	-0.04
ATP S8 30 Y-3	185.93	-0.90	0.18	22.53	0.92	9.45*	-0.02
CLWN201	720.74**	-2.20**	-0.25	-14.75	1.25	-7.38	-0.21*
TZMI 102	-240.31	-0.30	0.01	-40.50*	1.13	-1.45	0.03
J16-1	728.75**	-1.46**	-0.12	24.79	-0.25	-4.27	-0.27**
CLYN246	982.75**	-1.14*	-0.09	59.62*	2.66**	4.78	-0.22*
CML395	125.17	1.44**	0.18	4.24	-1.19	0.53	0.04
CML494	-16.75	0.97*	-0.29*	-12.34	-2.12*	1.13	0.13
CML165	-59.51	-0.10	0.11	-24.48	0.72	-7.71	-0.02
CLQRCWQ26	640.10**	-0.40	-0.02	16.14	-0.37	1.02	-0.14
CML451	19.49	1.80**	0.44**	-7.54	-0.94	-15.71**	0.31**
V-351-1/6	-557.39*	-1.44**	0.05	-51.82**	1.10	-14.42**	0.08
V-481-73	-751.85**	-0.66	0.01	-26.93	-1.15	2.99	0.01
TZ-STR-133	339.57	-0.90	0.01	-59.69**	-0.47	-1.05	0.08

*, **, Significant at 0.05 and 0.01 probability levels, respectively; ns = not significant; DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPAD = leaf chlorophyll content; PHT=plant height; EA=ear aspect, YIELD=grain yield.

Table 4.12 General combining ability effects of lines and testers for grain yield and other agronomic traits under optimal environments (Cont'd)

Lines	**Yield (Kg ha^{-1})**	**DTS (days)**	**ASI**	**LAREA**	**SPAD (%)**	**PHT**	**EA (1-5)**
TL-11-A-1642-5	675.86**	0.44	-0.15	-14.97	-0.64	-2.95	0.16
Ku1409	-26.32	0.07	-0.22	-28.98	0.76	10.40*	-0.12
ATP S6-20-Y-1	538.19*	-1.03*	-0.32*	34.70	0.92	2.99	-0.27**
CML343	402.90	1.40**	-0.02	94.05**	-0.46	4.12	-0.36**
CML 444	-250.34	3.77**	0.44**	-26.57	-0.95	1.46	0.29**
4001STR	190.86	0.07	-0.02	23.94	-0.12	0.95	0.03
Testers							
87036	262.49**	-0.14**	-0.06	11.18**	1.21**	8.65**	-0.11**
Exp1 24	21.36**	0.44**	0.03	-3.06**	-1.33**	-5.21**	-0.02
9071	-283.84**	-0.30**	0.03	-8.12**	0.12*	-3.44**	0.14**
SE lines	**298.11**	**1.09**	**0.21**	**34.48**	**1.25**	**6.82**	**0.17**
SE testers	**95.58**	**0.22**	**0.10**	**4.53**	**0.68**	**3.53**	**0.04**

*, **, Significant at 0.05 and 0.01 probability levels, respectively; ns = not significant; SE = standard error; DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPAD = leaf chlorophyll content; PHT=plant height; EA=ear aspect, YIELD=grain yield.

4.3.2.5 Specific combining ability effects for grain yield

Specific combining ability effects for grain yield under low N environments are presented in Table 4.14. The cross between ATP S6 20 Y-2 and Exp1 24 had the highest positive SCA (679.45) for grain yield under low N environments (Table 4.13). This was followed by TL-11-A -1642- 5 x Exp1 24 (648.39) and CML 494 x 9071 (626.40). The first two hybrids ATP S6 20 Y-2 x Exp1 24 and TL-11-A -1642- 5 x Exp1 24, with the highest SCA, were among the highest yielding hybrids while the third, CML494 x 9071 and other hybrids such as CML358 x Exp1 24, M131 x 9071 had very high SCA (626.40, 506.33, 455.89 respectively) but they were not among the highest yielding hybrids and produced 2933, 2993 and 2522 kg ha^{-1} respectively. In contrast, 1368 x Exp1 24 and ATP S6 20 Y-1 x 87036 had negative SCA (-114, 1 and -98) but yielded more (3149 and 3213 kg ha^{-1} respectively) than the above mentioned hybrids with high SCAs. Many other hybrids with high positive SCA performed poorly as well.

Under optimal environments, the best hybrid with the highest positive SCA effect (986.82) was 4001STR x 9071, followed by J18-1 x 87036 with an SCA effect of 905.58 and TZ-STR-133 x 87036 with 893.04 as SCA effect (Table 4.14). All these were high yielding hybrids, with two of them (TZ-STR-133 x 87036 and 4001STR x 9071) among the 20 best yielding under optimum conditions.

Table 4.13 Specific combining ability effects for grain yield under low N environments

Lines	Testers		
	87036	**Exp1 24**	**9071**
Cla 17	-157	156.12	0.88
9450	176.14	-36.55	-139.59
1368	39.78	-114.17	74.4
M 131	-314.4	-141.49	455.89
88094	309.16	-494.04	184.88
J18-1	196.68	-317.1	120.42
88069	-39.04	-90.83	129.87
Entrada 29	-721.19*	452.43	268.76
CML 358	16.68	506.33	-523.02
Entrada 3	265.88	-131.26	-134.62
CML 254	162.89	-62.79	-100.1
5012	-116.73	110.06	6.68
Cam inb gp1 17	86.6	-27.92	-58.68
9848	130.24	-411.97	281.73
CLA 18	155.1	-68.81	-86.29
ATP S9 30 Y-1	280.4	155.38	-435.78
ATP S5 31 Y-2	20.8	-130.12	109.33
KU1414	313.07	-272.61	-40.46
5057	30.32	-98.44	68.13
ATP S6 20 Y-2	-507.06	679.45*	-172.39
ATP S8 30 Y-3	-187.49	-6.86	194.36
CLWN201	275.45	-202.25	-73.2
TZMI 102	-355.56	344.13	11.44
J16-1	-115.2	303.93	-188.73
CLYN246	503.41	-456.75	-46.67
CML395	-480.61	229.27	251.34
CML494	-198.48	-427.93	626.403*
CML165	518.95	-355.12	-163.83
CLQRCWQ26	-109.46	159.52	-50.06
CML451	187.95	-374.18	186.23
V-351-1/6	-31.49	-43.26	74.75
V-481-73	-594.49	602.76	-8.27
TZ-STR-133	-272.85	120.64	152.21
TL-11-A-1642-5	51.38	648.395*	-699.77*
Ku1409	28.66	-16.79	-11.86
ATP S6-20-Y-1	-98.84	65.49	33.35
CML343	-23.52	-75.23	98.76
CML 444	165.75	468.08	-633.83*
4001STR	408.16	-645.52*	237.37
SE	**318.89**	**318.89**	**318.89**

*, **, Significant at 0.05 and 0.01 probability levels, respectively, and ns = not significant.

Table 4.14 Specific combining ability effects for grain yield under optimal environments

Lines	Testers		
	87036	**Exp1 24**	**9071**
Cla 17	198.45	293.24	-491.69
9450	97.77	532.12	-629.89
1368	-45.03	101.87	-56.84
M 131	-893.42*	301.29	592.13
88094	84.79	-471.23	386.44
J18-1	905.58*	-65.83	-839.75*
88069	-569.85	93.37	476.48
Entrada 29	-498.58	358.29	140.28
CML 358	570.35	394.44	-964.79*
Entrada 3	138.63	-330.23	191.6
CML 254	-643.06	508.75	134.32
5012	-115.8	254.75	-138.95
Cam inb gp1 17	158.46	-166.89	8.43
9848	27.2	-307.46	280.26
CLA 18	213.51	678.56	-892.06*
ATP S9 30 Y-1	634.38	-89.83	-544.55
ATP S5 31 Y-2	173.48	-388.74	215.25
KU1414	-111.2	-58.53	169.73
5057	-536.08	394.34	141.74
ATP S6 20 Y-2	-795.1*	339.79	455.31
ATP S8 30 Y-3	20.04	-9.05	-10.99
CLWN201	-221.98	143.04	78.94
TZMI 102	144.77	-11.23	-133.54
J16-1	-337.17	332.91	4.26
CLYN246	278.32	-232.95	-45.37
CML395	-888.88*	621.06	267.82
CML494	45	-808.92*	763.92
CML165	212.11	-43.25	-168.86
CLQRCWQ26	-290.71	409.14	-118.43
CML451	548.87	-497.01	-51.85
V-351-1/6	-285.87	-229.37	515.24
V-481-73	-263.1	309.21	-46.11
TZ-STR-133	893.04*	-624.02	-269.02
TL-11-A-1642-5	752.27	-176.46	-575.81
Ku1409	235.94	-392.6	156.66
ATP S6-20-Y-1	66.98	207.6	-274.58
CML343	1.66	-516.69	515.03
CML 444	-140.04	367.64	-227.6
4001STR	234.29	-1221.11*	986.82*
SE	**399.94**	**399.94**	**399.94**

*, **, Significant at 0.05 and 0.01 probability levels, respectively, and ns, not significant.

4.3.3 Heterotic groups of inbred lines

The different heterotic groups based on specific combining abilities (SCA) of lines with the three testers (87036, Exp1 24 and 9071) and testcross mean grain yields under low N, optimum and across environments are presented in Table 4.15.

Lines with positive SCA with a tester and mean grain yield higher than the yield of the best check 87036 x Exp1 24 were assigned to the group opposite to the tester's heterotic group while lines with negative SCA when crossed with a tester were considered to belong to the same heterotic group as the tester. Lines with positive SCA and higher yields than the yield of the best check with two testers were classified into heterotic groups opposite to both of these testers. For example, the lines TL-11-A-1642-5, CLWN201, and J-16 had positive SCA and higher yields than the best check when crossed to both Exp1 24 and 87036. These lines are classified into both anti- Exp1 24 and anti-87036 groups. Under low N the three testers classified 27 of the 39 inbred lines into three heterotic groups; group A (anti -87036), group B (anti-Exp1 24) and group C (anti-9071). Similarly, the three testers classified 24 lines of the 39 into three groups under optimal environments.

Table 4.15 Heterotic groups of inbred lines under low N and optimal environments

Group A (Anti-87036)	Group B (anti-Exp1 24)	Group C (anti-9071)
Under low N environments		
CML165	ATP S6 20 Y-2	CML494
CLYN246	V481-73	4001-STR
4001-STR	CML358	CML451
KU1414	Entrada29	TZSTR133
CLWN201	TZMI102	88069
Entrada3	J16-1	CML343
CML451	CLRCWQ26	1368
CML254	ATP S6 20 Y-1	ATPS620 Y-1
CLA18	TZSTR133	
Cam inb gp1 17	TL-11-A-1642-5	
1368	ATP S9 30 Y-1	
ATP S5 31 Y-2	CML444	
TL-11-A-1642-5		
ATP S9 30 Y-1		
CML444		
Under optimum environments		
J18-1	Cla18	4001-STR
TZSTR133	CML395	CML494
TL-11-A-1642-5	CML254	CML343
ATP S9 30 Y-1	CLRCWQ26	88069
CML358	ATP S6 20 Y-2	CLWN201
CML451	J16-1	J16-1
CLYN246	ATP S6 20 Y-1	
KU1409	CLWN201	
4001-STR	1368	
CML165	88069	
ATP S5 31 Y-2		
Cam inb gp1 17		
ATP S6 20 Y-1		
CML494		
ATP S8 30 Y-3		
CML343		

Anti-87036 = heterotic group opposite to group of 87036
Anti-Exp1 24 = heterotic group opposite to group of Exp1 24
Anti-9071 = heterotic group opposite to group of 9071

4.3.4 Performance *per se* of inbred lines under low N and optimal environments

Under low N environments, grain yields of inbred lines ranged from 213 kg ha^{-1} to 1352 kg ha^{-1} with a mean of 746 kg ha^{-1} (Table 4.16). Under optimum environments, grain yield ranged from 660 to 4231 kg ha^{-1} with a mean of 1625 kg ha^{-1}. CML 254 was the highest yielding line under low N environments, optimum conditions and across environments, with 1352 kg ha^{-1}, 3007 and 2179 kg ha^{-1} respectively (Table 4.16). Under low N, CML 254 was followed by 9071 (1161 kg ha^{-1}), TZMI 102 (1160 kg ha^{-1}), CML 343 (1127 kg ha^{-1}) and 1368 (1106 kg ha^{-1}). Low N selection index ranged from -7.8 to 5.1, with a mean of -0.4. Line CML343 had the highest index (5.1) and was the most tolerant line.

Table 4.16 Grain yield (kg ha^{-1}) of the best 20 inbred lines under low N and yield under optimal and across environments at Mbalmayo in 2012 and 2013

Inbreds	Low N	Optimal	Across	Yield reduction (%)	Low N index	Rank
CML 254	1352	3007	2179	55.0	3	6
9071	1161	1485	1323	21.8	1.39	12
TZMI 102	1159	1677	1418	30.9	3.95	4
CML343	1127	1855	1491	39.3	5.12	1
1368	1106	1957	1532	43.5	1.79	9
CML 264	1061	1663	1362	36.2	1.36	13
Exp1 24	1025	1889	1457	45.8	2.56	7
87036	907	2032	1470	55.4	0.43	21
5012	899	1143	1021	21.3	0.08	25
CML165	885	1553	1219	43.0	0.2	23
V481-73/2	864	1267	1066	31.9	4.94	2
TZ-STR-133	860	1624	1242	47.0	3.14	5
J18-1	846	1653	1249	48.8	2.51	8
KU1414	836	4306	2571	80.6	4.41	3
CLA 18	773	1361	1067	43.3	-1.06	33
TZSTR132	752	1271	1011	40.9	-0.68	29
CLQRCWQ26	737	1346	1041	45.2	-0.69	30
88069	727	1704	1215	57.4	0.55	17
4001STR	722	1493	1108	51.6	0.5	20
9006	716	3321	2018	78.4	-1.53	34
Mean	**746**	**1625**	**1185.30**	**54.1**	**-0.41**	
Min	**213**	**660**	**485.6**	**21.3**	**-7.78**	
Max	**1352**	**4231**	**2571.0**	**80.6**	**5.12**	
Lsd	**806**	**2683**	**1373.1**			

4.3.5 Relationship between yield performance of parental lines and their hybrids

Under low N environments at Mbalmayo, mid-parent heterosis of hybrids ranged from 34.3 to 495.14% with an average of 265.64% (Table 4.17). CLYN246 x 87036 had the highest mid-parent heterosis (495.14%), followed by CML444 x Exp1 24 (456.97%) and Entrada 29 x Exp1 24 (434.88%). The lowest mid-parent heterosis were recorded for J18-1 x 9071 (34.43%), CML358 x 87036 (50.52%) and CML358 x Exp1 24 (56.73%).

High parent heterosis ranged from -5.81 to 379.78% with an average of 189.72%. CLYN246 x 8703 had the highest value (379.78%) followed by CLWN 201 x 87036 (338.31%) and 4001-STR x 87036 (327.72) (Table 4.17). The same three hybrids with the lowest Mid-parent values had the lowest high parent heterosis (16.17, -5.84 and 0.63, respectively) (Table 4.17).

Standard heterosis ranged from -60.93% to 26.05% with an average of -11.72%. The hybrid CLYN246 x 87036 had the highest standard heterosis (26.05%).It was followed by ATPS9 30-Y-1 x Exp1 24 (22.36%) and CLWN201 x Exp1 24 (22.15%). J18-1 x 9071, 9050 x 9450 and 9848 x Exp1 24 had the lowest values (-60.93%, -58.28% and -54.9%, respectively).

Under optimal environments, mid-parent heterosis ranged from 24.40% for CLQRCWQ26 x 9071 to 352.97 % for CML444 x Exp1 24 while high parent heterosis ranged from -15.98% for CLQRCWQ26 x 9071 to 260.28% for 4001-STR x 9071 (Table 18). The average was 179.70% and 136.21% for mid-parent and high parent, respectively. Standard heterosis ranged from -59.82% for CML165 x 9071 to 6.24% for CML358 x 87036 with an average of -20.58%. Only four hybrids out-yielded the best check but with a standard heterosis of less than 10%.

Table 4.17 Twenty best hybrids based on standard heterosis, mid-parent and high parent heterosis for grain yield under low N environments in Mbalmayo in 2012 and 2013

Hybrids	**Mid-parent heterosis (%)**	**High parent heterosis (%)**	**Standard heterosis (%)**
CLYN246 x 87036	495.14	379.78	26.05
ATP S9 30 Y-1 x Exp1 24	429.00	312.44	22.36
CLWN201 x Exp1 24	394.33	311.73	22.15
CML343 x 87036	307.44	267.77	19.99
J16-1 x Exp1 24	409.87	299.17	18.43
1368 x 87036	297.19	261.55	15.76
Entrada 29 x Exp1 24	434.88	289.93	15.69
CML343 x 9071	249.00	243.80	15.61
CLWN201 x 87036	400.39	338.31	15.15
CML 444 x Exp1 24	456.97	285.14	14.27
CLQRCWQ26 x Exp1 24	347.23	284.55	14.09
1368 x 9071	243.79	235.57	12.84
4001STR x 87036	376.33	327.72	12.37
CLA 18 x 87036	361.80	327.54	12.33
Cam inb gp1 17 x 87036	434.37	320.88	10.58
CML395 x Exp1 24	354.91	265.66	8.49
CML165 x 87036	317.08	312.04	8.25
ATP S5 31 Y-2 x 87036	410.02	306.85	6.89
TL-11-A-1642-5 x 87036	373.03	302.28	5.69
Best check			
87036 x Exp1 24	-	-	-
Average	**265.64**	**189.72**	**-11.72**
Min	**34.43**	**-5.81**	**-60.93**
Max	**495.14**	**379.78**	**26.05**

Table 4.18 Twenty best hybrids based on standard heterosis, mid-parent, high parent and standard heterosis for grain yield under optimal environments in Mbalmayo 2012 and 2013

Hybrids	Mid-parent heterosis (%)	High parent heterosis (%)	Standard heterosis (%)
CML 358 x 87036	228.40	196.87	6.24
ATP S8 30 Y-3 x 9071	255.37	218.13	5.83
Entrada 3 x Exp1 24	254.13	194.30	5.32
ATP S8 30 Y-3 x 87036	270.12	213.46	4.28
M 131 x 87036	310.04	179.37	-0.03
Cam inb gp1 17 x 87036	190.35	177.66	-0.64
CLWN201 x Exp1 24	295.83	195.30	-1.76
TZMI 102 x Exp1 24	244.27	194.73	-1.95
KU1414 x 87036	212.43	191.90	-2.89
J18-1 x 9071	73.42	27.63	-3.22
88094 x 9071	220.85	167.90	-4.13
CML 254 x 9071	197.23	167.37	-4.32
CLWN201 x 87036	207.45	187.33	-4.41
4001STR x 9071	261.31	260.28	-5.27
88094 x 87036	191.21	163.18	-5.82
J16-1 x 9071	204.42	183.05	-5.84
CML395 x Exp1 24	242.26	182.99	-5.86
KU1414 x 9071	228.45	182.57	-6.00
CLYN246 x 87036	184.68	182.49	-6.02
4001STR x 87036	218.99	187.19	-6.22
Entrada 3 x 87036	195.29	160.50	-6.78
Best check			
87036 x Exp1 24	-	-	-
Average	**179.70**	**136.21**	**-20.58**
Min	**24.40**	**-15.98**	**-59.82**
Max	**352.97**	**260.28**	**6.24**

4.3.6 Correlation between grain yield and secondary traits

Under low N environments, grain yield was positively correlated with leaf area (0.47**), leaf chlorophyll content (0.49**), plant height (0.42**) but was negatively correlated with days to silking (-0.36**), anthesis silking interval (-0.20**) leaf senescence (-0.23**) and ear aspect (-0.58**) (Table 4.19).

Under optimum conditions, grain yield was positively correlated with leaf area (0.34**), leaf chlorophyll content (0.28**), plant height (0.29**) and negatively correlated with days to silking (-19**), anthesis silking interval, (-18**) and ear aspect (-54**) (Table 4.19).

Table 4.19 Pearson correlation coefficients between grain yield and other agronomic traits under low N, optimum and across environments

Traits	Grain yield (kg ha^{-1})		
	Low N	Optimum	Across
DTS	-0.36**	-0.19**	-0.37**
ASI	-0.2**	-0.18**	-0.34**
LAREA	0.47**	0.34**	0.52**
SPAD	0.49**	0.28**	0.54**
LSENE	-0.23**	-	-
PHT	0.42**	0.29**	0.44**
EPP	0.01ns	0.15ns	0.07**
EA	-0.58**	-0.58**	-0.64**

*, **, Significant at 0.05 and 0.01probability levels, respectively; ns = not significant; DTS = days to 50% silking; ASI= anthesis silking interval; LAREA= Ear leaf area; SPAD = leaf chlorophyll content; PHT=plant height; EPP=ears per plant; EA=ear aspect, YIELD=grain yield.

4.4 Discussion

Significant differences among environments suggest that environments were variable and it is important to evaluate hybrids both under low N and optimum environments. The significant hybrid x environment interaction suggests that the performance of hybrids for all traits was not consistent across environments. These results are in agreement with t the findings of Ifie (2013) who also reported significant genotype x environment interactions for maize grain yield and other agronomic traits under low N. This shows the importance of evaluating hybrids in many environments over several years.

The significant differences observed in all traits among the hybrids under low N suggests that there was genetic variability among hybrids for these traits and selection is possible to identify the most desirable hybrids under low N. Fifteen out of the 20 best yielding hybrids were among the best 20 low N tolerant hybrids. All the lowest yielding hybrids were among the least tolerant when the index was used.

The best hybrid among the four checks evaluated was 87036 x Exp1 24, and the performance of this hybrid under low N was similar to that obtained (3 t ha^{-1}) by The *et al.* (2013).

The best high yielding hybrids under low N (TL-11-A-1642-5 x Exp1 24, CLWN201 x 87036, ATP S6 20 Y-2 x Exp1 24, J16-1 x Exp1 24, ATP S9 30 Y-1 x Exp1 24 and CLYN246 x 87036) out-yielded the four checks by 18 %, including the commercial hybrid (87036 x Exp1 24) of the Humid Forest Zone of Cameroon, the target zone of the present study. These six hybrids could therefore be selected as low N tolerant.

Under optimal environments, two of the five highest yielding hybrids TL-11-A-1642-5 x 87036 , CLYN246 x 87036, TZ-STR-133 x 87036, CLWN201 x Exp1 24, J16-1 x Exp1 24 were also selected among the six best hybrids under low N. These were CLYN246 x 87036 and J16-1 x Exp1 24.

Six hybrids were selected from the 20 best hybrids both under low N and optimal and across environments. These included CLYN246 x 87036, CLWN201 x Exp1 24, J16-1 x Exp1 24, 1368 x 87036 ATP S6-20-Y-1 x Exp1 24 and Cam inb gp1 17 x 87036. They appear to be 10% superior to the best check. Exp1 24 appears to be an excellent line and could be used as a tester for source populations between TL-11-A-1642-5, ATP S6 20 Y-2, J16-1, and ATP S9 30 Y-1. CLWN201 and CLYN246 could be recombined to form a source pop with 87036 as the tester.

Under low N, optimum and across environments, the majority of hybrids selected for high grain yield had one CIMMYT line and one line developed by the Cameroon national breeding program as parental lines. This suggests that these introduced lines from CIMMYT and those from IRAD are genetically diverse.

Two hybrid checks yielded more than 5000 kg ha^{-1} under optimum conditions; these included 87036 x Exp1 24, one of the commercial hybrids of the Humid Forest Zone of Cameroon, and Exp1 24 x 9071. Although these checks were not among the 20 highest yielding hybrids in the present study, the grain yield was more stable and higher than those of open pollinated varieties (OPVs) normally grown in the study area. The higher yield compared to OPVs justify the use of 87036 x EXP1 24 as a commercial hybrid. The fact that none of the checks was among the 20 best yielding under all environments suggests that higher yielding hybrids could be selected from the evaluated hybrids. However, the performance of the selected hybrids should be confirmed through additional evaluations followed by on-farm trials before they could be released.

Under optimum conditions, days to silking and anthesis silking interval were shorter than under low N. This is consistent with the findings of Bänziger *et al*. (2000), Betràn *et al.* (2003b), Mosiza (2005) and Ifie (2013) who showed that these traits are delayed by low N stress. Ear leaf area and leaf chlorophyll content were higher under optimum condition than under low N. Bänziger *et al*. (2000) and Mosiza (2005) reported similar results.

Information on yield reduction as a result of stress is important to determine if the level of stress was high enough to discriminate among genotypes and allow for identification of tolerant genotypes (Ifie, 2013). The overall mean under optimum conditions was 4887 kg ha^{-1}, compared to 2721 kg ha^{-1} under low N. This is a yield reduction of 44.31% under low N environments compared to optimum environments. The yield reduction obtained is close to that of Below (1997) and Presterl *et al.*(2003), who reported yield reduction under low N stress of 35% and 37% respectively. Makumbi *et al.* (2011) obtained yield reduction of 55% while evaluating hybrids under low N.

Under low N environments, the non-significant difference between GCA mean squares of testers for days to anthesis, anthesis silking interval under low N environments suggests that the testers used had comparable potential for these traits.

GCA effects are associated with additive gene action while SCA effects are associated with non-additive gene action. Under low N conditions mean squares of both GCA and SCA were significant for all traits except leaf senescence and plant height which had only significant GCA. This suggests that, apart from these two traits which were controlled by only additive gene action, all other traits were controlled by both additive and non-additive gene effects. The magnitude of sums of squares of SCA over GCA suggests that non-additive gene action was predominant in the control of grain yield, anthesis silking interval, leaf chlorophyll content and ear aspect while days to silking, leaf senescence and plant height were influenced mainly by additive gene effects. The predominance of non-additive gene action in controlling grain yield under low N was earlier reported by Betràn *et al.* (2003a), Meseka *et al.*(2006), Makumbi *et al.* (2011), Meseka *et al.*(2013) and Ndhlela (2012). However, this result is contradictory to those of Kling *et al*. (1997), Below *et al.* (1997), Tamilarasi *et al.*(2010), Badu-Apraku *et al.*(2013) and Ifie (2013) who reported predominance of additive gene effects compared to non-additive gene effects for grain yield under low N. The contradiction of the current results with the results obtained by other researchers might be due to the difference in testing environments (N stress level) under which the genotypes were tested or genotypic differences among sets of genotypes included in the studies. The predominance of non-additive genetic effects for grain yield and other traits observed in this set of inbred lines suggests that hybrid development could be employed under low N in order to exploit non-additive gene action which is based on over dominance and epistasis and more predictive of heterotic potential.

Under optimal environments, GCA mean squares were significant for all traits while SCA mean squares were significant only for grain yield, days to silking, leaf area and ear aspect. These four traits are therefore controlled by both additive and non-additive gene effects. The contribution of GCA to the sum of square of crosses was higher than the contribution of SCA for all traits except anthesis silking interval. The higher magnitude of GCA effects than those of SCA plant suggests that additive effects are more important than non-additive gene effect in controlling all traits except anthesis silking interval under optimum conditions. These results are consistent with the findings of Below *et al.* (1997), De Souza *et al.* (2008) and Makumbi *et al.*(2011).This result implies that, due to predominant GCA effects under optimum environment, inbred lines with favorable GCA effects for grain yield and other traits are likely to transmit their characteristics to the progeny and could be useful in a breeding program (Badu-Apraku *et al*., 2013).

The significant GCA x environment interaction for grain yield and other traits indicates that GCA effects associated with the lines and testers were not consistent over environments. Lines with best GCA for grain yield under low N were CML 343, ATP S6 20-Y1 CLWN201 1368, ATP S9 30 Y-1 and CLQRCWQ26. The good combining ability under low N of CLWN201, and CLQRCWQ26 from CIMMYT are in agreement with the description given by CIMMYT (2014). CML343 another line from CIMMYT was also identified by Makumbi *et al.* (2011) as a good general combiner for grain yield across all environments in a study of combining ability under low N, drought and well watered environments. Three lines in this study were also the best general combiners under optimum conditions; these are CLWN201, 1368 and CLQRCWQ26. Cla 17 was the best general combiner for days to silking under low N and optimum condition, whereas 5012 was best combiner in both environments for plant height. The best combiners for shorter anthesis to silking interval were Cla 17 under low N and ATPS6 20 Y-1 under optimum environments. A shorter anthesis to silking interval under low N may imply that the varieties are able to synchronise pollen shedding with silk emergence (Ndhlela, 2012). A reduced anthesis silking interval is a sign of improved partitioning of assimilates to ears around flowering time (Edmeades *et al*., 1993). The best combiners for larger leaf area were CLQRCWQ26 under low N and CML343 under optimum environments. A larger leaf area could imply a better interception of light by the plant for photosynthesis. These lines identified as best combiners could be used as parents in a breeding program to improve the respective traits.

Testers 87036 and Exp 1 24 are good general combiners compared to 9071 for grain yield and other traits except for days to anthesis and days to silking. This suggests that under low N, 87036 and Exp1 24 were more capable of contributing to the hybrids alleles for improvement of these traits.

Under low N, optimum and across environments, even though many crosses with high positive SCA were also high yielding including ATP S6 20 Y-2 x Exp1 24 and TL-11-A -1642- 5 x Exp1 24 under low N, others such as CML494 x 9071, CML358 x Exp1 24, and M131 x 9071 had high positive SCA but produced lower yields than 1368 x Exp1 24 and ATP S6 20 Y-1 x 87036 which had low negative SCA. These results show that positive estimates of SCA are not indicative of high performance in hybrids. Therefore, using SCA solely as suggested by Vasal *et al.*(1992) is not very efficient to classify inbred line into opposite heterotic groups. In fact, classifiying two lines from a cross with high positive SCA that produce low yield into opposite heterotic groups might result in low yield from inter group crossing. SCA must be used together with mean grain yield of test crosses as suggested by Menkir *et al.* (2004) in order to maximize heterosis between lines assigned to opposite heterotic group.

Classification of inbred lines into heterotic group using SCA and mean grain yield of testcrosses as suggested by Menkir *et al.* (2004) allowed the formation of three main heterotic groups A for anti-87036, B for anti-Exp1 24 and C for anti-9071. Based on the known performance of the hybrid 87036 x Exp1 24 which is high yielding, 87036 and Exp1 24 represent opposite heterotic groups, therefore their anti-groups A and B may be opposite. Similarly, Exp1 24 and 9071 are of opposite heterotic groups and B and C their anti-groups could also be opposite. Therefore, one line from group A should produce a high yielding hybrid when crossed with a line of group B and a line from group B should give a high yielding hybrid when crossed to a line from group C.

The assignment of lines into different heterotic groups varied from one environment to the other. This suggests that SCA effects are influenced by the interaction between hybrids and environments as indicated by Fan *et al.* (2009). The heterotic groups formed for each type of environment should therefore be used in hybrid development programs specific to low N or optimum environments.

Bänziger *et al.*(2000) also indicated that the use of secondary traits highly correlated with grain yield and highly heritable could speed up the development of genotypes adapted to low N environments. Under low N, the significant correlation obtained between grain yield and all measured traits except ears per plant indicates a relationship between these traits and may justify the use of some of these traits, especially ASI, leaf chlorophyll content, leaf senescence and ears per plant as selection criteria under low N by many researchers. Bänziger *et al.* (2000) reported that grain yield, number of ears per plant, anthesis-silking interval and leaf senescence were important in identifying superior genotypes under low N. Moreover, Badu-Apraku *et al.*(2011a) reported that, under low N, the most reliable traits were days to anthesis, days to silking, stay green characteristic, anthesis silking interval, plant height, number of ears per plant, ear aspect and plant aspect, but concluded that progress in selecting for improved grain yield is possible using only the number of ears per plant, ear aspect, plant aspect and anthesis silking interval. Even though the relationship between yield and number of ears per plant was not significant in the present study, this trait was found to be correlated with yield and was an important selection criterion in early studies. Under optimum condition, grain yield was also significantly correlated to all measured traits except ears per plant. However, Badu-Apraku *et al.* (2011c) indicated that plant height, number of ears per plant, plant aspect and ear aspect were the most reliable traits under high-N environments.

At Mbalmayo, CML 254, 9071, TZMI 102, CML343 and 1368 were the five highest yielding indreds under low N. CML343 had the highest low N tolerance index and together with 1368 were also among the best general combiners for yield under low N. Thirteen of the 20 highest yielding inbreds were among the most tolerant based on low N tolerance index. CML343 and CML 264 which are tolerant lines in this study were among the low N tolerant checks obtained from CYMMYT. Lines 87036 and 9071 which are among the highest yielding in the current study were also among the outstanding lines under low N in previous studies carried out in the same region (The *et al.*, 2013). In the contrary, Exp1 24 and 5012 two tolerant lines in the present study were among the poorest lines in that earlier study.

The results on heterosis showed an average mid-parent heterosis under low N of 265.64%. This is close to the results of Makumbi *et al.* (2011) who reported an average of mid- parent heterosis of 283 in one low N stress environment and those of Ifie (2013) who observed an average mid-parent heterosis of 220%. Average high parent heterosis (189.72%) is close to the findings of Ifie (2013) who reported 169%. CLYN246 x 87036 was the best hybrid with the highest value for all types of heterosis. This hybrid was also the highest yielding under low N environments in Mbalmayo and across all low N environments.

Mid-parent, high parent and standard heterosis of hybrids were not consistent across environments. They were higher under low N compared to optimum environments. This result is consistent with the findings of Makumbi *et al.* (2011), Betràn *et al.* (2003a) and Welcker *et al.* (2005).These authors reported higher average mid-parent heterosis for grain yield with increasing intensity of stress. The higher heterosis values under low N might be due to the poor performance of inbreds under low N stress.

Similarly, standard heterosis, determined to estimate the superiority of hybrids over the best check was higher under low N. This is probably because the check was developed under high N and did not tolerate low levels of N. Only four hybrids out-yielded the best check under optimum environments. This confirms the good performance of the best check and justifies again its selection as a commercial hybrid.

4.5 Conclusions

Genetic variability was observed among hybrids. Many hybrids out-yielded 87036 x Exp1 24 the commercial hybrid used as check in the study. Among these, six hybrids : CLYN246 x 87036, CLWN201 x Exp1 24, J16-1 x Exp1 24, 1368 x 87036 ATP S6-20-Y-1 x Exp1 24 and Cam inb gp1 17 x 87036 were identified as higher yielding under low N, optimum and across environments than the best check. CLWN201 x Exp1 24, J16-1 x Exp1 24, 1368 x 87036 are candidates for release. CLYN246 x 87036 and ATP S6-20-Y-1 x Exp1 24 and Cam inb gp1 17 x 87036 cannot be considered for release because they are crosses between yellow and white lines. However, their parental lines could be used as testers to classify lines into heterotic groups in further studies or they could be recombined within heterotic groups to develop source populations for new inbred development. For specific areas with low N stress or for farmers who cannot afford N fertilizer, TL-11-A-1642-5 x Exp1 24, CLWN201 x 87036, J16-1 x Exp1 24 may be candidates for release as low N tolerant hybrids and TL-11-A-1642-5 x 87036, TZ-STR-133 x 87036, CLWN201 x Exp1 24 and J16-1 x Exp1 24 could be proposed for optimum N conditions.

Non-additive gene effects were predominant in controlling grain yield and most traits under low N while additive gene effects were more important under optimum N conditions. With the predominance of non-additive genetic effects under low N, it may be possible to develop high yielding hybrids tolerant to low N through exploitation of heterosis.

The high yielding hybrids selected should be evaluated in multi-location trials followed by on farm trials to confirm their performance before they are released. This release process should be done simultaneously with the process of development of new lines. The lines of these selected hybrids could also be used as testers in future research to assign lines into heterotic groups.

The inbred lines identified in the three heterotic groups for each of the two research conditions may be inter-crossed to develop three complementary populations in line with the suggestions of Vasal *et al*. (1992).

CHAPTER FIVE

5.0 GENOTYPE X ENVIRONMENT INTERACTION AND STABILITY ANALYSIS FOR GRAIN YIELD OF MAIZE SINGLE CROSS HYBRIDS

5.1 Introduction

Maize is one of the most important cereals in Cameroon. The crop is grown in all the agro ecological zones both by small and large scale farmers (Etoundi and Dia, 2008; Ngo Nonga, 2008b). Maize is grown under a wide range of conditions such as different soil types, soil fertility levels, moisture levels, different temperatures and cultural practices.

Most farmers, especially, small scale farmers usually grow varieties based on many criteria, but they usually don't consider the suitability of the variety to the environment which is usually influenced by many biotic and abiotic stresses among which is low soil nitrogen. Consequently, this always results in low yields compared to yields obtained in research stations (Derera, 2005). The low yields obtained by farmers are probably due to poor and unstable environmental conditions in their field.

Environmental conditions can fluctuate as a result of drought, reduced soil fertility, pressure from insects and diseases (Bänziger *et al.*, 2004). These authors also reported that environmental conditions can further be amplified by socio-economic constraints faced by small scale farmers. These farmers usually have limited access to technology and inputs, especially fertilizer, irrigation facilities and pesticides and have no means to modify or condition the production environment (Bänziger *et al.*, 2004). Large genotype by environment interactions (G x E) commonly occur under stress conditions; consequently a variety which performs well in one environment during one season or year may not perform well in a different period or in different site within the same region (Sibiya *et al.*, 2012).

Maize growers need cultivars that are reliable and consistent across a wide array of stress conditions and have high yield potential that may be expressed when conditions become more favorable. Plant breeders should therefore develop cultivars capable of withstanding unpredictable environmental variations (Kenga, 2001). In addition, the varieties developed should be stable across environments in order to be widely accepted by farmers throughout a region (Kenga, 2001; Mashark *et al.*, 2007; Miti, 2007; Khalil *et al.*, 2011). For this reason, it is important for newly improved maize cultivar to be evaluated at many sites and for a number of years before release (Badu-Apraku *et al.*, 2012; Ndhlela, 2012). Unfortunately, in these multi-location trials, varietal selection is often inefficient due to genotype by environment interactions and relative rankings of varieties usually differ across environments (Mashark *et al.*, 2007; Badu-Apraku *et al.*, 2011b; Khalil *et al.*, 2011; Badu-Apraku *et al.*, 2012; Adu *et al.*, 2013). As a result, it becomes difficult to demonstrate the superiority of any single variety. This can be done through the use of various statistical models (Ndhlela, 2012).These statistical analyses give information on adaptability and stability of varieties across target environments. It would then be possible to identify varieties that are appropriate for specific environment and those with stable performance across environments.

Many stability analysis models exist. These include joint regression analysis, multivariate analysis among which are the additive main effects and multiplicative interaction (AMMI) and genotype and genotype by environment interaction (GGE) biplot analysis (Ndhlela, 2012). AMMI and GGE biplot analysis are the most powerful statistical tools widely used for the analysis of multi-environment trials (Badu-Apraku *et al.*, 2012).

The objectives of the study were to determine the effect of genotype by environment interaction on grain yield and yield stability of maize single cross hybrids across low N stress and optimal environments.

5.2 Materials and Methods

5.2.1 Germplasm

A total of 80 single-cross hybrids out of 121 hybrids evaluated in Chapter 4 were used in this study. The choice of these hybrids was based on the availability of seeds in sufficient quantity. Seventy six hybrids out of the 80 derived from crosses between some of the 39 lines used in Chapter 4 and the three testers (87036, Exp1 24 and 9071). Four were the hybrids checks described in section 4.2.1 of Chapter 4. Genotypes names and codes are presented in Table 5.1.

Table 5.1 Names and codes of 80 single cross hybrids evaluated across 11 environments in 2012 and 2013

Genotypes	Code	Genotypes	Code
CLYN246 x 87036	G1	88069 x 87036	G39
TL-11-A-1642-5 x 87036	G2	ATP S8 30 Y-3 x 87036	G40
CLWN201 x Exp1 24	G3	CML 254 x Exp1 24	G41
J16-1 x Exp1 24	G4	CLYN246 x 9071	G42
1368 x 87036	G5	CLWN201 x 9071	G43
CLQRCWQ26 x Exp1 24	G6	CML343 x Exp1 24	G44
TL-11-A-1642-5 x Exp1 24	G7	CLQRCWQ26 x 9071	G45
TZ-STR-133 x 87036	G8	ATP S9 30 Y-1 x Exp1 24	G47
CLWN201 x 87036	G9	ATP S6-20-Y-1 x 9071	G48
ATP S6-20-Y-1 x Exp1 24	G10	J16-1 x 9071	G49
CLA 18 x Exp1 24	G11	CML 358 x Exp1 24	G50
ATP S6-20-Y-1 x 87036	G12	Entrada 3 x 87036	G51
Cam inb gp1 17 x 87036	G13	CML494 x 87036	G52
J16-1 x 87036	G14	J18-1 x 87036	G53
4001STR x 87036	G15	CML 444 x 87036	G54
CML343 x 87036	G16	Cam inb gp1 17 x 9071	G55
CLA 18 x 87036	G17	ATP S5 31 Y-2 x 9071	G56
CML395 x Exp1 24	G18	V-481-73 x Exp1 24	G57
CML451 x 87036	G19	Cla 17 x Exp1 24	G58
CML343 x 9071	G20	5057 x Exp1 24	G59
88069 x 9071	G21	ATP S8 30 Y-3 x Exp1 24	G60
CLQRCWQ26 x 87036	G22	KU1414 x Exp1 24	G61
ATP S6 20 Y-2 x Exp1 24	G23	TZ-STR-133 x Exp1 24	G62
4001STR x 9071	G24	ATP S5 31 Y-2 x Exp1 24	G63
ATP S5 31 Y-2 x 87036	G25	ATP S6 20 Y-2 x 9071	G64
ATP S9 30 Y-1 x 87036	G26	Cla 17 x 87036	G66
1368 x Exp1 24	G27	ATP S8 30 Y-3 x 9071	G67
CML165 x 87036	G28	CML 254 x 87036	G68
CML 358 x 87036	G29	88094 x 87036	G69
KU1414 x 87036	G30	TZ-STR-133 x 9071	G70
Entrada 29 x Exp1 24	G31	CML451 x 9071	G71
CML494 x 9071	G32	CML 254 x 9071	G72
CML 444 x Exp1 24	G33	TZMI 102 x 87036	G73
88069 x Exp1 24	G34	TZMI 102 x Exp1 24	G74
Cam inb gp1 17 x Exp1 24	G35	Ku1409 x 9071	G75
CLYN246 x Exp1 24	G36	Entrada 3 x 9071	G76
1368 x 9071	G37	5012 x 87036	G77
Ku1409 x 87036	G38	Ku1409 x Exp1 24	G78
Checks			
87036 x Exp1 24	G46	87036 x 9071	G79
Exp1 24 x 9071	G65	88069 x Cam inb gp1 17	G80

5.2.2 Sites

The 80 hybrids were evaluated at two locations (Mbalmayo and Nkolbisson) of the Humid Forest Zone of Cameroon with bimodal rainfall pattern, during the minor season of 2012 and the major and minor seasons of 2013 in eleven environments. At each location, the trials were established under both low N (20 kg ha^{-1}) and optimum N (100 kg ha^{-1}) conditions. The details on the materials and methods are given on the materials and methods are presented in Chapter 4 (section 4.2.2 and 4.2.3 respectively). Geographical coordinates and details on average rainfall during the growing seasons in each location are shown in Table 5.2.

Table 5. 2 Description of the evaluation sites used for the trials at Mbalmayo and Nkolbisson in 2012 and 2013.

Site	Latitude, longitude and altitude	Environments code	Year	Season	Management	Average rain fall
Mbalmayo	3°31' N, 11°30'E , 641m asl	E1	2012	Minor	Low N	488.87mm
		E2	2012	Minor	Optimum	488.87mm
		E5	2013	Major	Low N	583.46mm
		E6	2013	Major	Optimum	583.46mm
		E9	2013	Minor	Low N	499.66mm
		E10	2013	Minor	Optimum	499.66mm
Nkolbisson	3° 44 N, 11°36 E, 650m asl	E3	2012	Minor	Low N	281(Oct-Nov)*
		E4	2012	Minor	Optimum	281(Oct-Nov)*
		E7	2013	Major	Low N	936mm
		E8	2013	Major	Optimum	936mm
		E11	2013	Minor	Optimun	662mm

asl = above sea level
Low N=low soil nitrogen
Rainfall data were collected at Mbalmayo by IITA and at Nkolbisson by the Rice Project PRODERiP
Major season: From March to June; Minor season: From September to November
* Data for the entire season in this environment were not available.

5.2.3 Experimental design and data collected

Eighty maize hybrids were arranged in an 8 x 10 alpha lattice design in 2 replications. At Mbalmayo, the experimental unit consisted of a single row, 5m long while at Nkolbisson, hybrids were planted in single rows, 4m long. The spacing was 0.75m between rows and 0.5m between hills within a row. Three seeds were planted per hill and later thinned to 2 plants, for a final density of 53,330 plants per hectare.

Fertilization and trial management were carried out as described in section 4.2.4 of Chapter 4.

5.2.4 Data collection

Grain yield and other agronomic data such as days to 50 % anthesis (DTA), days to 50 % silking (DTS), anthesis silking interval (ASI), plant height (PHT), ear height (EHT), ear leaf chlorophyll content (SPAD), leaf senescence (SEN), number of ears per plant (EPP) and ear aspect were collected during the growth period of the crop as described in the materials and methods section of Chapter 4 (section 4.2.5). However, only grain yield data were used for stability analysis.

5.2.5 Statistical analysis

The combined analysis of variance (ANOVA) was done with the PROC GLM procedure in SAS (SAS institute, version 9.2, 2008) using the RANDOM statement with the TEST option. Environments were treated as random effects and genotypes as fixed effects. Entry means were adjusted for block effects according to lattice design (Cochran and Cox, 1960). Each environment was defined as year x season x site x nitrogen treatment. Means were separated using Tukey’s test at $P<0.05$.

The AMMI statistical analysis of yield data was performed with Breeding View software in Breeding Management System version 2.1 (Murray *et al.*, 2013).

GGE biplot analysis was performed using Genstat 15th edition (Genstat, 2012) in order to identify genotypes that were suitable for the different environments as well as genotypes stable across the various environments, and to identify the different mega-environments.

It was difficult to present the eighty hybrids on the AMMI and GGE biplot. Therefore, for a better visualization and interpretation of AMMI and GGE biplot, the 20 best performing hybrids across environments and the four checks were used for the analysis.

5.3 Results

5.3.1 Analysis of variance for grain yield across environments

The results of the combined ANOVA across environments for the 80 hybrids showed that genotype main effect (G), environment main effect (E) and G×E were all highly significant ($P<0{\cdot}001$) for grain yield (Table 5.3). The test environments contributed 60.13% of the total variation in the sum of squares for grain yield, while G and G×E sources of variation accounted for 6.81% and 33.05% of the total variation, respectively.

The ratio of genotype (G) effect over genotype +genotype x environment (G+G x E) was 0.17.

Table 5.3 Combined analysis of variance for grain yield of 80 hybrids across eleven environments

Source	DF	Sum of squares	% contribution to sum of squares	Mean Square	Pr > F
Env	10	2447399522	60.13	244739952	<.0001
Rep(Env)	11	127598961		11599906	<.0001
Block (Env*Rep)	220	382845773		1740208	0.0001
Genotype	79	277051837	6.81	3506985	<.0001
Env*Genotype	790	1345460727	33.05	1703115	<.0001
Error	649	767427967		1182478	
Corrected Total	1759	6096183487			
CV	26.15				
R^2	0.87				

CV= Coefficient of variation; Pr = probability

5.3.2 Yield performance of the 20 best performing hybrids and four checks across eleven environments

The 20 best performing hybrids were selected from the 80 hybrids evaluated across environments. The four checks were added to the 20 hybrids. Yield performance data of these 24 hybrids across eleven environments is presented in Table 5.4. The overall mean across the 11 environments for the 20 selected hybrids ranged from 4484.7 kg ha^{-1} to 5198.3 kg ha^{-1}. The highest yielding hybrid across environments was TL-11-A-1642-5 x 87036 with a yield of 5198 kg ha^{-1}. All the 20 hybrids selected yielded higher than the four checks. The best check across environments was Exp1 24 x 9071 (3912.4 kg ha^{-1}) followed by 87036 x Exp1 24 (3908.9 kg ha^{-1}). The bold and underlined mean yields are for those hybrids that were the highest yielding in each environment. TL-11-A-1642-5 x 87036 was the highest yielding in two optimum environments E4 and E8 with 9531 kg ha^{-1} and 8874 kg ha^{-1}. TL-11-A-1642-5 x Exp1 24 was the best performing in E2 (optimum) and E3 (low N) with 6427 and 5402 kg ha^{-1} respectively.

Entrada 29 x Exp1 24 was also the highest yielding in two environments, E9 (low N) and E11 (optimum). Hybrid 87036 x Exp1 24 one of the checks was not the best in any environment but was among the five highest yielding hybrids in E6 (optimum), E9 (low N) and E10 (optimum) with grain yield of 4232 kg.ha^{-1} and 6410 kg ha^{-1} respectively (Table 5.4).

Table 5.4 Mean grain yield (kg ha^{-1}) of 24 hybrids across 11 environments in Mbalmayo and Nkolbisson in 2012 and 2013

Genotypes	**E1 LO**	**E2 OP**	**E3 LO**	**E4 OP**	**E5 LO**	**E6 OP**	**E7 LO**	**E8 OP**	**E9 LO**	**E10 OP**	**E11 OP**	**Mean across**
1368 x 87036	**4790.3**	6117.5	2547.3	8253.0	3955.5	4953.0	2038.0	5876.0	3247.0	4419.0	3734.0	4545.9
TZ-STR-133 x 87036	4382.4	5665.2	1508.4	8269.0	2224.5	5507.0	3603.6	7397.0	1602.0	5129.0	4166.0	4498.6
CLQRCWQ26 x Exp1 24	4252.8	4817.2	1519.9	6324.0	5403.8	6317.0	2777.9	6816.0	2163.1	5570.0	5110.0	4639.0
CLWN201 x 87036	4092.6	4739.4	2798.5	4987.0	5292.5	**7657.0**	3317.6	6535.0	2544.7	3223.0	4779.0	4540.4
CLYN246 x 87036	3979.3	4782.0	1326.8	7809.0	5157.1	7437.0	3174.8	7017.0	3922.3	5880.0	4940.0	5039.5
TL-11-A-1642-5 x Exp1 24	3939.5	**6427.4**	**5401.2**	7311.0	2807.1	4755.0	2986.6	3773.0	3718.0	4828.0	4449.0	4582.5
CML343 x 9071	3910.5	4774.0	1233.8	5672.0	3810.3	6142.0	2910.3	6011.0	4256.6	5062.0	5672.0	4486.1
CML395 x Exp1 24	3896.0	4396.2	1023.9	6999.0	3748.5	6599.0	2989.4	5127.0	3594.5	5742.0	6342.0	4572.4
CLQRCWQ26 x 87036	3556.8	4087.7	2545.7	5711.0	2144.4	7155.0	3646.1	5188.0	4550.4	5081.0	5783.0	4484.7
CLA 18 x Exp1 24	3426.3	4744.7	2317.2	7627.0	4369.8	5485.0	2357.9	5906.0	2911.0	5785.0	5376.0	4566.6
J16-1 x Exp1 24	3290.0	4706.9	2530.9	6424.0	4315.1	6054.0	2782.1	5789.0	4663.9	**7270.0**	3724.0	4694.4
CML451 x 87036	3284.1	4477.7	1528.0	6569.0	2879.0	5796.0	**4915.5**	7004.0	2846.8	4799.0	6569.0	4589.8
ATP S5 31 Y-2 x 87036	3198.1	4407.4	1424.6	6711.0	4636.0	5877.0	2554.3	6812.0	3239.6	4604.0	7038.0	4570.7
ATP S6-20-Y-1 x 87036	3076.4	4950.8	2447.4	6167.0	3170.8	4555.0	4716.7	8184.0	2654.9	4973.0	4829.0	4517.9
Cam inb gp1 17 x 87036	3042.7	4332.0	760.9	6957.0	3809.4	6089.0	3923.1	5703.0	4603.5	5624.0	4663.0	4499.3
ATP S6 20 Y-2 x Exp1 24	3035.8	3336.3	3651.2	6138.0	3684.2	5448.0	4336.8	6321.0	3074.4	4527.0	7549.0	4621.4
Entrada 29 x Exp1 24	2988.6	3666.9	1535.5	4077.0	4091.8	5742.0	3085.1	5846.0	**4904.5**	5981.0	**9114.0**	4602.0
CLWN201 x Exp1 24	2889.0	4490.5	1208.8	6464.0	**5707.2**	7568.0	3212.0	6532.0	4058.8	5708.0	4380.0	4750.2
TL-11-A-1642-5 x 87036	2734.4	3302.5	1448.0	**9531.0**	4984.6	6231.0	3531.4	**8874.0**	3230.3	5006.0	8619.0	5198.3
ATP S6-20-Y-1 x Exp1 24	2554.3	3220.4	2376.4	7367.0	4640.8	6739.0	4697.0	7719.0	2558.1	3281.0	7458.0	4760.5
Checks												
87036 x Exp1 24	2887.0	3800.8	622.6	2765.0	3241.2	6826.0	3350.0	6045.0	4231.6	6410.0	2710.0	3908.9
87036 x 9071	2175.2	2510.9	698.5	6253.0	1902.5	3273.0	2374.5	4011.0	3985.7	5968.0	2067.0	3211.2
Exp1 24 x 9071	1791.0	3474.9	983.7	4559.0	2850.0	5635.0	2280.5	7950.0	3778.0	4692.0	5155.0	3912.4
88069 x Cam inb gp1 17	782.3	1279.8	1798.6	4049.0	1804.1	2754.0	2783.2	4600.0	1951.6	4424.0	5032.0	2823.4
Means	**3065.6**	**4132.4**	**1660.7**	**5881.6**	**3718.9**	**5413.0**	**3129.9**	**5832.4**	**3208.4**	**4992.7**	**4737.6**	

LO= Low N environment; OP = Optimum environment.

5.3.3 Additive main effect and multiplicative interaction (AMMI) analysis of 24 hybrids for grain yield

The results of the AMMI biplot analysis of the 24 hybrids evaluated in 11 environments showed that environment accounted for 59.82% of the total variation in the sum of squares, while genotype and genotype by environment interaction accounted for 7.89% and 32.28 % of variation observed in grain yield respectively (Table 5.5).

Table 5.5 Analysis of variance for additive main effects and multiplicative interaction model for grain yield of 24 hybrids across 11 environments

Source	df	Sum of squares	Mean squares	Contribution to total variation (%)	F probability
Genotypes	23	67848890	2949952	7.891443	<0.001
Environments	10	514356619	51435662	59.82435	<0.001
Interactions (G xE)	230	277572490	1206837	32.2842	
IPCA 1	32	80827507	2525860	29.22	<0.001
IPCA 2	30	58189285	1939643	20.96	<0.001
Residuals	168	138555699	824736		

df = degree of freedom ; GxE = Genotypes x Environment; IPCA = Interaction Principal Component Axis.

In the AMMI biplot (Fig 5.1) the genotype and environment main effects for grain yield are on the x-axis while the IPCA1 (Interaction Principal Component Axis 1) scores are on the y-axis. The vertical line is the grand mean for grain yield and the horizontal line (y-ordinate) represents the IPCA1 value of zero.

In the AMMI biplot, the IPCA scores of a genotype are an indication of the stability of the genotype across environments. The more the IPCA score is close to zero, the more stable the genotype is across environments. The greater the IPCA scores, either positive or negative, the more specifically adapted a genotype is to certain environments. Accordingly, ATP S6-20-Y-1 x 87036 (G12) and CML395 x Exp1 24 (G18) had their IPCA1 close to zero and can be considered to have small interaction with the environments and to be the most stable hybrids (Fig. 5.1). CML395 x Exp1 24 (G18) and ATP S6-20-Y-1 x 87036 (G12) had grain yield above the grand mean and CML395 x Exp1 24 (G18) was higher yielding than ATP S6-20-Y-1 x 87036 (G12) even though the difference was small. Among the 24 hybrids selected, 87036 x Exp1 24 (G46), Exp1 24 x 9071 (G65), 87036 x 9071(G79) and 88069 x Cam inb gp1 17 (G80) had grain yield response below the grand mean. The other 20 hybrids had grain yield above the grand mean. Among these 20 hybrids, TL-11-A-1642-5 x 87036 (G2) had the highest grain yield, followed by CLYN246 x 87036 (G1), ATP S6-20-Y-1 x Exp1 24 (G10) and CLWN201 x Exp1 24 (G3). TL-11-A-1642-5 x 87036 (G2) had a negative interaction with IPCA1. In contrast, TL-11-A-1642-5 x Exp1 24 (G7), 1368 x 87036 (G5) and J16-1 x Exp1 24 (G4) had yield above the grand mean with high positive IPCA1 scores. CLYN246 x 87036 (G1) and CLWN201 x Exp1 24 (G3) had comparable IPCA1 score and small interaction with environments. TL-11-A-1642-5 x 87036 (G2) was higher yielding than CLYN246 x 87036 (G1), but CLYN246 x 87036 (G1) was more stable than TL-11-A-1642-5 x 87036 (G2). ATP S6-20-Y-1 x Exp1 24 (G10)**,** Entrada 29 x Exp1 24 (G31)**,** ATP S6 20 Y-2 x Exp1 24 (G23) , ATP S5 31 Y-2 x 87036 (G25) and CML451 x 87036 (G19) had grain yield above the grand mean and had negative interaction with IPCA1, and therefore negative interaction with the environments.

Among the four low yielding hybrids, 88069 x Cam inb gp1 17 (G80) was the lowest yielding, followed by 87036 x 9071 (G79) which was the least stable among them.

In AMMI biplot (Fig 5.1), environments are distributed from lower yielding in quadrant A (top left) and C (bottom left) to the higher yielding in quadrants B (top right) and D (bottom right). This graph identified E1, E3, E5, E7 and E9 as low yielding environments. These were all low N environments in Mbalmayo and Nkolbisson in 2012 and 2013. Environments E4, E6, E8, E11 were identified as the high yielding. These were optimum N plots in both locations in 2012 and 2013. The lowest yielding optimum environment was E2. The highest yielding environment was E4 (optimum N, minor season of 2012 at Nkolbisson) while the lowest was E3 (low N, minor season of 2012 at Nkolbisson).

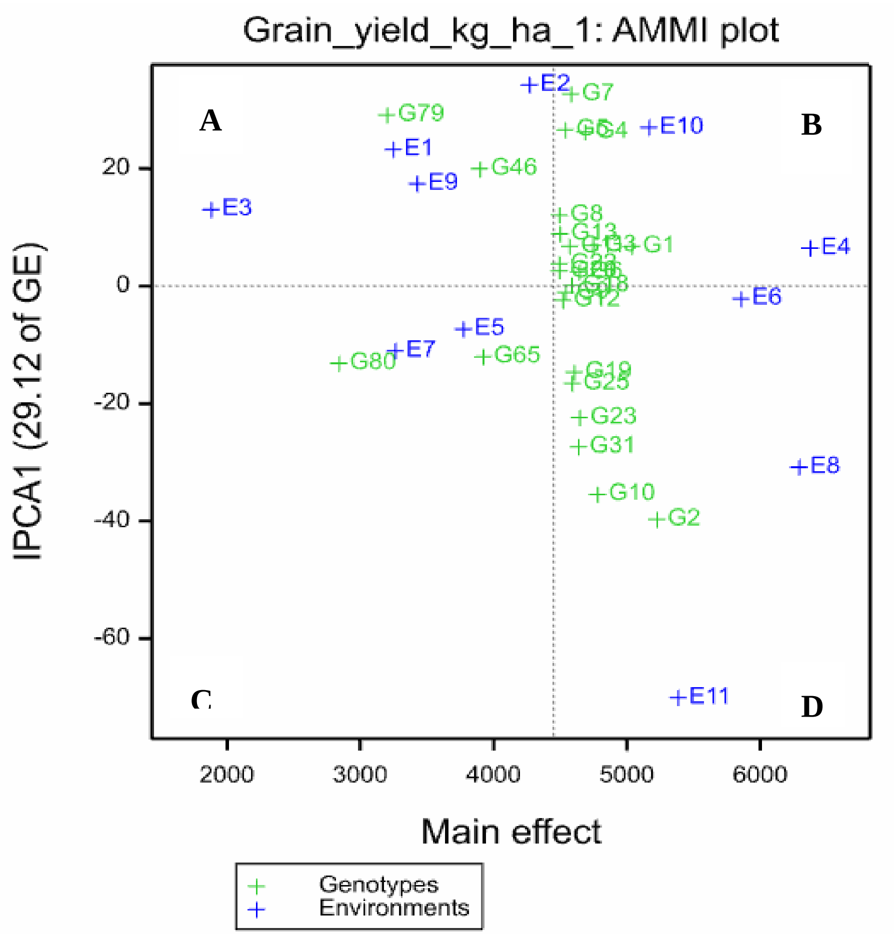


Figure 5.1 AMMI Biplot for grain of 24 maize hybrids showing genotypes and environments (E1-E11) plotted against their IPCA1 scores

G1 = CLYN246 x 87036; G2 = TL-11-A-1642-5 x 87036; G3 = CLWN201 x Exp1 24; G4 = J16-1 x Exp1 24; G5 = 1368 x 87036; G6 = CLQRCWQ26 x Exp1 24; G7 = TL-11-A-1642-5 x Exp1 24; G8 = TZ-STR-133 x 87036; G9 = CLWN201 x 87036; G10 = ATP S6-20-Y-1 x Exp1 24; G11 = CLA 18 x Exp1 24; G12 = ATP S6-20-Y-1 x 87036; G13 = Cam inb gp117 x 87036; G18 = CML395 x Exp1 24; G19 = CML451 x 87036; G20 = CML343 x 9071; G22 = CLQRCWQ26 x 87036; G23 = ATP S6 20 Y-2 x Exp1 24; G25 = ATP S5 31 Y-2 x 87036; G31 = Entrada 29 x Exp1 24; G46 = 87036 x Exp1 24; G65 = Exp1 24 x 9071; G79 = 87036 x 9071; G80 = 88069 x Cam inb gp1 17.

AMMI biplot based on environment scaling showed that the PC1 explained 29.12% of total variation while PC2 explained 20.96% and together the two PCs accounted for 50.08% of the total variation for grain yield (Fig 5.2). Environment E5 (low N plot in major season in 2013 at Mbalmayo) and E7 (low N plot in major season in 2013 at Nkolbisson) contributed less to GE.

These environments were close to the origin of the biplot. On the other hand, E11 (optimum N plot in minor season in 2013 at Nkolbisson) and E4 (optimum N plot in minor season in 2012 at Nkolbisson) were further away from the origin of the biplot and contributed more to the G x E interaction.

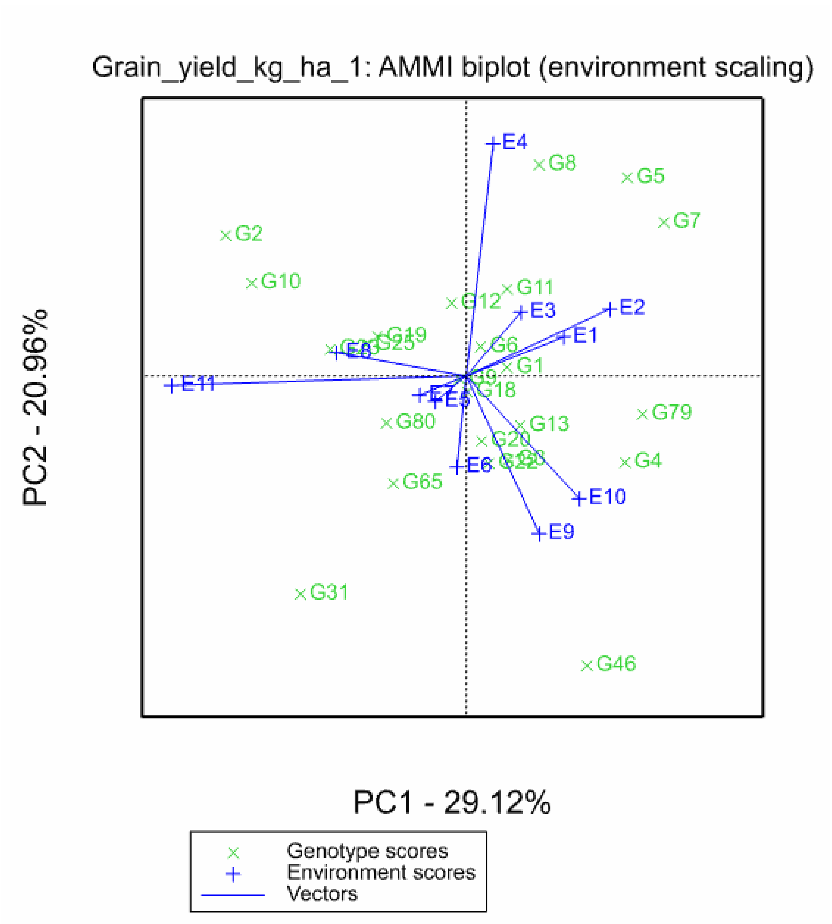


Figure 5.2 Biplot of the additive main effects and multiplicative interaction (AMMI) showing the relationship among 11 testing environments (E1-E11)

The four highest yielding hybrids selected by AMMI for each environment are presented in Table 5.6. TL-11-A-1642-5 x 87036 (G2) appeared as the best hybrid in four (E5, E7, E8 and

E11) out of 11environments. TL-11-A-1642-5 x 87036 (G2) was followed by TL-11-A-1642-5 x Exp1 24 (G7) which was the best in three environments (E1, E2 and E3) and 87036 x Exp1 24 (G46) which was the highest yielding in two environments (E9 and E10). CLYN246 x 87036 (G1) appeared as the third in three environments and as fourth in three other environments. CLWN201 x Exp1 24 (G3) appeared as second, third and fourth in three different environments while ATP S6-20-Y-1 x Exp1 24 (G10) appeared as second in two environments and as third and fourth in two different environments.

Table 5.6 Means and scores of the first four genotypes selected by AMMI for each environment in 2012 and 2013

Environments	Mean	Score	First	Second	Third	Fourth
E2	4271	34.23	G7	G5	G8	G4
E10	5166	26.98	G46	G4	G3	G1
E1	3248	23.25	G7	G5	G1	G4
E9	3429	17.42	G46	G4	G31	G3
E3	1885	13.03	G7	G5	G8	G1
E4	6375	6.43	G5	G8	G2	G7
E6	5858	-2.14	G31	G3	G1	G4
E5	3776	-7.3	G2	G31	G1	G10
E7	3264	-11.04	G2	G31	G10	G1
E8	6293	-30.83	G2	G10	G23	G31
E11	5386	-70.03	G2	G10	G31	G23

G2= TL-11-A-1642-5 x 87036; G3= CLWN201 x Exp1 24; G4= J16-1 x Exp1 24; G5=1368 x 87036; G7= TL-11-A-1642-5 x Exp1 24; G8= TZ-STR-133 x 87036; G10= ATP S6-20-Y-1 x Exp1 24; G23= ATP S6 20 Y-2 x Exp1 24; G31= Entrada 29 x Exp1 24; G46=87036 x Exp1 24.

5.3.5 GGE biplot analysis of best 20 hybrids and four checks

The polygon view of the genotypes in the GGE biplot for 24 genotypes is presented in Fig. 5.3. Primary (PC1) and secondary (PC2) scores were significant and explained 29.98% and 21.44% of the variation, respectively. Together they explained 51.42% of the genotype main effect and G x E interaction for the grain yield of maize hybrids evaluated in the 11 environments at Mbalmayo and Nkolbisson in 2012 and 2013.

The polygon view of a GGE biplot displayed the "which-won-where" pattern (Fig.5.3). The vertices of the polygon were the genotype markers located farthest away from the biplot origin in various directions, such that all genotype markers were contained within the resulting polygon. The biplot was divided into six sectors and three mega-environments and showed five vertex cultivars 1368 x 87036 (G5), TL-11-A-1642-5 x 87036 (G2), Entrada 29 x Exp1 24 (G31), 87036 x 9071 (G79) and 88069 x Cam inb gp1 17 (G80). The first mega-environment comprised E1, E2, E3 and E4 and had 1368 x 87036 as the highest yielding hybrid. These four environments were low N (E1and E3) and optimum N (E2 and E4), minor season of 2012 at Mbalmayo and Nkolbisson. The second mega-environment consisted of E5, E6, E7, E8 and E11 and had TL-11-A-1642-5 x 87036 (G2) as the highest yielding hybrid. These environments were low N (E5 and E7) and optimum N (E8 and E11) of major season in 2013 at Mbalmayo and Nkolbisson plus E11 which is optimum N plot of minor season of 2013 at Nkolbisson The third comprised E9 and E10 (low N, and optimum N plots of minor season in 2013 at Mbalmayo), with the highest yielding hybrid as 87036 x 9071 (G79). This mega-environment contained 87036 x Exp1 24 (G46). No environment fell within the sector with Entrada 29 x Exp1 24 (G31) and 88069 x Cam inb gp1 17 (G80), indicating that these hybrids were not the best in any of the mega-environments, or they were the poorest cultivars in some or all of the environments. Genotypes within the polygon were less responsive than the vertex genotypes.

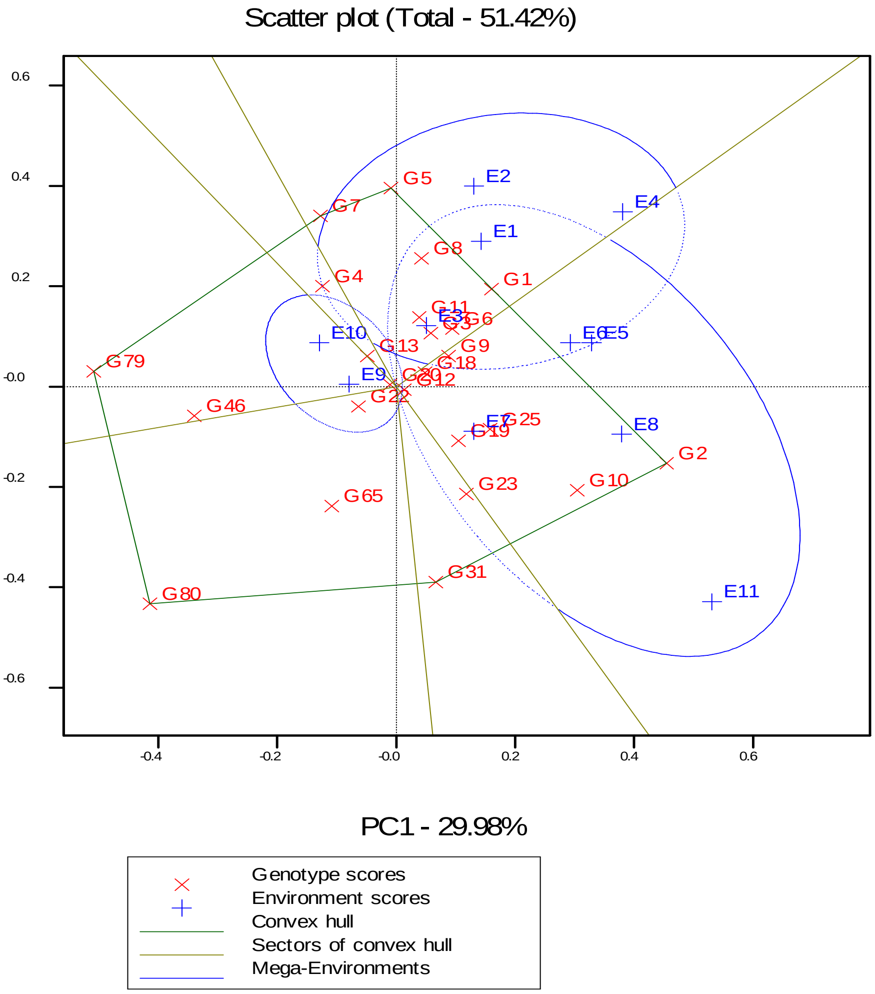


Figure 5.3 A "which won where" biplot based on grain yield of 24 single hybrids evaluated in 11 environments

G1 = CLYN246 x 87036; G2 = TL-11-A-1642-5 x 87036; G3 = CLWN201 x Exp1 24; G4 = J16-1 x Exp1 24; G5 = 1368 x 87036; G6 = CLQRCWQ26 x Exp1 24; G7 = TL-11-A-1642-5 x Exp1 24; G8 = TZ-STR-133 x 87036; G9 = CLWN201 x 87036; G10 = ATP S6-20-Y-1 x Exp1 24; G11 = CLA 18 x Exp1 24; G12 = ATP S6-20-Y-1 x 87036; G13 = Cam inb gp117 x 87036; G18 = CML395 x Exp1 24; G19 = CML451 x 87036; G20 = CML343 x 9071; G22 = CLQRCWQ26 x 87036; G23 = ATP S6 20 Y-2 x Exp1 24; G25 = ATP S5 31 Y-2 x 87036; G31 = Entrada 29 x Exp1 24; G46 = 87036 x Exp1 24; G65 = Exp1 24 x 9071; G79 = 87036 x 9071; G80 = 88069 x Cam inb gp1 17.

Ranking of genotypes based on both mean grain yield and stability performance of the 20 best genotypes and four checks is presented in Fig. 5.4 in order to identify the highest yielding and stable genotypes (Fig. 5.4). Genotypes that are located at the center of the concentric circles are the ideal (highest yielding and stable). The GGE biplot identified CLYN246 x 87036 (G1) and TL-11-A-1642-5 x 87036 (G2) as superior since they were located close to the center of the concentric circles. Both were high yielding but TL-11-A-1642-5 x 87036 (G2) was the highest yielding while CLYN246 x 87036 (G1) was nearest to the ideal genotype and was therefore the most desirable genotype. These hybrids were followed by CLQRCWQ26 x Exp1 24 (G6) and CLWN201 x 87036 (G9) (Fig 5.4).

The four checks were low yielding compared to the 20 hybrids selected. Hybrid 88069 x Cam inb gp1 17 (G80) was located far from the vertical axis at the left and far from the center of the concentric circle, therefore it was the most inferior hybrid in both mean grain yield and stability of performance.

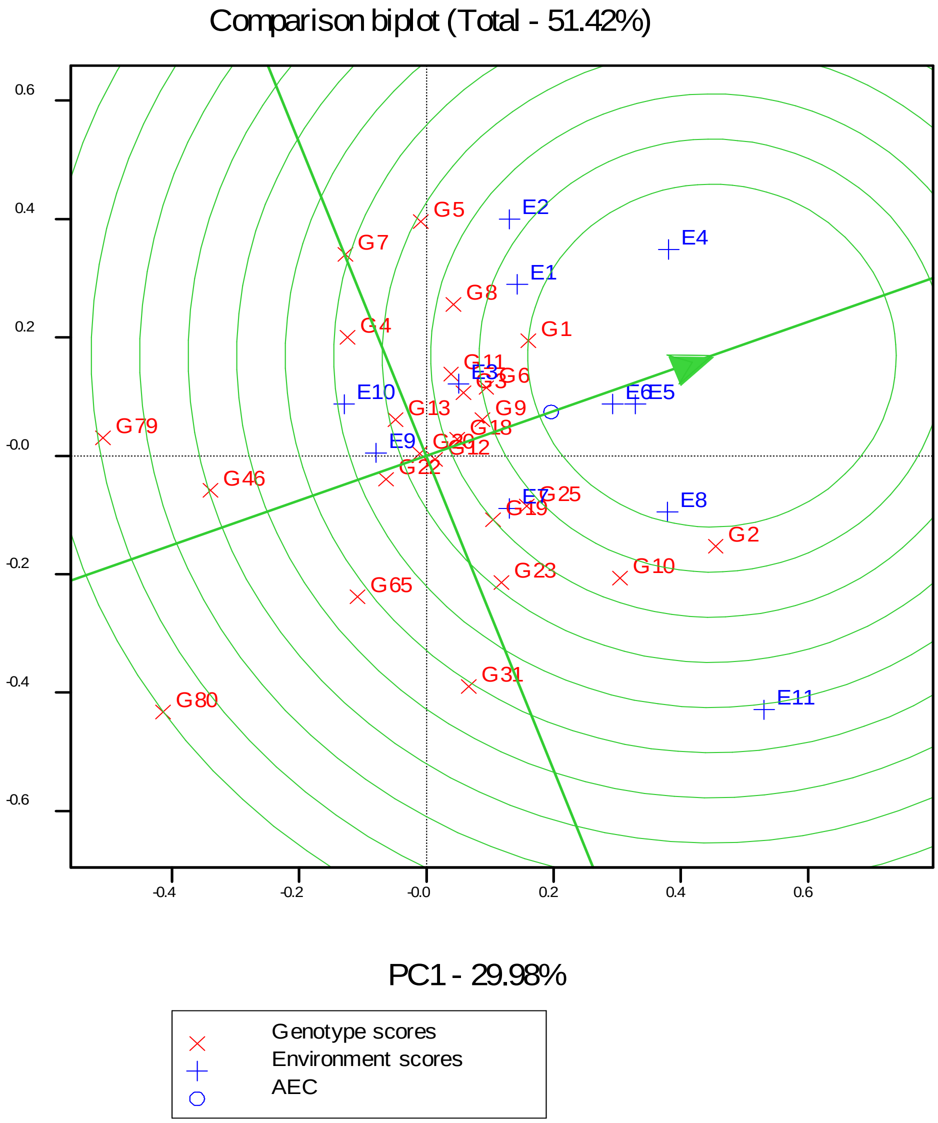


Figure 5.4 Comparison view of 24 hybrids with the ideal genotype based on average grain yield and stability for grain yield across 11 environments in 2012 and 2013

G1 = CLYN246 x 87036; G2 = TL-11-A-1642-5 x 87036; G3 = CLWN201 x Exp1 24; G4 = J16-1 x Exp1 24; G5 = 1368 x 87036; G6 = CLQRCWQ26 x Exp1 24; G7 = TL-11-A-1642-5 x Exp1 24; G8 = TZ-STR-133 x 87036; G9 = CLWN201 x 87036; G10 = ATP S6-20-Y-1 x Exp1 24; G11 = CLA 18 x Exp1 24; G12 = ATP S6-20-Y-1 x 87036; G13 = Cam inb gp117 x 87036; G18 = CML395 x Exp1 24; G19 = CML451 x 87036; G20 = CML343 x 9071; G22 = CLQRCWQ26 x 87036; G23 = ATP S6 20 Y-2 x Exp1 24; G25 = ATP S5 31 Y-2 x 87036; G31 = Entrada 29 x Exp1 24; G46 = 87036 x Exp1 24; G65 = Exp1 24 x 9071; G79 = 87036 x 9071; G80 = 88069 x Cam inb gp1 17.

5.4 Discussion

The greater variation contributed by environment than those from genotype and genotype x environment interaction indicated that the test environments were highly variable. This result is in agreement with Badu-Apraku *et al.* (2012) who reported that contribution of test environments are much greater than from the other sources of variation in most multi-environmental trials. The highly significant genotype × environment interaction for grain yield justified the use of AMMI and GGE biplots to decompose the genotype × environment interactions and to determine the yield potential and stability of the evaluated single cross hybrids.

The results of the AMMI biplot analysis of the 24 hybrids evaluated in 11 environments also showed that environment effects accounted for 59.82% of the total variation in the sum of squares and was the highest value compared to the other components.

The AMMI biplot revealed large variability among the 11 environments, but the yield range among the 24 hybrids was narrow. This is probably because the 20 hybrids were selected among the best hybrids. ATP S6-20-Y-1 x 87036 and CML395 x Exp1 24 have IPCA1 scores near zero and therefore had small interaction with the environments. This small interaction with environments suggests that these hybrids are stable across environments (Yan and Tinker, 2005).. TL-11-A-1642-5 x 87036 was identified as the highest yielding hybrid. It was followed by CLYN246 x 87036, ATP S6-20-Y-1 x Exp1 24 and CLWN201 x Exp1 24. All these hybrids, except ATP S6-20-Y-1 x Exp1 24 are crosses between one CIMMYT line and an IRAD line. Acquaah (2007) indicated that the development of adapted high yielding hybrids requires that the varieties used as parents are genetically divergent. The high yields obtained between these CIMMYT lines and IRAD lines could therefore imply that they are genetically diverse.The negative interaction of TL-11-A-1642-5 x 87036 with the IPCA1 suggests that this hybrid was less sensitive to environmental changes and was likely to be adapted to unfavorable environments as indicated by Badu-Apraku *et al.* (2012). In contrast, TL-11-A-1642-5 x Exp1 24, 1368 x 87036 and J16-1 x Exp1 24 had large positive interaction with IPCA1 and might be more sensitive to environmental changes, and probably more adapted to favorable environments. TL-11-A-1642-5 x 87036 was higher yielding than CLYN246 x 87036, but CLYN246 x 87036 was more stable than TL-11-A-1642-5 x 87036. Hybrids ATP S6-20-Y-1 x Exp1 24, Entrada 29 x Exp1 24, ATP S6 20 Y-2 x Exp1 24, ATP S5 31 Y-2 x 87036 and CML451 x 87036 had grain yield above the grand mean and negative interaction with the environments. This suggests that these hybrids were less sensitive to variation in the environments. They are also most likely to be adapted to unfavorable environments which in this study are low N environments.

AMMI biplot displayed the distribution of environments from low yielding to the high yielding in different quadrants of the graph. This graph placed all low N environments (E1, E3, E5, E7, E9) in the quadrants of lower yielding genotypes and showed the optimum environments (E4, E6, E8, E11) in quadrants of high yielding genotypes as expected.

The GGE biplot analysis of grain yield response and stability of 24 hybrids showed that PC1 explained 29.98% of total variation while PC2 explained 21.44% and together, the two axes accounted for 51.42%. This suggests that the biplot of PC1 and PC2 adequately approximated the environment centered data. The biplot for 24 hybrids was divided into six sectors and three mega-environments in which different cultivars should be selected and deployed to similar environments as suggested by Yan and Tinker (2006). According to Yan and Rajcan (2002) a mega-environment is defined as the subset of locations that consistently share the best set of genotypes across years and the growing regions are relatively homogeneous with similar biotic and abiotic stresses and cropping system requirements.

In the polygon view, the vertex genotype in each sector represents the highest yielding genotype in the location that falls within that particular sector (Yan *et al.*, 2000; Yan and Tinker, 2005; Yan and Tinker, 2006). Accordingly, the biplot identified five vertex genotypes: 1368 x 87036, TL-11-A-1642-5 x 87036, Entrada 29 x Exp1 24, 87036x 9071 and 88069 x Cam inb gp1 17.

Two out of the three mega-environments identified by the GGE biplot included both low and optimum N plots of the two locations**,** but they were related to different years and different growing seasons. The third mega-environment was related to one specific season of one specific year, but included two nitrogen treatments of one site. This could imply that the mega-environments constructed are based on growing seasons (minor or major) and not on different sites, or different nitrogen treatments. This suggests that seasons and years may have accounted more for significant environmental differences and to different genotypic responses to environments as indicated by Sibiya *et al.* (2012). This might probably be due to similar variation in rainfall amount and distribution and biotic stresses within seasons of each year which might have caused the 24 genotypes to have similar relative performance from one environment to another in the mega-environments. In the Bimodal Humid Forest Zone of Cameroon, there are two growing seasons, the major season and the minor season. During the minor season, the total rainfall was lower (Table 5.2), the duration of the rainy period is usually shorter than in the major season. Moreover, during the minor season there is prevalence of many biotic stresses such as fungal diseases (eg. Maize leaf blight caused by *Exserohilum turcicum*) and maize stem borers among which the main species is *Busseola fusca* Fuller (Aroga and Coderre, 2000; Aroga *et al.*, 2001).

The results obtained suggest that highest yielding hybrids identified for each mega-environment should be proposed for environments similar to those of these mega-environments. Therefore, hybrids 1368 x 87036 could be proposed for the minor season and TL-11-A-1642-5 x 87036 for the major season. However, this should be done after further evaluation of hybrids in more environments including more locations, years and seasons as recommended by Yan and Tinker (2005) who indicated the need for crossover interactions to be repeatable across the years so that target environments can be divided into mega-environments and genotypes be recommended based on METs (multi-environment trials). Yan and Tinker (2006) indicated that an ideal genotype should be one that combines both high mean yield performance and high stability across environments; it should be on average environmental coordinate (AEC) on positive direction and have a vector length equal to the longest vector of the genotype as indicated by an arrow pointed to it. Accordingly, the GGE biplot identified TL-11-A-1642-5 x 87036 and CLYN246 x 87036 as closest to the ideal genotype. According to Badu-Apraku *et al.* (2011b), for selection for broad adaptation in maize production, an ideal genotype should have both high mean performance and high stability. TL-11-A-1642-5 x 87036 and CLYN246 x 87036 which were the highest yielding and the most stable hybrids across environments could therefore be selected for broad adaptation (production across environments). These hybrids were followed by CLQRCWQ26 x Exp1 24 and CLWN201 x Exp1 24. The top 20 hybrids performed better than the checks. The poor performance of the check 87036 x Exp1 24 a commercial hybrid, compared to the other hybrids might be due to the fact that it was developed many years ago and might not be adapted to changes (climatic, diseases) that might have occurred in the environments.

5.5 Conclusions

The objectives of this study were to analyze genotype by environment and yield stability among a set of maize single cross hybrids. The study revealed that genotypes, environments and genotype x environment interaction were significant for grain yield. The genotypes therefore performed differently with respect to yield in each of the eleven test environments and their relative performance varied from one environment to another.

AMMI analysis showed that environment effects accounted for a larger proportion of the total variation in the sum of squares for grain yield than genotype effects and genotype x environment effects. The AMMI biplot showed large variability among the environments but a narrow range for yields among hybrids.

The GGE biplot classified the study area into three mega-environments. These mega-environments seemed to be related to the two growing seasons of the year (minor and major). High yielding hybrids were identified for each mega-environment and could be proposed for release for production in similar conditions. These hybrids are 1368 x 87036 for mega-environment 1 which is related to the minor season and TL-11-A-1642-5 x 87036 for Mega environment 2 which is related to the major season.

The most outstanding hybrid was TL-11-A-1642-5 x 87036. This hybrid has the potential for production across environments and should therefore be tested further in multiple environments to confirm consistency of its high yield performance and stability to facilitate its release as a commercial hybrid. Hybrids which were selected as high yielding, but were not stable across environments could be recommended for the specific environments where they performed well.

AMMI and GGE biplot analysis revealed a wide diversity among the environments and the hybrids. The two analyses provided similar results in terms of stability and yield performance of hybrids. However, AMMI could not divide the environments into mega-environments.

In this study, the environments did not include minor and major seasons of all the years, in all locations. Moreover hybrid evaluations were conducted at only two locations. The results of this study should therefore be confirmed through further evaluation of hybrids at different locations of the Bimodal Humid Forest Zone during both minor and major seasons for several years.

CHAPTER SIX

6.0 GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 General discussion

The development and promotion of high yielding maize hybrids with tolerance to low N could reduce the need for nitrogen fertilizer; increase maize production and productivity in sub-Saharan Africa with a concomitant reduction in input costs serving as an incentive to farmers.

This research was conducted in order to identify maize production constraints in the Bimodal Humid Forest Zone of Cameroon and farmers' preferred characteristics in maize varieties. Other objectives were to identify high yielding maize hybrids tolerant to low soil nitrogen and examine the combining abilities of some intermediate and late maturing maize inbreds and classify these lines into heterotic groups. In addition to these objectives, an analysis of genotype x environment interaction and yield stability of single cross maize hybrids across low N and optimum N environments was done.

A participatory rural appraisal conducted in six villages of the Bimodal Humid Forest Zone of Cameroon revealed that almost all the maize farmers interviewed had agriculture as their main occupation. The majority of farmers were small scale farmers who have difficulties in accessing production factors such as fertilizers, seeds, and credit. Despite these difficulties, many households were food secure. These households had enough food from one year to the other due to the use of products from agriculture for both home consumption and income generation and to the presence of two maize growing seasons per year. Farmers make more profit by selling maize during the off-season compared to the main season. This allows them to sustain the household while waiting for the next season as earlier reported by Etoundi and Dia (2008). The production of maize for two seasons was made possible by the rainfall pattern of the area. Farmers cited lack of labor, low soil fertility, unavailability of improved seeds, difficulty in weeding, high cost and unavailability of fertilizer and post-harvest losses as the major constraints to maize production. These were among the constraints identified earlier in the Bimodal Humid Forest Zone of Cameroon (Ngoko *et al.*, 2002; Nguimgo *et al.*, 2003; Ngo Nonga, 2008a). Majority of farmers were not able to apply fertilizers in their fields due to the high cost of fertilizers and the lack of access to credit. The lack of access to credit might be due to the fact that most of the farmers did not belong to an association as reported earlier by Ngo Nonga (2008b).

Unlike an earlier report by Etoundi and Dia (2008), many farmers planted improved maize varieties. This is probably due to the activities of the extension services and other projects carried out by the national research institute or the Ministry of agriculture in the region. However some farmers complained about the high cost of seeds of improved varieties and the lack of availabilty of seeds of most of these varieties on time or in sufficient quantities in their area. They also mentioned that improved varieties, due to the flinty texture of the grains were not suitable for processing for their local meals. These were the main reasons why they grew local varieties. A number of farmers were however satisfied with the improved varieties. Those who have grown hybrids were satisfied with their performance. These were mostly farmers in the Lekié Division who had been introduced to these varieties by a project run by the national research institute. Most farmers from other villages were not aware of the existence of hybrids. This suggests that if maize hybrids are introduced to farmers they might appreciate their superior yield compared to improved open pollinated varieties or local varieties and grow them.

Low soil fertility was ranked as the third most important constraint and non-availability and high cost of fertilizers as fifth most important. Because of the high cost or the lack of availability of fertilizers, most farmers were not able to apply fertilizer. Those who applied fertilizer did not use the recommended rate, especially for the top dressing nitrogen fertilizer. Maize hybrids adapted to low N should be developed and promoted in order to reduce input costs, increase yield per unit of area and therefore maize production of the area. The hybrids developed should possess farmers preferred traits in order to be widely adopted as suggested by Sibiya *et al.* (2013).

The evaluation of 121 hybrids under low N and optimum N soil conditions revealed significant differences among the hybrids for all traits. This suggests that there is genetic variability among these hybrids and selection is possible to identify the most desirable hybrids. Significant hybrid x environment interaction occurred, suggesting the importance of evaluating the hybrids in many environments over several years in both optimum and low N environments which are present in farmers' fields.

Six hybrids (CLYN246 x 87036, CLWN201 x Exp1 24, J16-1 x Exp1 24, 1368 x 87036, ATP S6-20-Y-1 x Exp1 24 and Cam inb gp1 17 x 87036) were identified as high yielding under low N, optimum and across environments. Their yield was 10% better than the best check, 87036 x EXP1 24, a commercial hybrid. Among these, CLWN201 x Exp1 24, J16-1 x Exp1 24, 1368 x 87036 may be candidates for release. CLYN246 x 87036, ATP S6-20-Y-1 x Exp1 24 and Cam inb gp1 17 x 87036 which are crosses from yellow and white lines cannot be released.Their parental lines could be used as testers to classify lines into heterotic groups in further studies or they could be recombined within heterotic groups to develop source populations to develop new inbreds. For specific areas with low N stress, TL-11-A-1642-5 x Exp1 24, CLWN201 x 87036 and J16-1 x Exp1 24 could be proposed for release as low N tolerant hybrids. TL-11-A-1642-5 x

87036, TZ-STR-133 x 87036, CLWN201 x Exp1 24 and J16-1 x Exp1 24 could be proposed for release for optimum N conditions.

The majority of hybrids selected for high grain yield had one CIMMYT line as a parent crossed to a line developed by the National Breeding Program of Cameroun. This suggests that introduced lines from CIMMYT and those from IRAD are genetically diverse. The lines from CIMMYT should therefore be used to improve the diversity of the local germplasm.

The study of mode of gene action of lines revealed that, under low N conditions, grain yield and some agronomic characteristics are controlled by both additive and non-additive gene effects with the predominance of non-additive gene action. The predominance of non-additive gene action in controlling grain yield under low N had earlier been reported by Betràn *et al.* (2003a), Makumbi *et al.* (2011), Meseka *et al.*(2006), Ndhlela (2012) and Meseka *et al.*(2013). However, this result is contradictory to the findings of Kling *et al*.(1997), Tamilarasi *et al.*(2010), Badu-Apraku *et al.* (2013) and Ifie (2013). The difference between the current results and those cited above might be due to the different testing environments or to genotypic differences among inbreds used. The predominance of non-additive genetic effects for grain yield and other traits observed in the inbred lines used here implies that hybrid development could be employed under low N conditions in order to exploit non-additive gene action which is based on overdominance and epistasis and more predictive of heterotic potential.

Lines CML 343, ATP S6 20-Y-1, CLWN201, 1368, ATP S9 30 Y-1 and CLQRCWQ26 were the best general combiners for grain yield under low N. CML 343, CLWN201 and CLQRCWQ26 are CIMMYT lines. CLWN201 and CLQRCWQ26 were described as good general combiners under low N by CIMMYT (CIMMYT, 2014) and CML343 was identified earlier as a good general combiner across low N and drought stress environments (Makumbi *et* *al.*, 2011). These lines could be used in breeding programs to develop low N tolerant varieties or source populations from which new inbred lines could be extracted.

In order to classify inbreds into heterotic groups, SCA and testcross mean grain yields were used as suggested by Menkir *et al*. (2004). Inbreds were assigned to three heterotic groups opposite to the three testers used. These are group A (anti-87036), group B (anti-Exp1 24) and group C (anti-9071). Based on performance of the hybrid 87036 x Exp1 24 which is high yielding, 87036 and Exp1 24 belong to opposite heterotic groups, therefore their anti-groups A and B may be opposite. Similarly, Exp1 24 and 9071 are in opposite heterotic groups and B and C their anti-groups could also be opposite. Lines from group A should produce high yielding hybrid when crossed with lines of group B and lines from group B should give a high yielding hybrid when crossed to lines from group C.

The assignment of lines to different heterotic groups varied from one environment to the other as indicated earlier by Fan *et al.* (2009). This implies that SCA effects are influenced by the interaction between hybrids and environments and heterotic groups formed for each type of environment should be used in hybrid development programs specific to low N or optimum environments.

AMMI analysis of 24 selected hybrids revealed highly significant differences between environments, genotypes, and highly significant genotype x environment interactions. The environment contributed more to the variation than genotypes and genotype x environment interaction, and this was in agreement with Badu-Apraku *et al.* (2013). The GGE biplot analysis identified three mega-environments in the study area. These mega-environments seemed to be based on growing seasons (minor and major). This suggests that seasons and years may have accounted for significant environmental differences and to different genotypic responses to environments. This is probably due to similar variation in rainfall amount and distribution and biotic stresses within seasons. These similarities might have caused the hybrids to have similar relative performance from one environment to another in the mega-environments. These results suggest that the highest yielding hybrids identified for each mega-environment could be proposed for environments similar to those of these mega-environments. Therefore, 1368 x 87036 was the highest yielding hybrids for minor season while TL-11-A-1642-5 x 87036 was the best for major season. TL-11-A-1642-5 x 87036, CLYN246 x 87036, CLQRCWQ26 x Exp1 24, and CLWN201 x 87036 were the best in terms of high yield and stability. Among these TL-11-A-1642-5 x 87036 was the most outstanding hybrid. All these hybrids were crosses between CIMMYT lines (TL-11-A-1642-5, CLYN246, CLQRCWQ26 and CLWN201) and IRAD lines (87036 and Exp1 24), indicating again the genetic diversity between CIMMYT and IRAD lines, that could be exploited to produce adapted high yielding hybrids as suggested by Acquaah (2007).

6.2 General conclusions

Maize production constraints in the Central region of the Bimodal Humid Forest Zone of Cameroon included lack of labor, low soil fertility, non availability and high cost of seeds of improved varieties, difficulty in weeding, high cost and lack of availability of fertilizer, and post-harvest losses. Low soil fertility and high cost of fertilizers are among the most important constraints, thus suggesting the need to develop high yielding maize varieties more adapted to low N conditions.

Some farmers mentioned the high costs and the lack of availability of seeds of improved varieties and in some cases the unsuitability of these for the preparation of local dishes as reasons that prevented them from growing improved maize varieties. However, many farmers had adopted improved varieties including hybrids and were satisfied. In order for varieties developed to be adopted by more farmers, the desirable varietal characteristics which include large grain size, soft grain texture, large ear size, high prolificacy, early maturity, short plant height, resistance to lodging, resistance to pests and reduced post-harvest losses should be considered in the development of new varieties.

Significant genetic variability was observed among the 121 hybrids evaluated under low N and optimum environments. Many hybrids out-yielded 87036 x Exp1 24 the commercial hybrid used as check in the study by at least 10%, and six hybrids,CLYN246 x 87036, CLWN201 x Exp1 24, J16-1 x Exp1 24, 1368 x 87036 ATP S6-20-Y-1 x Exp1 24 and Cam inb gp1 17 x 87036) performed well across environments. Three of these (CLWN201 x Exp1 24, J16-1 x Exp1 24, 1368 x 87036) may be candidates for release. CLYN246, ATP S6-20-Y-1 and Cam inb gp1 17, 87036 and Exp1 24 could be used as testers to classify lines into heterotic groups or they could be recombined within heterotic groups to develop source populations for extraction of new inbreds. For specific areas with low N stress or for farmers who cannot afford N fertilizer, TL-11-A-1642-5 x Exp1 24, CLWN201 x 87036, J16-1 x Exp1 24 may be candidates for release as low N tolerant hybrids while TL-11-A-1642-5 x 87036, TZ-STR-133 x 87036, CLWN201 x Exp1 24 and J16-1 x Exp1 24 could be proposed for optimum N conditions.

Non-additive gene effects predominantly control grain yield and most traits under low N suggesting the possibility to develop high yielding hybrids tolerant to low N through exploitation of heterosis. Towards this end, inbreds were assigned to three heterotic groups in each environment (low N and optimum).

Lines CML 343, ATP S6 20-Y-1, CLWN201, 1368, ATP S9 30 Y-1 and CLQRCWQ26 were the best general combiners for grain yield under low N and could therefore be used in breeding programs to develop low N tolerant varieties or source populations for extraction of new inbred lines.

Stability analysis revealed that hybrids performed differently with respect to yield in each of the eleven test environments and their relative performance varied from one environment to another.

The study area was divided into three mega-environments which appeared to be related more to the major growing seasons of the years. Hybrids 1368 x 87036 was identified as the best for the minor season and TL-11-A-1642-5 x 87036 as the best for the major season. TL-11-A-1642-5 x 87036 was the outstanding hybrid and combined high yield and stability across environments. This hybrid has the potential for commercialization across environments.

6.3 Recommendations

- Low soil fertility and high cost of fertilizers were among the most important constraints to maize production in the Central Region of the Bimodal Humid Forest Zone of Cameroon and most small scale farmers were satisfied with improved maize varieties, especially hybrids. It is therefore necessary to develop and promote high yielding and low N tolerant maize hybrids adapted to the area.
- In developing these hybrids, farmers' preferred characteristics should be considered. Moreover, farmers should be involved throughout the process of varietal development, starting from the onset of breeding objectives to on-farm evaluations of hybrids. This may increase the adoption of the developed hybrids by farmers and therefore maize productivity in the area.

- The high yielding hybrids identified in this study should be evaluated in multi-location trials followed by on farm trials to confirm their performance before they are released. The release process should be initiated simultaneously with the process of development of new lines. The parental lines of these selected hybrids could also be used as testers in future research to assign lines into heterotic groups.
- The heterotic groups formed should be used for line improvement.
- Yield performance and stability of hybrids should be confirmed through further evaluation of hybrids in different locations of the Bimodal Humid Forest Zone during both minor and major seasons for a couple of years.
- Introduced lines from CIMMYT should be used to improve the genetic diversity of the local germplasm.

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APPENDICES

Appendix 3.1 Questionnaire for farmers' survey

Production constraints and farmers' preferred characteristics in maize varieties in the Bimodal Humid Forest Zone of Cameroon and the implications for Plant Breeding

PART 1: GENERAL INFORMATION

P1Q01	Questionnaire n°	
P1Q02	Date of Survey :	
P1Q03	Name of surveyor :	
P1Q04	Division	
P1Q05	Village	

PART 2: GENERAL HOUSEHOLD CHARACTERISTICS

P2Q01	Last name/first name of the household head:	
P2Q02	Sex : 1. Male 2. Female	
P2Q03	Age (years)	
P2Q04	Phone number	
P2Q05	Marital status: 1. Single; 2. Married; 3. Divorced; 4. Widower	
P2Q06	Level of education : 1. none 2. Primary school 3. Secondary school 4. Higher education 5. Other	
P2Q07	Religion 1. Christian 2. Muslim 3. Other	
P2Q08	Ethnic group	
P2Q09	Years of residence in the village : 1. under 5 years 2. 5- 10 years 3. Above 10 years	
P2Q10	Is the household head member of a farmer association? 1. Yes 2. No	
P2Q11	If yes specify.	
P2Q12	If no, why ?	
P2Q13	Main activity : 1. Agriculture ; 2. Crafts; 3. Trade ; 4. executive/employee 5. Other	

P2Q14 Household composition

Age group of members of the household (years)	Total number
under 5 years	
5-15 years	
16-25 years	
26-35 years	
36-45 years	
46-55 years	
56 years and above	

P2Q15 Is the family labor of the farm adequate for your field work? 1. Yes 2. No

P2Q16 How do you qualify the contact with the extension agent over the past two years ?

1. Regular 2. Rare 3. Absent

PART 3: HOUSEHOLD LIVELIHOOD STRATEGIES

P3Q1: What are the livelihood strategies of the household? Rank them

Number	Livelihood strategies	Rank from 1 to 6 (1= most important, 6=least important)
P3Q11	Crop production	
P3Q12	Animal production	
P3Q13	Fishing	
P3Q14	Hunting	
P3Q15	Trade	
P3Q16	Other (specify)	

P3Q2 : Estimate the size of the farm 1. Less than 1 ha 2. [1- 5 ha] 3. More than 5 ha

P3Q3 : Estimate the distance from your house to the farm 1. Less than 5 km 2. [5- 20 km] 3. [20- 50 km] 4. More than 50 km

P3Q4 : Estimate the distance from your farm to the main source of inputs (seeds, fertilizer) 1. Less than 5 Km 2. [5,20 Km] 3. [20,50 Km] 4.More than 50 Km

P3Q5 : Are the quantities produced on the farm sufficient enough to feed the family from one year to the next? 1. Yes 2. No

P3Q6 List the major constraints to crop production in your area

Numbers	Constraints to crop production	Rank from 1 to 8 (1= most important, 8=least important)
P3Q61	Lack of labour	
P3Q62	Difficulty of weeding	
P3Q63	Lack of land	
P3Q64	Lack of improved seeds	
P3Q65	Lack of fertilizer	
P3Q66	High cost of fertilizers	
P3Q67	Insects damage	
P3Q68	Other (specify)	

PART 4 : MAIZE PRODUCTION ACTIVITIES AND CONSTRAINTS

P4Q1: Is the land area used for farming adequate? 1. Yes 2. No

P4Q2: Have you ever had access to credit when needed ? 1. Yes 2. No

P4Q3 : If yes, is the access to credit regular ? 1. Yes 2. No

P4Q4 : What are the means of land preparation in the farm ? Tick the appropriate response

P4Q41. Ploughing using tractor P4Q42. Animal plough P4Q43. Manual (using hoe) P4Q44. Zero tillage P4Q45. Other (specify)

P4Q5 When do you plant maize (depending on the agricultural calender)? (tick only one answer) 1. Always on time 2. Sometimes on time 3. Always late

P4Q6 if 3, give reasons (tick one or more boxes) P4Q61. Seeds not available P4Q62.

Lack of labour P4Q63. Lack of funding P4Q64. No reason

P4Q71 what are the main crops grown ? Rank by order of importance (1= most important)

P4Q711. Maize P4Q712. cassava P4Q713. yam P4Q714. Plantain

P4Q715. Macabo P4Q716. groundnut P4Q717. Soybean P4718. beans

P4Q719. Cash crops (cacao, oil palm, tea, citrus) P4Q7110. Other (specify)

If P4Q711 is not ticked, end of questionnaire

P4Q72 What is the cropping system in your farm?

P4Q721. Sole cropping P4Q722. Mixed cropping P4Q723. Crop rotation

P4Q8 : What is the use of maize cultivated in the farm. Tick the corresponding boxes? P4Q81. Human consumption P4Q82. Animal feed P4Q83. Source of income P4Q84. Social and cultural role

P4Q9 How many seasons did you cultivate maize during the year 2012-2013?

P4Q10 Maize land area planted with maize during the year 2012-2013

1. Less than 1 ha 2. [1- 5 ha] 3. More than 5 ha

P4Q11 What are the major constraints to maize production

Number	Constraints to production	Rank from 1 to 8 (1= more important, 8= les important)
P4Q111	Lack of labour	
P4Q112	Difficulty of weeding	
P4Q113	Lack of land	
P4Q114	Lack of improved seeds	
P4Q115	Lack of fertilizer	
P4Q116	High cost of fertilizers	
P4Q117	Presence of insects	
P4Q118	Other (specify)	

P4Q12**.** How do you manage soil fertility in the maize fields?

1. Use of inorganic fertilizer 2. Use of organic fertilizer 3. Fallowing 4. Other (specify)

P4Q13 Have you applied fertilizer during the season 2012 ? 1. Yes 2. No

P4Q14 If yes, specify?

P4Q141 1. NPK (20-10-10) P4Q142. Urea P4Q143.DAP

P4Q144. Special Maize P4Q145. Other (Specify)

P4Q15 What was the total quantity of fertilizer used during the last season?

P4Q15a Basal fertilizer (first application) (per ha)

1. Less than 50 kg 2. [50 – 100 kg] 3. More than 100 kg.

P4Q15 Top dressing fertilizer (second application) per ha

1. Less than 50 kg 2. [50 – 100 kg] 3. More than 100kg

P4Q16 Have you done the chemical control of diseases, insects and pest? 1. Yes 2. No

P4Q17 If yes, which disease / pest? 1. Insects 2. Diseases 3. rodents

PART 5: TYPES OF MAIZE VARIETIES GROWN, SEED SOURCES AND IMPORTANT VARIETY CHARACTERISTICS.

P5Q1. Do you use improved maize varieties? 1. Yes 2. No

P5Q2 If yes, which varieties (tick more than one box if necessary)

P5Q21. CMS 8704 P5Q22 CMS 8501 P5Q23. CLH103 P5Q24.CHH101 P5Q25.CHH105 P5Q26.CHC202 P5Q27.CHH300 P5Q28. Other (specify)

P5Q3 If no, give reasons (tick the appropriate response)

P5Q31. Not aware of the existence of improved varieties P5Q32. Non availability of seeds of improved varieties P5Q33.High costs of seeds of improved varieties P5Q34. No mastery of the technical itinerary of cultivation of these varieties P5Q35. Improved varieties do not meet our needs P5Q36. Other (specify)

P5Q4. Rank the most critical problems encountered when using improved maize varieties

N	**Problems**	**1= Most important**
P5Q41	High distance to the source of seeds	
P5Q42	No seed source	
P5Q43	Difficulties in buying seeds	
P5Q44	Lower yield compared to local varieties	
P5Q45	No mastery of the appropriate cultural practices	
P5Q46	Lack of availability of fertilizers	
P5Q47	High costs of fertilizer	
P5Q48	Disease problem	
P5Q49	Post harvest losses	
P5Q410	Difficult of commercialization grains of improved varieties	
P5Q411	other (specify)	
P5Q412	None	

P5Q5. What are the most important problems encountered in the distribution of seeds improved seeds in your area?

N	**Problems**	**1= Most important**
P5Q51	Improved seeds arrive late	
P5Q52	Very few farmers buy improved seeds	
P5Q53	Farmers prefer local seeds (less demanding in fertiliser)	
P5Q54	Long distance to the source of seeds.	
P5Q55	High cost of seeds	
P5Q56	Seeds sold are not always of good quality	
P5Q57	Presence of illegal seed multipliers	
P5Q58	Other (specify)	
P5Q59	None	

P5Q6. What type of maize varieties did you plant last year (2012)?

1. Improved varieties 2.local varieties 3. Do not know the type

P5Q7. What was type and source the source of maize seeds you planted last year (2012)?

1. Seeds of improved varieties from previous harvest 2. Local seeds from previous harvest 3. Seeds of local varieties bought from the market 4. Seeds of improved varieties bought 5. Improved seeds provided by relatives 6. Seeds of local varieties provided by friends and relatives 7. Seeds of improved varieties, offered by the government or NGOs. 8. Other

P5Q8. Considering provision of seeds of improved varieties with respect to small-scale farmers, how do you rate maize varieties?

Question	Item	1.good 2.fair 3.bad
P5Q81	Quality of maize varieties released	
P5Q82	Compatibility with the farmers means and needs	
P5Q83	Desired varieties released on time	
P5Q84	Seed delivery to farmers	
P5Q85	Varieties suitability for your soil type	
P5Q86	Varieties suitability for your climate.	
P5Q87	Varieties tolerance to low soil fertility	

P5Q9. Are you interested in growing the improved varieties? 1 Yes 2 No

P5Q10. Provide reasons for growing the local cultivar. Rank the reasons

Question	Reasons	Rank (1= best reason)
P5Q101	Seeds of improved varieties are not available on time.	
P5Q102	Seeds of improved varieties is not readily available	
P5Q103	Seeds of improved varieties lack market within the village	
P5Q104	Local varieties are better adapted to local meals.	
P5Q105	Local varieties are easy to store	
P5Q107	Local varieties are less expensive	
P5Q108	Local variety is more resistant to pest and diseases	
P5Q109	Local seeds can be recycled	
P5Q1010	No reason	

P5Q11 when do you select seeds for planting from your local maize crop**?**

1. When the crop is growing in the field 2. At harvesting 3. At bagging 4. At planting 5. No particular selection

P5Q12. Select and rank the top 3 criteria for which you use to select your local seeds for planting

Questions	Criteria	Rank : 1= 1st criterion for selection
P5Q121	Best germination	
P5Q122	resistance to lodging	
P5Q123	good plant height	
P5Q124	prolificacy (more ears /plant)	
P5Q125	leaf orientation	
P5Q126	leaves Coulor	
P5Q127	maturity	
P5Q128	Tassel size	
P5Q129	Ear size	
P5Q1210	Grain size	
P5Q1211	Grain form	
P5Q1212	Grain color	
P5Q1213	Grain texture	
P5Q1214	Good grain storability	
P5Q1215	Resistance to pest and diseases	
P5Q1216	High yield	
P5Q1217	Taste	
P5Q1218	Other (Specify)	

P5Q13. Rate the following characteristics in terms of your experience in maize production (In the last season 2011/2012). 1 = High, 2 = Medium, 3 = low to no

		1 =High, 2=Medium 3 = low to no
P5Q131	How good was your maize yield High = > 4t ha^{-1}, Medium= 1-4 t ha^{-1} low= < 1 t ha^{-1}	
P5Q132	How was the problem of pest attack on your crop	
P5Q133	How serious was the disease problem on your maize field	
P5Q134	How tolerant was your maize crop to low soil fertility	
P5Q136	How tolerant was your maize crop to water stress	

P5Q14 What was your best maize cultivar grown last year (2012) ?

1.CMS 8704 ; 2. CMS 8501 ; 3.CLH103 ; 4.CHH101 ; 5.CHH105 ; 6.CHC202 ; 7.CHH300 ; 8.Other (Specify)

P5Q15 What is your best maize cultivar wanted but not grown last year (2012) ?

1.CMS 8704 ; 2.CMS 8501 ; 3.CLH103 ; 4.CHH101 ; 5.CHH105 ; 6.CHC202 ; 7.CHH300 ; 8.Other (Specify)

P5Q16 compare your best maize cultivar grown to that not grown (but dsired) in terms of the following characteristics

Question	Characteristics	1.Better , 2. Similar , 3. Lower
P5Q161	Yield	
P5Q162	Resistance to pest and diseases	
P5Q163	Tolerance to low soil fertility	
P5Q164	Palatability (taste)	
P5Q165	Storability	
P5Q166	Grain texture (ease to grind)	

P5Q17 Compare your best local cultivar grown with the best improved cultivar that you have ever grown in terms of the following characteristics

Question	Characteristics	1. Better 2.Similar 3. Low
P5Q171	Yield	
P5Q172	Resistance to pest and diseases	
P5Q173	Tolerance to low soil fertility	
P5Q174	Palatability (Taste)	
P5Q175	Storability	
P5Q176	Texture (ease to grind)	

P5Q18. Have you ever attended a farmers' field day for the past three years? (tick one answer)

1. Yes 2. No

Appendix 4.1 Grain yield and other agronomic traits of hybrids across low N environments in 2012 and 2013 season

Hybrids	YIELD	DTS	ASI	LAREA	CHLORO	LSENE	PHT	EPP	EA	% Yield reduction	Low N tolerance index
TL-11-A-1642-5 x Exp1 24	3770.51	66.7	2.6	531.77	41.47	2.9	155.78	1.14	2.4	30.42	6.18
CLWN201 x 87036	3609.2	66.1	4.2	504.41	41.62	3.8	175.6	1.06	2.35	33.51	2.09
ATP S6 20 Y-2 x Exp1 24	3556.47	64.5	2.9	589.33	41.85	3.2	158.67	1.07	2.7	31.00	3.94
J16-1 x Exp1 24	3516.41	65.7	3.8	601.41	39.95	3.2	162.07	1.11	2.55	41.87	3.63
ATP S9 30 Y-1 x Exp1 24	3514.44	66.4	3.1	585.44	44.16	3.7	167.13	1.05	2.5	22.04	2.49
CLYN246 x 87036	3512.06	65	2.7	602.02	41.42	3.28	173.73	1.19	2.65	46.67	4.97
ATP S9 30 Y-1 x 87036	3464.15	66.6	2.7	536.29	41.98	3.7	179.73	1.18	2.95	33.34	3.88
CLWN201 x Exp1 24	3415.18	65.3	2.5	491.7	41.09	3.5	153.9	1.09	2.75	44.49	3.26
ATP S6-20-Y-1 x Exp1 24	3365.33	64	2.7	556.5	34.25	3.4	162.9	1.02	2.9	40.60	2.43
Entrada 29 x Exp1 24	3321.12	66.2	3.3	594.61	42.86	2.85	174.23	1.12	2.5	34.40	3.92
CML165 x 87036	3319.69	66.5	3.1	585.71	44.38	3.6	174.97	1.09	2.6	36.83	2.37
1368 x 87036	3315.63	66.7	3.5	574.84	41.11	3.45	173.83	1.06	2.65	44.03	2.05
CML343 x 87036	3306.36	68.5	2.6	568.73	43.41	3.25	172	1.05	2.95	40.59	2.82
4001STR x 87036	3290.93	66.5	3.2	543.45	43.25	3.6	163.67	1.13	2.8	41.08	2.58
CLQRCWQ26 x 87036	3288.68	64.7	2.9	558.68	38.54	3.55	169.83	1.06	2.7	39.60	2.1
CML 444 x Exp1 24	3275.13	71.7	2.6	529.34	40.32	3.65	160.8	1.13	3.05	34.98	2.87
V-481-73 x Exp1 24	3255.76	68.9	3.6	559.71	44.1	2.6	165.1	1.06	2.63	27.28	3.27
CML343 x Exp1 24	3242.41	68.2	3.6	527.04	40.78	3.25	160.63	1.04	2.75	32.53	1.82
Cam inb gp1 17 x 87036	3227.94	66	3.7	556.25	37.12	3.4	169.9	1.01	2.65	43.77	1.18
CML343 x 9071	3224.32	69	2.5	509.9	41.94	3.6	171.08	1.19	2.75	41.72	3.42
CLQRCWQ26 x Exp1 24	3223.48	67.6	2.9	590.25	38.35	3	161.8	1.07	2.95	45.99	3.01
ATP S6-20-Y-1 x 87036	3213.24	67.8	3.6	518.4	45.08	3.4	157.93	1.07	2.75	44.27	1.82
TL-11-A-1642-5 x 87036	3185.73	68	2.8	499.33	41.17	3.75	165.13	1.18	2.95	51.65	2.73
1368 x Exp1 24	3149.44	65.4	3.1	514.62	38.56	3.75	153.83	1.08	3	42.55	1.3
1368 x 9071	3145.93	65.7	2.9	552.94	42.33	3.9	163.93	1.07	2.6	38.21	1.12
ATP S6-20-Y-1 x 9071	3141.11	65.9	3.6	575.43	46.16	3.55	168.77	1.1	2.65	35.61	1.54
CLA 18 x 87036	3131.05	67.3	3.5	556.45	41.87	3.85	166.7	1.09	2.7	45.01	0.93
88069 x Exp1 24	3113.17	65.5	3.1	539.12	40.23	3.1	161.17	1.07	2.55	39.86	2.25
J16-1 x 87036	3107.22	66.1	3.4	535.84	44.22	3.5	171.77	1.15	2.7	46.25	2.18
CML451 x 87036	3090.68	66.4	3.3	537.11	40.84	3	173.15	1.05	2.7	46.05	2.01
CLA 18 x Exp1 24	3076.44	68.1	2.8	530.59	42.53	3.4	159.27	1.09	2.7	47.94	1.99

Hybrids	YIELD	DTS	ASI	LAREA	CHLORO	LSENE	PHT	EPP	EA	% Yield reduction	Low N tolerance index
88069 x 9071	3061.69	65.9	3.1	509.57	41.73	2.9	161.73	1.05	2.75	46.17	2.27
CML395 x Exp1 24	3050.44	70.1	2.9	524.21	36.84	3.3	164.22	1.16	3.1	47.16	2.71
88069 x 87036	3037.59	67	3.1	541.65	40.9	3.35	161.93	1	2.95	41.20	0.84
TZ-STR-133 x Exp1 24	3037.25	68.3	2.8	527.82	40.99	3.85	164.37	1.07	2.95	34.47	0.87
Cam inb gp1 17 x Exp1 24	3032.69	67.1	3.3	534.01	37.98	3.85	161.33	1.07	2.9	41.96	0.52
ATP S5 31 Y-2 x 87036	3010.53	65.9	2.8	549.17	39.45	3.65	175.33	1.13	2.65	47.02	1.73
CML 358 x Exp1 24	2993.84	67.3	3.8	566.8	39.37	3.6	157.42	1.07	2.8	39.89	0.46
KU1414 x 87036	2993.1	65.5	2.7	468.93	43.98	3.35	174.28	1.08	2.95	44.93	1.74
CML 444 x 87036	2985.04	68.4	3.1	448.73	38.73	3.4	176.7	0.99	3.3	37.43	0.42
Entrada 3 x 87036	2972.3	65.6	2.8	481.62	42.25	3.83	170.67	1.06	3	40.15	0.5
TZMI 102 x Exp1 24	2967.81	66	2.9	491.9	45.11	2.65	157.03	1.03	2.9	32.32	2.29
CML494 x 9071	2932.66	67.6	2.6	626.59	43.02	3.45	168.1	1.02	2.75	45.74	0.7
Cam inb gp1 17 x 9071	2919.04	66.6	3.9	555.56	44.23	3.15	156.03	1.06	2.85	39.62	0.83
4001STR x 9071	2915.82	65.6	3.6	523.24	42.11	3.5	160.93	1.01	2.85	49.66	-0.12
CML451 x 9071	2914.18	68.3	2.6	550.97	41.75	2.9	173.15	1	2.95	36.40	1.48
CLQRCWQ26 x 9071	2902.88	67	3.6	565.22	38.64	3.35	165.53	1.07	3.15	43.48	0.69
CML 254 x 87036	2901.38	66.8	2.4	594.44	42.73	4	182.92	1.04	2.7	37.80	-0.01
TZ-STR-133 x 9071	2876.73	65.9	3.1	517.25	41	4.25	171.6	1.15	3.5	38.60	0.11
ATP S5 31 Y-2 x 9071	2866.93	65.6	3	572.85	40.53	3.6	167.03	1.08	3	41.31	0.6
Ku1409 x 87036	2851.73	65.9	2.5	521.01	45.75	3.75	175.4	1.03	2.8	46.90	0.09
CML 358 x 87036	2832.98	66	2.7	510.46	39.16	3.55	176.47	1.04	2.65	50.29	0.34
J16-1 x 9071	2807.08	68.2	3.5	567.54	41.42	3.8	156.53	1.07	3.15	46.01	-0.39
ATP S8 30 Y-3 x Exp1 24	2806.46	64.9	2.9	555.86	40.34	3.1	164.83	1.04	2.7	42.52	0.89
88094 x 87036	2794.39	69	3.7	562.99	43.28	3.5	155.07	1.05	2.65	41.39	-0.29
Ku1409 x Exp1 24	2794.04	67.2	3	544.89	41	3	165.17	1.02	3	37.92	0.75
CLYN246 x 9071	2755.65	65.4	2.7	545.55	42.33	3.5	161.83	1.04	2.8	47.98	0.19
5012 x Exp1 24	2732.64	66.3	3	529.91	37.79	3.38	165.87	1.07	2.95	39.09	0.38
V-351-1/6 x Exp1 24	2721.61	62.8	1.9	433.31	43.33	2.95	135	1.05	3	34.15	1.59
Cla 17 x Exp1 24	2716.49	63.7	2.7	472.41	42.48	3.25	158.03	1.03	2.9	45.84	0.32
CLWN201 x 9071	2699.86	64.5	2.8	488.7	37.8	3.6	149.58	1.03	3.4	49.54	-0.42
CLA 18 x 9071	2668.23	69.1	2.9	554.24	41.34	3.68	166.23	1.04	3	30.63	-0.63
CML 254 x Exp1 24	2664.82	68.5	3.9	550.92	37.01	4.05	151.18	1.03	3.1	50.62	-2.1

Hybrids	YIELD	DTS	ASI	LAREA	CHLORO	LSENE	PHT	EPP	EA	% Yield reduction	Low N tolerance index
TZ-STR-133 x 87036	2664.19	62.5	3.1	498.42	44.12	3.7	171.47	0.88	3	58.33	-2.45
ATP S8 30 Y-3 x 9071	2660.42	66.5	3.4	541.65	41.44	4	163.83	1.08	3.1	45.83	-1.15
ATP S6 20 Y-2 x 87036	2648.25	67.5	3.3	502.15	46.22	3.45	178.92	1.1	2.9	36.83	0.09
ATP S5 31 Y-2 x Exp1 24	2635.19	66.3	2.7	552.98	37.17	3.45	149.03	1.05	3.2	47.46	-0.08
5012 x 87036	2634.66	70.2	3.4	460.59	42.37	3.4	181.38	1.01	3.1	43.98	-0.88
V-351-1/6 x 87036	2633.82	65.5	2.8	512.2	41.55	3.05	159.73	1.01	2.85	39.00	0.12
5012 x 9071	2619.59	67.5	3.5	531.07	40.78	3.35	168.98	1.07	3.2	39.72	-0.35
Ku1409 x 9071	2606.89	65.6	4.5	481.9	37.95	4	166.28	1.04	3.33	45.06	-2.45
9848 x 9071	2602.8	64.9	3.4	537.3	40.23	3.85	157.43	1.09	3.3	43.46	-0.96
Entrada 3 x 9071	2602.7	65.7	2.8	514.23	42.2	3.1	168.83	1.03	2.95	45.04	0.1
ATP S8 30 Y-3 x 87036	2598.02	66.1	2.7	493.86	41.06	3.55	158.9	1.1	3.15	52.78	0.05
J18-1 x 87036	2595.45	71.7	2.9	525.2	42.13	4	179.23	1.3	3.35	50.00	1.18
TZMI 102 x 9071	2594.11	64.9	2.4	450.42	43.25	3.45	156.8	1.06	3.45	39.34	0.05
88094 x 9071	2584.62	67.6	3.2	538.5	38.26	3.95	147.53	1.11	3.6	45.00	-0.95
5057 x 87036	2562	69.4	4.1	504.99	37.7	4.1	178.33	1.16	3.25	41.33	-1.35
KU1414 x Exp1 24	2551.17	69.7	3.6	555.99	42.38	3.35	154.47	1.03	3.05	50.21	-1.01
CLYN246 x Exp1 24	2534.84	65.8	3.5	430.85	40.41	3.3	146.9	1.05	3.15	55.60	-0.72
CML 254 x 9071	2532.47	68	2.8	548.89	39.97	3.35	154.55	0.99	3.35	48.45	-1.07
5057 x Exp1 24	2530.36	68	2.8	523.9	37	3.75	159.53	1.01	3.05	51.00	-1.49
ATP S6 20 Y-2 x 9071	2529.78	65.3	3	513.37	43.47	3.4	158.93	1.1	3	50.57	-0.16
M 131 x 9071	2522.11	67	3.4	510	43.82	3.8	162.68	1.01	3.25	42.16	-2.05
CML165 x 9071	2488.72	64.3	3.1	539.42	43.48	4.1	156.1	1.06	3.05	44.07	-2.05
M 131 x Exp1 24	2451.38	68.4	2.9	532.31	38.14	3.6	162.8	1.12	3.15	44.90	-0.47
ATP S9 30 Y-1 x 9071	2425.02	67.6	2.9	578.86	42.74	3.75	172	1.1	3.3	33.09	-1.1
Cla 17 x 87036	2415.61	65.7	2.6	530.57	40.57	3.55	177.07	1.2	3.1	53.20	0.48
J18-1 x 9071	2376.64	69.3	3.4	472.75	37.64	4.4	159.92	1.22	4.05	21.47	-1.47
CML494 x 87036	2374.88	69.1	3.3	545.16	38.81	3.65	157.53	1	3.25	56.80	-2.34
CML451 x Exp1 24	2372.94	67.3	3	557.57	40.66	3	154.68	1.02	3.65	46.58	-0.83
Cla 17 x 9071	2369.17	64	2.5	517.8	36.62	3.45	157.3	1.11	3.4	39.64	-0.35
TZMI 102 x 87036	2349.64	67.2	2.9	517.45	43.95	3.4	175.82	1.16	3.15	53.67	-0.07
V-351-1/6 x 9071	2332.05	63.2	2.3	546.14	41.03	4	142.3	1.1	3.15	49.00	-1.47
CML395 x 9071	2314.66	66.1	4	514.06	42.26	3.55	165.8	1.04	3.1	50.99	-2.49
Entrada 29 x 9071	2303.72	71.1	3.9	573.36	45.52	3.65	160.1	0.92	3.4	45.80	-3.83

Hybrids	**YIELD**	**DTS**	**ASI**	**LAREA**	**CHLORO**	**LSENE**	**PHT**	**EPP**	**EA**	**% Yield reduction**	**Low N tolerance index**
KU1414 x 9071	2281.26	69.8	3.6	527.16	43.31	3.35	172.3	1.06	3.15	54.49	-1.79
Entrada 3 x Exp1 24	2278.5	67.1	3.3	447.11	37.77	3.7	148.3	1.07	3.35	38.97	-2.1
TL-11-A-1642-5 x 9071	2230.26	69.3	2.9	494.51	40.51	3.55	170.17	1.07	3.4	52.69	-1.78
4001STR x Exp1 24	2225	65.1	2.9	482.53	37.18	3.35	157.57	1.06	3.3	42.79	-1.57
9848 x 87036	2208.31	65.9	3.4	480.09	41.08	4.05	171.47	1.17	3.35	51.33	-2.04
CML165 x Exp1 24	2177.43	67.9	3.4	530.96	38.96	3.4	148.63	1.16	3.1	51.84	-1.09
CML494 x Exp1 24	2154.63	68.3	2.4	467.58	39.5	3.45	152.67	1.02	3.8	47.67	-2.07
9450 x 87036	2117.88	66.2	3.6	497.17	41.76	3.35	170	1.07	3.15	51.62	-2.28
V-481-73 x 9071	2084.7	66.2	3.7	558.38	41.84	3.45	174.13	1.04	3.15	45.38	-2.94
5057 x 9071	2071.85	67.4	3.7	482.32	42.87	3.6	143.52	1.01	3.65	53.46	-3.61
M 131 x 87036	2021.81	67.4	3.4	525.02	42.64	4.3	168.2	1.14	3.2	39.52	-3.53
CML395 x 87036	2013.89	71.5	3.4	479.98	38.62	3.85	168.53	1.07	3.75	54.39	-3.42
88094 x Exp1 24	1996.45	68.5	3.4	551.32	31.5	3.95	148.17	1.07	3.4	45.49	-3.66
CML 444 x 9071	1981.13	69.4	4.9	444.13	38.25	3.7	158.13	1.05	3.6	52.11	-4.46
V-481-73 x 87036	1972.49	68.4	3.6	565.16	42.34	3.6	175.9	1.08	3.4	52.42	-3.15
J18-1 x Exp1 24	1972.26	68.1	3.3	432.88	37.13	3.5	148.43	1.1	3.95	52.59	-2.63
9450 x Exp1 24	1892.95	67.7	3.3	497.58	36.43	3.8	161.47	0.92	3.3	58.59	-5.28
9848 x Exp1 24	1874.5	66.4	3.2	510.08	36.27	3.85	154.33	1.06	3.45	55.52	-3.99
Entrada 29 x 87036	1748.67	68.1	4.2	462.73	36.7	3.7	159.33	1.13	3.85	56.41	-4.05
9450 x 9071	1597.83	68.8	4.9	458.71	37.73	4	152.3	1.12	3.4	47.75	-5.76
CML 358 x 9071	1539.3	65.1	3.8	404.93	36.37	3.4	150.95	1.14	3.95	53.86	-3.98
Checks											
87036 x Exp1 24	2866.47	69.9	3.7	521.43	43.03	3.45	175.1	1.05	2.75	44.55	0.07
Exp1 24 x 9071	2336.64	67.3	2.7	548.51	37.71	3.9	160.15	1.09	3.1	55.60	-1.64
87036 x 9071	2227.29	68.7	2.4	551.56	40.1	3.45	175.6	1.17	2.95	49.41	-0.28
88069 x Cam inb gp1 17	1823.97	67.9	4.2	475.83	41.26	3.6	148.13	1.2	3.4	46.69	-2.93

Appendix 4.2 Grain yield and other agronomic traits of hybrids across optimum environments in 2012 and 2013 season

Hybrids	YIELD	DTS	ASI	LAREA	CHLORO	PHT	EPP	EA
TL-11-A-1642-5 x 87036	6588.84	65.20	1.70	650.86	51.08	193.57	1.13	2.40
CLYN246 x 87036	6584.97	63.40	2.20	740.32	54.19	197.70	1.09	2.05
TZ-STR-133 x 87036	6393.32	62.50	2.50	582.73	51.64	194.03	1.14	2.40
CLWN201 x Exp1 24	6152.26	63.10	2.00	617.83	49.52	174.17	1.07	2.05
J16-1 x Exp1 24	6048.74	63.00	2.20	652.95	47.84	174.97	1.10	2.10
CLQRCWQ26 x Exp1 24	5968.82	64.90	2.30	606.80	47.04	174.40	1.08	2.10
1368 x 87036	5923.65	64.30	2.00	625.94	48.64	195.30	1.07	2.10
CLA 18 x Exp1 24	5909.70	64.20	2.00	635.94	48.63	168.81	1.01	2.05
4001STR x 9071	5792.07	63.00	2.20	645.79	48.67	177.80	1.08	2.45
J16-1 x 87036	5780.49	63.70	1.90	654.25	51.02	181.73	1.07	2.30
CML395 x Exp1 24	5772.47	66.30	2.10	656.09	45.69	177.13	0.93	2.35
ATP S6-20-Y-1 x 87036	5765.88	63.60	1.60	671.13	52.65	198.03	0.98	1.90
Cam inb gp1 17 x 87036	5741.05	64.60	2.90	614.06	55.90	196.33	1.06	1.85
CML451 x 87036	5729.07	66.30	2.70	616.98	47.88	187.50	0.99	2.45
CLYN246 x Exp1 24	5708.79	63.40	2.10	677.84	50.52	175.92	1.13	2.15
CML 358 x 87036	5699.02	65.60	2.30	644.87	46.79	197.07	1.08	2.40
CLA 18 x 87036	5694.14	64.20	2.20	663.14	54.10	199.67	1.12	2.15
88069 x 9071	5687.94	62.30	2.40	709.45	53.63	188.73	1.03	2.40
ATP S5 31 Y-2 x 87036	5682.27	63.50	2.30	639.69	51.14	180.47	1.22	2.40
ATP S6-20-Y-1 x Exp1 24	5665.37	63.60	2.10	668.94	47.33	178.10	1.09	2.30
4001STR x 87036	5585.86	64.10	2.30	699.57	53.09	192.07	0.99	2.25
CML343 x 87036	5565.27	66.00	2.10	772.06	53.18	194.10	1.17	2.10
CML343 x 9071	5532.31	66.50	2.60	692.04	46.81	189.57	1.02	2.35
ATP S8 30 Y-3 x 87036	5502.53	63.40	2.10	654.02	52.73	210.07	1.11	2.20
CML494 x 87036	5497.58	65.50	1.60	722.26	51.18	194.67	1.05	1.90
1368 x Exp1 24	5481.83	65.00	2.30	696.88	47.55	178.50	1.14	2.25
CLQRCWQ26 x 87036	5444.69	63.60	1.80	693.36	51.99	194.87	1.20	2.45
KU1414 x 87036	5435.37	65.20	2.40	626.26	52.07	183.20	1.01	2.30
CLWN201 x 87036	5428.28	61.90	2.00	614.43	52.24	182.85	1.18	2.20
TL-11-A-1642-5 x Exp1 24	5418.98	64.80	2.30	592.64	47.63	161.47	1.02	2.70
CML494 x 9071	5404.46	64.50	2.40	685.66	50.41	180.23	1.01	2.35

Hybrids	YIELD	DTS	ASI	LAREA	CHLORO	PHT	EPP	EA
CML 254 x Exp1 24	5397.00	66.30	2.60	643.12	48.50	165.05	1.01	2.20
Ku1409 x 87036	5370.33	63.70	1.90	659.46	51.68	208.83	1.01	2.20
CLWN201 x 9071	5350.47	62.60	2.00	622.72	52.01	166.35	1.11	2.55
CLYN246 x 9071	5297.04	63.80	2.20	660.61	53.70	185.50	1.18	2.60
CML165 x 87036	5255.06	65.30	2.40	584.95	51.53	163.55	1.10	2.35
Cam inb gp1 17 x Exp1 24	5225.16	66.40	2.20	662.78	47.08	187.00	1.03	2.15
J16-1 x 9071	5198.99	62.70	2.20	665.48	50.97	178.43	1.04	2.25
ATP S9 30 Y-1 x 87036	5196.98	64.90	2.20	656.42	49.97	203.17	1.12	2.65
J18-1 x 87036	5190.64	64.30	1.90	553.69	47.00	187.08	1.01	3.05
88069 x Exp1 24	5176.70	64.50	2.10	644.35	50.41	175.83	1.09	2.10
88069 x 87036	5165.73	64.80	2.20	642.64	51.21	197.07	1.14	2.27
5057 x Exp1 24	5164.18	64.90	2.50	638.34	49.73	167.83	0.98	2.20
Cla 17 x 87036	5161.73	61.20	2.10	630.43	51.25	188.53	1.18	2.40
ATP S6 20 Y-2 x Exp1 24	5154.28	63.90	2.10	638.11	49.81	177.97	1.12	2.35
CLQRCWQ26 x 9071	5136.05	64.00	2.40	645.97	48.65	184.60	1.07	2.60
KU1414 x Exp1 24	5124.23	65.70	2.50	628.07	52.10	174.47	0.99	2.35
ATP S6 20 Y-2 x 9071	5118.22	62.80	2.20	668.99	52.90	185.23	1.02	2.30
1368 x 9071	5091.14	63.90	2.60	686.78	51.24	179.00	1.08	2.55
TZMI 102 x 87036	5071.03	64.60	2.40	626.61	52.04	195.63	1.06	2.35
Entrada 29 x Exp1 24	5062.81	66.10	2.30	676.93	49.73	178.20	0.99	2.20
CML 444 x Exp1 24	5036.89	67.00	2.50	554.68	45.98	178.33	1.08	2.79
ATP S5 31 Y-2 x Exp1 24	5015.68	63.70	2.30	613.51	49.72	182.40	1.09	2.35
Cla 17 x Exp1 24	5015.38	62.10	2.40	608.26	47.61	183.13	1.13	2.50
KU1414 x 9071	5012.71	65.20	2.60	633.71	53.13	184.63	1.09	2.35
CML 358 x Exp1 24	4980.59	64.40	2.30	658.11	46.32	169.17	1.05	2.00
Entrada 3 x 87036	4966.58	64.80	2.60	685.46	53.57	192.43	1.13	2.30
CML 254 x 9071	4912.28	65.00	2.00	635.30	51.65	160.30	1.11	2.65
ATP S8 30 Y-3 x 9071	4911.69	63.20	2.00	634.11	50.82	185.30	1.11	2.65
ATP S5 31 Y-2 x 9071	4884.58	65.10	1.90	619.19	53.43	176.08	1.06	2.80
ATP S8 30 Y-3 x Exp1 24	4882.34	64.30	3.10	661.66	48.33	179.53	1.00	2.60
ATP S6-20-Y-1 x 9071	4878.00	63.70	2.10	654.01	52.71	179.84	1.05	2.45
Cam inb gp1 17 x 9071	4834.70	64.40	2.30	657.85	52.07	183.93	1.10	2.30
CML343 x Exp1 24	4805.79	65.70	2.00	708.00	48.56	175.70	1.03	1.95
CML 444 x 87036	4770.34	69.40	2.70	589.91	49.53	193.93	0.98	2.70

Hybrids	**YIELD**	**DTS**	**ASI**	**LAREA**	**CHLORO**	**PHT**	**EPP**	**EA**
88094 x 87036	4767.87	64.80	2.00	679.48	48.88	196.05	1.11	2.35
Ku1409 x 9071	4744.72	66.20	1.90	505.08	53.05	184.98	1.03	2.60
Entrada 3 x 9071	4735.40	62.10	2.20	619.50	47.93	189.00	0.98	2.50
CML395 x 9071	4723.31	65.80	3.10	594.74	48.99	181.00	1.02	2.75
TL-11-A-1642-5 x 9071	4714.44	65.30	2.30	601.55	49.30	183.13	1.06	2.85
5012 x 87036	4703.14	65.20	1.80	678.38	52.85	206.30	1.07	2.30
88094 x 9071	4699.56	63.10	2.00	631.79	47.43	182.30	1.05	2.15
TZ-STR-133 x 9071	4684.93	64.20	1.90	553.12	47.70	178.55	1.07	2.80
CML 254 x 87036	4664.32	64.20	2.10	681.16	51.96	194.40	1.06	2.25
TZ-STR-133 x Exp1 24	4635.13	64.60	2.40	575.10	49.16	171.27	1.13	2.50
9848 x 9071	4603.57	61.60	2.30	633.11	50.86	171.57	1.09	2.70
CML451 x 9071	4582.02	65.10	3.00	587.86	49.63	159.13	1.02	2.70
V-351-1/6 x 9071	4572.22	63.70	2.20	656.08	52.04	162.37	0.98	2.50
9450 x Exp1 24	4570.78	66.50	2.20	662.08	46.49	198.03	1.17	2.75
9848 x 87036	4537.06	63.60	2.50	684.23	54.20	197.48	1.11	2.55
CML165 x Exp1 24	4521.10	64.80	2.30	659.52	48.71	176.97	1.06	2.50
ATP S9 30 Y-1 x Exp1 24	4507.88	64.60	2.10	629.41	51.26	168.20	1.08	2.60
Ku1409 x Exp1 24	4500.67	64.30	2.30	638.48	47.47	184.40	1.03	2.30
5012 x Exp1 24	4486.29	64.40	2.30	647.39	48.07	183.83	1.03	2.15
V-481-73 x Exp1 24	4476.94	64.80	2.30	596.88	48.17	183.92	1.07	2.25
5057 x 9071	4451.87	63.70	2.30	648.86	51.20	179.70	1.03	2.60
CML165 x 9071	4449.66	63.30	2.50	585.38	52.72	181.78	1.23	2.55
M 131 x Exp1 24	4449.28	64.90	2.40	628.32	47.23	176.83	1.02	2.65
CML451 x Exp1 24	4442.06	68.00	2.40	662.50	49.58	153.23	1.11	3.25
CML395 x 87036	4415.13	66.70	2.10	602.53	50.05	187.98	1.00	2.55
TZMI 102 x Exp1 24	4384.90	65.20	2.00	540.25	47.87	168.03	1.16	2.35
9450 x 87036	4377.56	64.40	2.20	653.17	49.88	188.93	1.25	2.55
5057 x 87036	4366.69	65.10	2.60	597.63	51.68	185.62	1.19	2.85
M 131 x 9071	4360.76	64.80	2.80	656.59	49.87	176.60	1.06	2.80
5012 x 9071	4345.79	65.40	2.40	637.27	48.49	189.63	1.04	2.45
V-351-1/6 x 87036	4317.45	63.00	2.30	597.42	50.38	179.83	1.14	2.00
TZMI 102 x 9071	4276.67	63.30	2.50	591.09	52.43	181.47	1.10	2.90
Entrada 29 x 9071	4250.39	64.10	2.10	647.73	49.78	178.70	0.99	2.60
9848 x Exp1 24	4213.84	64.70	2.40	622.96	48.33	179.93	1.05	2.65

Hybrids	**YIELD**	**DTS**	**ASI**	**LAREA**	**CHLORO**	**PHT**	**EPP**	**EA**
ATP S6 20 Y-2 x 87036	4192.58	68.20	1.90	586.89	53.79	202.10	1.05	2.70
J18-1 x Exp1 24	4160.16	66.60	2.70	627.44	46.20	183.27	1.21	3.00
V-481-73 x 87036	4145.77	63.60	2.00	601.35	50.91	186.67	0.98	2.60
CML 444 x 9071	4136.45	68.90	2.90	665.67	51.55	179.13	1.00	2.85
V-351-1/6 x Exp1 24	4132.82	63.00	2.40	481.00	50.79	161.53	0.96	3.20
CML494 x Exp1 24	4117.59	66.80	1.90	472.70	43.02	178.33	1.05	3.50
Entrada 29 x 87036	4011.27	67.20	2.00	564.24	50.62	182.20	1.02	3.05
Cla 17 x 9071	3925.26	62.40	2.10	521.92	47.13	173.80	1.00	2.85
4001STR x Exp1 24	3889.33	67.10	2.20	616.43	47.79	180.00	1.16	2.85
CLA 18 x 9071	3846.45	65.60	1.80	584.33	49.77	178.97	1.08	2.70
V-481-73 x 9071	3816.42	63.60	2.50	610.95	47.40	185.40	1.01	2.65
Entrada 3 x Exp1 24	3733.40	67.90	2.10	607.96	47.27	177.70	1.09	2.90
88094 x Exp1 24	3662.45	66.40	2.40	604.37	44.83	169.43	1.06	3.00
ATP S9 30 Y-1 x 9071	3624.28	65.40	2.00	586.54	49.98	174.27	1.08	3.30
M 131 x 87036	3342.69	65.00	2.70	592.23	48.84	181.93	1.02	2.95
CML 358 x 9071	3336.22	66.20	2.10	558.81	46.88	174.83	1.18	3.05
9450 x 9071	3057.98	65.10	2.10	571.76	49.08	176.07	1.21	2.95
J18-1 x 9071	3026.49	65.60	2.40	492.36	49.57	179.42	1.08	3.10
Checks								
87036 x Exp1 24	5169.43	64.60	2.50	655.17	49.73	185.60	1.13	2.35
87036 x 9071	4403.03	67.70	2.30	669.81	47.22	193.60	1.08	2.70
Exp1 24 x 9071	5262.24	68.20	2.10	680.24	47.74	176.23	1.16	2.90
88069 x Cam inb gp1 17	3421.34	66.20	2.60	592.51	53.64	168.13	1.15	2.95

Appendix 4.3 Grain yield and other agronomic traits of hybrids across research environments in 2012 and 2013 season

GENOTYPE	YIELD	DTS	ASI	LAREA	CHLORO	PHT	EPP	EA
CLYN246 x 87036	5048.51	64.2	2.45	671.17	47.81	185.72	1.14	2.35
TL-11-A-1642-5 x 87036	4887.28	66.6	2.25	575.09	46.13	179.35	1.16	2.68
CLWN201 x Exp1 24	4783.72	64.2	2.25	554.77	45.31	164.03	1.08	2.4
J16-1 x Exp1 24	4782.58	64.35	3	627.18	43.89	168.52	1.11	2.33
1368 x 87036	4619.64	65.5	2.75	600.39	44.87	184.57	1.07	2.38
CLQRCWQ26 x Exp1 24	4596.15	66.25	2.6	598.53	42.7	168.1	1.08	2.53
TL-11-A-1642-5 x Exp1 24	4594.74	65.75	2.45	562.2	44.55	158.62	1.08	2.55
TZ-STR-133 x 87036	4528.76	62.5	2.8	540.58	47.88	182.75	1.01	2.7
CLWN201 x 87036	4518.74	64	3.1	559.42	46.93	179.23	1.12	2.28
ATP S6-20-Y-1 x Exp1 24	4515.35	63.8	2.4	612.72	40.79	170.5	1.05	2.6
CLA 18 x Exp1 24	4493.07	66.15	2.4	583.27	45.58	164.04	1.05	2.38
ATP S6-20-Y-1 x 87036	4489.56	65.7	2.6	594.76	48.87	177.98	1.03	2.33
Cam inb gp1 17 x 87036	4484.5	65.3	3.3	585.16	46.51	183.12	1.04	2.25
J16-1 x 87036	4443.85	64.9	2.65	595.05	47.62	176.75	1.11	2.5
4001STR x 87036	4438.39	65.3	2.75	621.51	48.17	177.87	1.06	2.53
CML343 x 87036	4435.82	67.25	2.35	670.39	48.3	183.05	1.11	2.53
CLA 18 x 87036	4412.59	65.75	2.85	609.79	47.98	183.18	1.1	2.43
CML395 x Exp1 24	4411.45	68.2	2.5	590.15	41.27	170.68	1.04	2.73
CML451 x 87036	4409.88	66.35	3	577.04	44.36	180.33	1.02	2.58
CML343 x 9071	4378.32	67.75	2.55	600.97	44.37	180.33	1.1	2.55
88069 x 9071	4374.82	64.1	2.75	609.51	47.68	175.23	1.04	2.58
CLQRCWQ26 x 87036	4366.69	64.15	2.35	626.02	45.27	182.35	1.13	2.58
ATP S6 20 Y-2 x Exp1 24	4355.37	64.2	2.5	613.72	45.83	168.32	1.09	2.53
4001STR x 9071	4353.94	64.3	2.9	584.51	45.39	169.37	1.04	2.65
ATP S5 31 Y-2 x 87036	4346.4	64.7	2.55	594.43	45.3	177.9	1.18	2.53
ATP S9 30 Y-1 x 87036	4330.57	65.75	2.45	596.35	45.98	191.45	1.15	2.8
1368 x Exp1 24	4315.64	65.2	2.7	605.75	43.06	166.17	1.11	2.63
CML165 x 87036	4287.38	65.9	2.75	585.33	47.95	169.26	1.1	2.48
CML 358 x 87036	4266	65.8	2.5	577.66	42.98	186.77	1.06	2.53
KU1414 x 87036	4214.23	65.35	2.55	547.59	48.03	178.74	1.05	2.63
Entrada 29 x Exp1 24	4191.97	66.15	2.8	635.77	46.3	176.22	1.06	2.35
CML494 x 9071	4168.56	66.05	2.5	656.13	46.72	174.17	1.01	2.55
CML 444 x Exp1 24	4156.01	69.35	2.55	542.01	43.15	169.56	1.1	2.92

GENOTYPE	YIELD	DTS	ASI	LAREA	CHLORO	PHT	EPP	EA
88069 x Exp1 24	4144.93	65	2.6	591.73	45.32	168.5	1.08	2.33
Cam inb gp1 17 x Exp1 24	4128.93	66.75	2.75	598.39	42.53	174.17	1.05	2.53
CLYN246 x Exp1 24	4121.81	64.6	2.8	554.35	45.47	161.41	1.09	2.65
1368 x 9071	4118.53	64.8	2.75	619.86	46.79	171.47	1.08	2.58
Ku1409 x 87036	4111.03	64.8	2.2	590.23	48.72	192.12	1.02	2.5
88069 x 87036	4101.66	65.9	2.65	592.15	46.06	179.5	1.07	2.61
ATP S8 30 Y-3 x 87036	4050.28	64.75	2.4	573.94	46.9	184.48	1.1	2.68
CML 254 x Exp1 24	4030.91	67.4	3.25	597.02	42.76	158.12	1.02	2.65
CLYN246 x 9071	4026.35	64.6	2.45	603.08	48.02	173.67	1.11	2.7
CLWN201 x 9071	4025.17	63.55	2.4	555.71	44.91	157.97	1.07	2.98
CML343 x Exp1 24	4024.1	66.95	2.8	617.52	44.67	168.17	1.03	2.35
CLQRCWQ26 x 9071	4019.46	65.5	3	605.59	43.65	175.07	1.07	2.88
ATP S9 30 Y-1 x Exp1 24	4011.16	65.5	2.6	607.42	47.71	167.67	1.06	2.55
ATP S6-20-Y-1 x 9071	4009.55	64.8	2.85	614.72	49.43	174.3	1.07	2.55
J16-1 x 9071	4003.03	65.45	2.85	616.51	46.2	167.48	1.06	2.7
CML 358 x Exp1 24	3987.21	65.85	3.05	612.45	42.85	163.29	1.06	2.4
Entrada 3 x 87036	3969.44	65.2	2.7	583.54	47.91	181.55	1.09	2.65
CML494 x 87036	3936.23	67.3	2.45	633.71	45	176.1	1.03	2.58
J18-1 x 87036	3893.04	68	2.4	539.44	44.56	183.16	1.15	3.2
CML 444 x 87036	3877.69	68.9	2.9	519.32	44.13	185.32	0.99	3
Cam inb gp1 17 x 9071	3876.87	65.5	3.1	606.71	48.15	169.98	1.08	2.58
ATP S5 31 Y-2 x 9071	3875.76	65.35	2.45	596.02	46.98	171.56	1.07	2.9
V-481-73 x Exp1 24	3866.35	66.85	2.95	578.3	46.13	174.51	1.06	2.44
Cla 17 x Exp1 24	3865.94	62.9	2.55	540.34	45.05	170.58	1.08	2.7
5057 x Exp1 24	3847.27	66.45	2.65	581.12	43.37	163.68	1	2.63
ATP S8 30 Y-3 x Exp1 24	3844.4	64.6	3	608.76	44.34	172.18	1.02	2.65
KU1414 x Exp1 24	3837.7	67.7	3.05	592.03	47.24	164.47	1.01	2.7
TZ-STR-133 x Exp1 24	3836.19	66.45	2.6	551.46	45.08	167.82	1.1	2.73
ATP S5 31 Y-2 x Exp1 24	3825.43	65	2.5	583.24	43.45	165.72	1.07	2.78
ATP S6 20 Y-2 x 9071	3824	64.05	2.6	591.18	48.19	172.08	1.06	2.65
Cla 17 x 87036	3788.67	63.45	2.35	580.5	45.91	182.8	1.19	2.75
ATP S8 30 Y-3 x 9071	3786.06	64.85	2.7	587.88	46.13	174.57	1.1	2.88
CML 254 x 87036	3782.85	65.5	2.25	637.8	47.35	188.66	1.05	2.48
88094 x 87036	3781.13	66.9	2.85	621.23	46.08	175.56	1.08	2.5
TZ-STR-133 x 9071	3780.83	65.05	2.5	535.19	44.35	175.08	1.11	3.15

GENOTYPE	YIELD	DTS	ASI	LAREA	CHLORO	PHT	EPP	EA
CML451 x 9071	3748.1	66.7	2.8	569.42	45.69	166.14	1.01	2.83
CML 254 x 9071	3722.38	66.5	2.4	592.1	45.81	157.43	1.05	3
TZMI 102 x 87036	3710.34	65.9	2.65	572.03	48	185.73	1.11	2.75
TZMI 102 x Exp1 24	3676.36	65.6	2.45	516.07	46.49	162.53	1.1	2.63
Ku1409 x 9071	3675.81	65.9	3.2	493.49	45.5	175.63	1.04	2.96
Entrada 3 x 9071	3669.05	63.9	2.5	566.87	45.07	178.92	1	2.73
5012 x 87036	3668.9	67.7	2.6	569.49	47.61	193.84	1.04	2.7
Ku1409 x Exp1 24	3647.35	65.75	2.65	591.68	44.24	174.78	1.02	2.65
KU1414 x 9071	3646.99	67.5	3.1	580.43	48.22	178.47	1.07	2.75
88094 x 9071	3642.09	65.35	2.6	585.15	42.85	164.92	1.08	2.88
5012 x Exp1 24	3609.46	65.35	2.65	588.65	42.93	174.85	1.05	2.55
9848 x 9071	3603.18	63.25	2.85	585.2	45.55	164.5	1.09	3
CML395 x 9071	3518.99	65.95	3.55	554.4	45.63	173.4	1.03	2.93
5012 x 9071	3482.69	66.45	2.95	584.17	44.64	179.31	1.05	2.83
V-351-1/6 x 87036	3475.64	64.25	2.55	554.81	45.97	169.78	1.07	2.43
TL-11-A-1642-5 x 9071	3472.35	67.3	2.6	548.03	44.91	176.65	1.06	3.13
CML165 x 9071	3469.19	63.8	2.8	562.4	48.1	168.94	1.14	2.8
5057 x 87036	3464.34	67.25	3.35	551.31	44.69	181.98	1.17	3.05
V-351-1/6 x 9071	3452.14	63.45	2.25	601.11	46.54	152.33	1.04	2.83
M 131 x Exp1 24	3450.33	66.65	2.65	580.32	42.69	169.82	1.07	2.9
M 131 x 9071	3441.43	65.9	3.1	583.29	46.85	169.64	1.04	3.03
TZMI 102 x 9071	3435.39	64.1	2.45	520.76	47.84	169.13	1.08	3.18
V-351-1/6 x Exp1 24	3427.22	62.9	2.15	457.15	47.06	148.27	1	3.1
ATP S6 20 Y-2 x 87036	3420.41	67.85	2.6	544.52	50.01	190.51	1.08	2.8
CML451 x Exp1 24	3407.5	67.65	2.7	610.03	45.12	153.96	1.06	3.45
9848 x 87036	3372.69	64.75	2.95	582.16	47.64	184.48	1.14	2.95
CML165 x Exp1 24	3349.26	66.35	2.85	595.24	43.84	162.8	1.11	2.8
Entrada 29 x 9071	3277.06	67.6	3	610.55	47.65	169.4	0.96	3
5057 x 9071	3261.86	65.55	3	565.59	47.03	161.61	1.02	3.13
CLA 18 x 9071	3257.34	67.35	2.35	569.28	45.56	172.6	1.06	2.85
9450 x 87036	3247.72	65.3	2.9	575.17	45.82	179.47	1.16	2.85
9450 x Exp1 24	3231.86	67.1	2.75	579.83	41.46	179.75	1.04	3.03
CML395 x 87036	3214.51	69.1	2.75	541.25	44.34	178.26	1.04	3.15
Cla 17 x 9071	3147.22	63.2	2.3	519.86	41.88	165.55	1.06	3.13
CML494 x Exp1 24	3136.11	67.55	2.15	470.14	41.26	165.5	1.04	3.65

GENOTYPE	YIELD	DTS	ASI	LAREA	CHLORO	PHT	EPP	EA
J18-1 x Exp1 24	3066.21	67.35	3	530.16	41.67	165.85	1.15	3.48
V-481-73 x 87036	3059.13	66	2.8	583.25	46.63	181.28	1.03	3
CML 444 x 9071	3058.79	69.15	3.9	554.9	44.9	168.63	1.02	3.23
4001STR x Exp1 24	3057.17	66.1	2.55	549.48	42.49	168.78	1.11	3.08
9848 x Exp1 24	3044.17	65.55	2.8	566.52	42.3	167.13	1.05	3.05
ATP S9 30 Y-1 x 9071	3024.65	66.5	2.45	582.7	46.36	173.13	1.09	3.3
Entrada 3 x Exp1 24	3005.95	67.5	2.7	527.53	42.52	163	1.08	3.13
V-481-73 x 9071	2950.56	64.9	3.1	584.66	44.62	179.77	1.03	2.9
Entrada 29 x 87036	2879.97	67.65	3.1	513.49	43.66	170.77	1.08	3.45
88094 x Exp1 24	2829.45	67.45	2.9	577.85	38.17	158.8	1.07	3.2
J18-1 x 9071	2701.57	67.45	2.9	482.56	43.61	169.67	1.15	3.58
M 131 x 87036	2682.25	66.2	3.05	558.63	45.74	175.07	1.08	3.08
CML 358 x 9071	2437.76	65.65	2.95	481.87	41.63	162.89	1.16	3.5
9450 x 9071	2327.91	66.95	3.5	515.24	43.41	164.18	1.16	3.18
Checks								
87036 x Exp1 24	4017.95	67.25	3.1	588.3	46.38	180.35	1.09	2.55
Exp1 24 x 9071	3799.44	67.75	2.4	614.37	42.73	168.19	1.13	3
87036 x 9071	3315.16	68.2	2.35	610.69	43.66	184.6	1.12	2.83
88069 x Cam inb gp1 17	2622.65	67.05	3.4	534.17	47.45	158.13	1.17	3.18

Appendix 4.4 Grain yield under low N, optimum, across environments, yield reduction and low N tolerance index of inbreds at Mbalmayo in 2012 and 2013

Inbreds	Yield low N (kg ha^{-1})	Yield optimum (kg ha^{-1})	%yield reduction	Low N tolerance index
CML 254	1351.80	3006.80	55.04	3.00
9071	1161.30	1484.70	21.78	1.39
TZMI 102	1159.50	1677.20	30.87	3.95
CML343	1126.70	1854.50	39.25	5.12
1368	1105.70	1957.40	43.51	1.79
CML 264	1060.80	1663.90	36.25	1.36
Exp1 24	1024.60	1889.20	45.77	2.56
87036	907.30	2032.20	55.35	0.43
5012	899.20	1143.00	21.33	0.08
CML165	885.30	1553.40	43.01	0.20
V481-73/2	863.50	1267.50	31.87	4.94
TZ-STR-133	860.10	1624.00	47.04	3.14
J18-1	845.90	1652.60	48.81	2.51
KU1414	835.70	4306.30	80.59	4.41
CLA 18	772.70	1361.50	43.25	-1.06
TZSTR132	751.70	1270.90	40.85	-0.68
CLQRCWQ26	737.40	1345.60	45.20	-0.69
88069	726.70	1704.20	57.36	0.55
4001STR	722.10	1493.20	51.64	0.50
9006	716.50	3320.50	78.42	-1.53
C-316-7	715.30	2046.10	65.04	-2.31
K9351-10-3	685.40	1739.50	60.60	-0.78
CLWN201	682.10	1310.70	47.96	-0.60
M 131	659.60	1264.80	47.85	-4.12
5057	652.30	2694.50	75.79	-2.55
C316-10	648.10	2241.70	71.09	-2.87
TL-11-A-1642-5	635.90	1860.20	65.82	0.88
ATP S6-20-Y-1	629.70	1551.30	59.41	-0.49
CML395	622.50	929.60	33.04	-1.58
88094	616.20	1185.10	48.00	-0.58
CML494	597.70	1106.80	46.00	1.61
J16-1	579.60	1493.30	61.19	1.40
ATP S9 30 Y-1	573.00	1411.40	59.40	-0.89
CLYN246	555.50	1642.00	66.17	0.92
ATP S5 31 Y-2	540.20	1039.00	48.01	0.55
Cam inb gp1 17	521.90	1640.90	68.19	0.19
V-481-73	487.30	841.00	42.06	1.33
Entrada 3	470.40	737.00	36.17	-4.39
Entrada 29	469.20	2101.90	77.68	-3.30
CML451	433.20	842.20	48.56	-4.83
ATP S6 20 Y-2	430.00	1418.90	69.69	0.36
Ku1409	411.30	757.90	45.73	0.55
CML 444	392.40	1234.90	68.22	-2.04

Inbreds	**Yield low N (kg ha^{-1})**	**Yield optimum (kg ha^{-1})**	**%yield reduction**	**Low N tolerance index**
Cla 17	372.10	660.40	43.66	-4.10
ATP S8 30 Y-3	296.00	986.40	69.99	-6.69
9450	286.00	1555.50	81.61	-7.78
9848	271.60	751.60	63.86	-5.45
V-351-1/6	212.60	758.50	71.97	-4.18
Mean	**686.70**	**1625.37**	**57.75**	**-0.41**
Min	**212.60**	**660.40**	**21.33**	**-7.78**
Max	**1351.80**	**4306.30**	**81.61**	**5.12**
Lsd (0.05)	**772.60**	**2683.10**		

Appendix 4.5 Grain yield, mid-parent, high parent and standard heterosis of hybrids for grain yield under low N environments in Mbalmayo in 2012 and 2013

Hybrids	Grain yield (kg ha-1)	Mid-parent Heterosis (%)	High parent heterosis (%)	Standard heterosis (%)
CLYN246 x 87036	4352.91	495.14	379.78	26.05
ATP S9 30 Y-1 x Exp1 24	4225.62	429	312.44	22.36
CLWN201 x Exp1 24	4218.35	394.33	311.73	22.15
CML343 x 87036	4143.53	307.44	267.77	19.99
J16-1 x Exp1 24	4089.67	409.87	299.17	18.43
1368 x 87036	3997.6	297.19	261.55	15.76
Entrada 29 x Exp1 24	3994.99	434.88	289.93	15.69
CML343 x 9071	3992.49	249	243.8	15.61
CLWN201 x 87036	3976.62	400.39	338.31	15.15
CML 444 x Exp1 24	3945.93	456.97	285.14	14.27
CLQRCWQ26 x Exp1 24	3939.88	347.23	284.55	14.09
1368 x 9071	3896.83	243.79	235.57	12.84
4001STR x 87036	3880.56	376.33	327.72	12.37
CLA 18 x 87036	3878.94	361.8	327.54	12.33
Cam inb gp1 17 x 87036	3818.56	434.37	320.88	10.58
CML395 x Exp1 24	3746.32	354.91	265.66	8.49
CML165 x 87036	3738.35	317.08	312.04	8.25
ATP S5 31 Y-2 x 87036	3691.24	410.02	306.85	6.89
TL-11-A-1642-5 x 87036	3649.75	373.03	302.28	5.69
V-481-73 x Exp1 24	3643.97	382.05	255.67	5.52
CML 358 x Exp1 24	3629.33	56.73	0.63	5.1
ATP S6-20-Y-1 x 9071	3578.36	299.6	208.14	3.62
CLA 18 x Exp1 24	3569.04	297.18	248.35	3.35
Cam inb gp1 17 x 9071	3557.67	322.73	206.36	3.02
J16-1 x 87036	3557.16	378.46	292.07	3.01
TZ-STR-133 x Exp1 24	3549.48	276.68	246.44	2.79
Entrada 3 x 87036	3520.78	411.14	288.06	1.95
Ku1409 x 9071	3513.42	346.85	202.55	1.74
CLQRCWQ26 x 9071	3508.73	269.61	202.15	1.61
TL-11-A-1642-5 x Exp1 24	3488.22	320.16	240.46	1.01
88094 x 87036	3471.86	355.79	282.67	0.54
1368 x Exp1 24	3463.21	225.15	213.22	0.29
J16-1 x 9071	3455.31	296.95	197.55	0.06
ATP S9 30 Y-1 x 87036	3445.63	365.53	279.78	-0.22
CML343 x Exp1 24	3441.4	219.95	205.45	-0.34
CLQRCWQ26 x 87036	3417.22	315.56	276.65	-1.04
CML494 x 9071	3407.32	287.42	193.41	-1.33
CLWN201 x 9071	3403.2	269.23	193.06	-1.45
CML 358 x 87036	3397.19	50.52	-5.81	-1.62
Cla 17 x Exp1 24	3333.82	377.41	225.39	-3.46
88069 x Exp1 24	3315.93	278.7	223.65	-3.98
ATP S8 30 Y-3 x 9071	3303.64	353.4	184.49	-4.33
M 131 x 9071	3296.93	262.12	183.91	-4.53

Hybrids	Grain yield (kg ha-1)	Mid-parent Heterosis (%)	High parent heterosis (%)	Standard heterosis (%)
Cam inb gp1 17 x Exp1 24	3271.55	323.1	219.32	-5.26
4001STR x 9071	3264.98	246.72	181.16	-5.45
ATP S6 20 Y-2 x Exp1 24	3264.79	348.9	218.66	-5.46
ATP S5 31 Y-2 x 9071	3258.39	283	180.59	-5.64
ATP S6-20-Y-1 x Exp1 24	3251.07	293.06	217.32	-5.86
V-351-1/6 x Exp1 24	3210.27	418.97	213.33	-7.04
5012 x Exp1 24	3207.63	233.47	213.08	-7.11
9848 x 9071	3201.5	346.85	175.69	-7.29
88069 x 9071	3200.08	239	175.57	-7.33
KU1414 x 87036	3180.97	265.01	250.61	-7.89
5012 x 87036	3152.91	249.06	247.52	-8.7
TZMI 102 x Exp1 24	3139.46	187.49	170.76	-9.09
CML 254 x 87036	3107.21	175.09	129.86	-10.02
CML165 x 9071	3101.04	203.04	167.04	-10.2
Ku1409 x Exp1 24	3099.04	331.68	202.48	-10.26
CLA 18 x 9071	3095.5	220.13	166.56	-10.36
CML 444 x 87036	3078.94	373.81	239.36	-10.84
KU1414 x Exp1 24	3052.8	228.21	197.96	-11.6
5057 x 87036	3046.66	290.7	235.81	-11.78
CML 254 x 9071	3044.97	142.33	125.26	-11.82
CML494 x 87036	3043.08	304.41	235.41	-11.88
Ku1409 x 87036	3040.27	361.16	235.1	-11.96
5057 x Exp1 24	3004.83	258.38	193.28	-12.99
CML451 x 87036	3003.31	348.09	231.03	-13.03
TZ-STR-133 x 9071	2990.61	195.9	157.53	-13.4
CML 254 x Exp1 24	2976.14	150.48	120.17	-13.82
ATP S6-20-Y-1 x 87036	2967.37	286.14	227.07	-14.07
TZ-STR-133 x 87036	2963.17	235.32	226.6	-14.19
M 131 x Exp1 24	2951.77	250.53	188.1	-14.52
Entrada 3 x 9071	2943.1	260.76	153.44	-14.77
5012 x 9071	2914.44	182.88	150.97	-15.6
CLYN246 x 9071	2904.34	238.34	150.1	-15.9
CLYN246 x Exp1 24	2851.23	260.89	178.29	-17.43
V-351-1/6 x 87036	2840.59	407.29	213.09	-17.74
ATP S5 31 Y-2 x Exp1 24	2802.61	258.21	173.55	-18.84
ATP S8 30 Y-3 x 87036	2795.09	364.58	208.08	-19.06
J18-1 x 87036	2773.77	216.43	205.73	-19.68
TZMI 102 x 9071	2750.57	137.04	136.86	-20.35
ATP S6 20 Y-2 x 9071	2744.49	244.94	136.34	-20.53
CML451 x 9071	2736.98	243.3	135.69	-20.74
TZMI 102 x 87036	2735.27	164.69	135.9	-20.79
TL-11-A-1642-5 x 9071	2734.15	204.28	135.44	-20.83
ATP S9 30 Y-1 x 9071	2714.97	213.09	133.79	-21.38
ATP S8 30 Y-3 x Exp1 24	2708.11	310.15	164.32	-21.58
88094 x 9071	2683.96	202	131.12	-22.28
M 131 x 87036	2611.51	233.34	187.84	-24.38
ATP S6 20 Y-2 x 87036	2590.7	287.46	185.55	-24.98

Hybrids	Grain yield (kg ha-1)	Mid-parent Heterosis (%)	High parent heterosis (%)	Standard heterosis (%)
V-351-1/6 x 9071	2569.28	274.01	121.25	-25.6
CML395 x 9071	2541.01	184.9	118.81	-26.42
Entrada 29 x 9071	2490.63	205.51	114.47	-27.88
5057 x 9071	2481.33	173.64	113.67	-28.15
Cla 17 x 87036	2445.14	282.25	169.51	-29.19
Entrada 3 x Exp1 24	2437.3	226.08	137.89	-29.42
V-481-73 x 9071	2431.67	195	109.4	-29.58
88094 x Exp1 24	2412.33	194.06	135.45	-30.14
4001STR x Exp1 24	2381.28	172.67	132.42	-31.04
KU1414 x 9071	2339.21	134.28	101.44	-32.26
CML395 x 87036	2302.37	201.01	153.77	-33.33
88069 x 87036	2295.86	181.02	153.05	-33.52
CML451 x Exp1 24	2293.53	214.66	123.86	-33.58
9848 x 87036	2287.51	288.07	152.13	-33.76
CML165 x Exp1 24	2242.63	134.84	118.89	-35.06
CML494 x Exp1 24	2230.4	174.98	117.7	-35.41
CML 444 x 9071	2088.64	168.87	79.86	-39.52
Cla 17 x 9071	2084.28	171.86	79.48	-39.64
J18-1 x Exp1 24	2046.02	118.78	99.7	-40.75
9450 x 87036	2018.72	238.34	122.5	-41.54
V-481-73 x 87036	2013.39	188.74	121.92	-41.7
9450 x Exp1 24	1997.68	204.85	94.98	-42.15
Entrada 29 x 87036	1964.36	185.41	116.51	-43.12
9848 x Exp1 24	1554.91	139.92	51.77	-54.97
CML 358 x 9071	1475.48	-38.11	-59.09	-57.27
9450 x 9071	1440.78	99.1	24.07	-58.28
J18-1 x 9071	1349.1	34.43	16.17	-60.93
Checks				
87036 x Exp1 24	3453.3			
87036 x 9071	2687.8			
Exp1 24 x 9071	2806.3			
88069 x Cam inb gp1 17	1512.7			
Average	**3048.44**	**265.65**	**189.72**	**-11.72**

Appendix 4.6 Grain yield, mid-parent, high parent and standard heterosis of hybrids for grain yield under optimum environments in Mbalmayo in 2012 and 2013

Hybrids	Grain yield (kg ha-1)	Mid-parent Heterosis (%)	High parent heterosis (%)	Standard heterosis (%)
CML 358 x 87036	6033.17	228.40	196.87	6.24
ATP S8 30 Y-3 x 9071	6010.14	255.37	218.13	5.83
Entrada 3 x Exp1 24	5980.87	254.13	194.30	5.32
ATP S8 30 Y-3 x 87036	5921.89	270.12	213.46	4.28
M 131 x 87036	5677.39	310.04	179.37	-0.03
Cam inb gp1 17 x 87036	5642.63	190.35	177.66	-0.64
CLWN201 x Exp1 24	5578.95	295.83	195.30	-1.76
TZMI 102 x Exp1 24	5568.14	244.27	194.73	-1.95
KU1414 x 87036	5514.63	212.43	191.90	-2.89
J18-1 x 9071	5496.14	73.42	27.63	-3.22
88094 x 9071	5444.43	220.85	167.90	-4.13
CML 254 x 9071	5433.65	197.23	167.37	-4.32
CLWN201 x 87036	5428.39	207.45	187.33	-4.41
4001STR x 9071	5379.84	261.31	260.28	-5.27
88094 x 87036	5348.35	191.21	163.18	-5.82
J16-1 x 9071	5347.44	204.42	183.05	-5.84
CML395 x Exp1 24	5346.28	242.26	182.99	-5.86
KU1414 x 9071	5338.43	228.45	182.57	-6.00
CLYN246 x 87036	5336.89	184.68	182.49	-6.02
4001STR x 87036	5325.89	218.99	187.19	-6.22
Entrada 3 x 87036	5294	195.29	160.50	-6.78
1368 x 9071	5275.86	68.46	24.68	-7.10
TL-11-A-1642-5 x 87036	5258.04	276.19	254.15	-7.41
5057 x 9071	5246.99	69.38	21.84	-7.61
Entrada 29 x 87036	5206.5	211.49	156.20	-8.32
Cla 17 x 9071	5163.13	158.83	154.06	-9.08
ATP S9 30 Y-1 x Exp1 24	5130.2	157.08	144.07	-9.66
CML 444 x Exp1 24	5079.11	352.97	242.10	-10.56
Entrada 3 x 9071	5024.13	249.57	147.22	-11.53
ATP S9 30 Y-1 x 9071	5004.1	63.52	18.26	-11.88
Entrada 29 x 9071	4997.47	183.50	145.91	-12.00
ATP S6-20-Y-1 x Exp1 24	4972.78	251.40	234.94	-12.43
J18-1 x Exp1 24	4962.9	223.18	144.21	-12.61
CLQRCWQ26 x 87036	4949.3	210.41	190.42	-12.85
ATP S6 20 Y-2 x 87036	4931.29	115.17	83.01	-13.16
V-351-1/6 x 87036	4908.36	214.07	199.12	-13.57
Cam inb gp1 17 x 9071	4851.74	175.24	138.74	-14.57
5012 x 87036	4846.49	149.02	138.48	-14.66
88069 x 9071	4838.27	220.56	138.08	-14.80
5012 x 9071	4826.02	169.34	137.47	-15.02
TZ-STR-133 x Exp1 24	4810.88	231.38	224.03	-15.29
9848 x 87036	4802.55	276.72	154.21	-15.43
9450 x Exp1 24	4707.2	192.62	131.63	-17.11
J16-1 x 87036	4673.47	253.01	147.38	-17.70

TZ-STR-133 x 9071	4668.49	277.85	214.44	-17.79
CML 444 x 9071	4662.42	207.14	200.54	-17.90
1368 x 87036	4655.53	149.20	129.08	-18.02
CML451 x 87036	4653.86	318.96	213.46	-18.05
CML395 x 87036	4651.7	148.51	146.22	-18.09
5057 x 87036	4636.49	180.95	145.42	-18.36
Ku1409 x 9071	4633.98	257.63	212.12	-18.40
TL-11-A-1642-5 x 9071	4628.87	210.87	209.98	-18.49
CML494 x 9071	4623.78	168.66	136.22	-18.58
9450 x 9071	4602.98	149.83	126.50	-18.95
ATP S9 30 Y-1 x 87036	4586.36	155.26	142.76	-19.24
CML 444 x 87036	4582.64	174.01	146.35	-19.30
Ku1409 x 87036	4566.65	192.11	178.11	-19.59
M 131 x 9071	4561.89	187.34	124.48	-19.67
Entrada 29 x Exp1 24	4554.91	145.59	124.13	-19.79
Cam inb gp1 17 x Exp1 24	4554.58	178.82	124.12	-19.80
CML451 x Exp1 24	4545.43	102.40	51.17	-19.96
V-481-73 x Exp1 24	4488.36	255.69	202.31	-20.96
CML 358 x 9071	4483.42	185.65	120.62	-21.05
9848 x 9071	4452.37	131.49	127.46	-21.60
ATP S6 20 Y-2 x Exp1 24	4437.4	168.28	134.88	-21.86
TZMI 102 x 9071	4435.31	224.76	134.77	-21.90
CLYN246 x 9071	4413.5	156.56	133.61	-22.28
M 131 x Exp1 24	4410.49	75.05	46.69	-22.34
CLA 18 x 87036	4375.19	177.43	131.59	-22.96
J16-1 x Exp1 24	4349.92	218.65	130.25	-23.40
ATP S5 31 Y-2 x 9071	4330.79	185.65	129.24	-23.74
ATP S6 20 Y-2 x 9071	4329.32	201.11	129.16	-23.76
V-351-1/6 x Exp1 24	4328.48	287.12	191.54	-23.78
CLWN201 x 9071	4282.09	185.85	126.66	-24.60
88069 x Exp1 24	4268.39	147.36	110.03	-24.84
CML 254 x 87036	4225.74	202.84	107.94	-25.59
J18-1 x 87036	4222.56	145.24	107.78	-25.64
5012 x Exp1 24	4203.68	201.33	106.85	-25.98
ATP S5 31 Y-2 x Exp1 24	4189.32	71.13	39.33	-26.23
CML343 x 9071	4176.23	168.69	157.16	-26.46
CML451 x 9071	4157.42	216.43	180.02	-26.79
V-481-73 x 9071	4132.55	42.72	-4.04	-27.23
5057 x Exp1 24	4112.27	180.87	117.67	-27.59
Cla 17 x Exp1 24	4109	129.06	102.19	-27.64
TZ-STR-133 x 87036	4058.01	94.20	50.60	-28.54
CML343 x 87036	4051.07	261.19	172.86	-28.66
V-351-1/6 x 9071	4024.79	182.82	171.09	-29.13
ATP S6-20-Y-1 x 87036	4020.65	164.68	158.82	-29.20
TZMI 102 x 87036	3975.8	130.97	110.45	-29.99
Ku1409 x Exp1 24	3970.78	228.93	167.45	-30.08
TL-11-A-1642-5 x Exp1 24	3931.71	148.70	134.43	-30.77
CLQRCWQ26 x Exp1 24	3926.88	118.97	86.82	-30.85
ATP S8 30 Y-3 x Exp1 24	3903.35	118.90	106.61	-31.27
V-481-73 x 87036	3897.66	169.17	162.53	-31.37
CML395 x 9071	3859.1	128.18	104.27	-32.04

Hybrids	**Grain yield (kg ha-1)**	**Mid-parent Heterosis (%)**	**High parent heterosis (%)**	**Standard heterosis (%)**
CML165 x 87036	3805.54	176.81	156.32	-32.99
ATP S6-20-Y-1 x 9071	3802.13	226.80	156.09	-33.05
CML165 x Exp1 24	3786.43	183.66	155.03	-33.32
88094 x Exp1 24	3758.56	170.03	84.95	-33.82
4001STR x Exp1 24	3726.78	174.07	151.02	-34.37
Cla 17 x 87036	3701.53	174.93	82.14	-34.82
CLA 18 x 9071	3662.25	106.80	93.85	-35.51
88069 x 87036	3636.37	53.86	34.96	-35.97
CLQRCWQ26 x 9071	3555.37	24.40	-15.98	-37.39
CML343 x Exp1 24	3502.88	201.24	135.94	-38.32
CML 254 x Exp1 24	3502.35	143.80	72.34	-38.33
CLYN246 x Exp1 24	3502.26	164.61	85.38	-38.33
1368 x Exp1 24	3452.44	67.02	64.25	-39.21
CML 358 x Exp1 24	3434.5	131.91	69.00	-39.52
CLA 18 x Exp1 24	3422.39	122.65	81.15	-39.73
9450 x 87036	3416.2	107.23	68.10	-39.84
9848 x Exp1 24	3380.14	96.25	78.92	-40.48
CML494 x 87036	3363.77	213.62	126.57	-40.77
KU1414 x Exp1 24	3348.33	153.58	77.23	-41.04
ATP S5 31 Y-2 x 87036	2990.04	127.71	58.27	-47.35
CML494 x Exp1 24	2862.09	88.28	84.00	-49.60
CML165 x 9071	2281.94	45.47	38.08	-59.82
Checks				
87036 x Exp1 24	5678.9			
87036 x 9071	3917.1			
Exp1 24 x 9071	4600.8			
88069 x Cam inb gp1 17	2819.2			
Average	**4510.37**	**179.70**	**136.21**	**-20.58**

Appendix 5.1 Grain yield (kg ha^{-1}) of 76 single cross hybrids and four checks in 11 environments.

Genotypes	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	Mean across
CLYN246 x 87036	3979.3	4782	1326.8	7809	5157.1	7437	3174.8	7017	3922.3	5880	4940	5039.5
TL-11-A-1642-5 x 87036	2734.4	3302.5	1448	9531	4984.6	6231	3531.4	8874	3230.3	5006	8619	5198.3
CLWN201 x Exp1 24	2889	4490.5	1208.8	6464	5707.2	7568	3212	6532	4058.8	5708	4380	4750.2
J16-1 x Exp1 24	3290	4706.9	2530.9	6424	4315.1	6054	2782.1	5789	4663.9	7270	3724	4694.4
1368 x 87036	4790.3	6117.5	2547.3	8253	3955.5	4953	2038	5876	3247	4419	3734	4545.9
CLQRCWQ26 x Exp1 24	4252.8	4817.2	1519.9	6324	5403.8	6317	2777.9	6816	2163.1	5570	5110	4639.0
TL-11-A-1642-5 x Exp1 24	3939.5	6427.4	5401.2	7311	2807.1	4755	2986.6	3773	3718	4828	4449	4582.5
TZ-STR-133 x 87036	4382.4	5665.2	1508.4	8269	2224.5	5507	3603.6	7397	1602	5129	4166	4498.6
CLWN201 x 87036	4092.6	4739.4	2798.5	4987	5292.5	7657	3317.6	6535	2544.7	3223	4779	4540.4
ATP S6-20-Y-1 x Exp1 24	2554.3	3220.4	2376.4	7367	4640.8	6739	4697	7719	2558.1	3281	7458	4760.5
CLA 18 x Exp1 24	3426.3	4744.7	2317.2	7627	4369.8	5485	2357.9	5906	2911	5785	5376	4566.6
ATP S6-20-Y-1 x 87036	3076.4	4950.8	2447.4	6167	3170.8	4555	4716.7	8184	2654.9	4973	4829	4517.9
Cam inb gp1 17 x 87036	3042.7	4332	760.9	6957	3809.4	6089	3923.1	5703	4603.5	5624	4663	4499.3
J16-1 x 87036	2610	3069.4	1274.9	7150	4527.8	6301	3589.7	6760	3533.6	5622	4901	4481.9
4001STR x 87036	3657.1	4405.7	1842.1	5560	3956.8	4960	2970.8	7814	4027.8	5189	4460	4440.1
CML343 x 87036	3624.6	4533	771.8	4742	4561	6516	3329.4	6157	4245	5879	2930	4310.4
CLA 18 x 87036	3631.2	4364.2	840	6115	4498.5	5777	3178.4	6022	3507.2	6192	4139	4389.8
CML395 x Exp1 24	3896	4396.2	1023.9	6999	3748.5	6599	2989.4	5127	3594.5	5742	6342	4572.4
CML451 x 87036	3284.1	4477.7	1528	6569	2879	5796	4915.5	7004	2846.8	4799	6569	4589.8
CML343 x 9071	3910.5	4774	1233.8	5672	3810.3	6142	2910.3	6011	4256.6	5062	5672	4486.1
88069 x 9071	3770	5181.7	2522.8	6376	3322.9	4981	3185.4	7216	2507.3	4685	4714	4403.1
CLQRCWQ26 x 87036	3556.8	4087.7	2545.7	5711	2144.4	7155	3646.1	5188	4550.4	5081	5783	4484.7
ATP S6 20 Y-2 x Exp1 24	3035.8	3336.3	3651.2	6138	3684.2	5448	4336.8	6321	3074.4	4527	7549	4621.4
4001STR x 9071	3447.4	5011.9	1973.3	7502	3787.7	6557	2810.8	5318	2559.8	4571	4739	4386.0
ATP S5 31 Y-2 x 87036	3198.1	4407.4	1424.6	6711	4636	5877	2554.3	6812	3239.6	4604	7038	4570.7
ATP S9 30 Y-1 x 87036	2254.5	3068.6	2645.2	7288	4557.6	5760	4338.7	6029	3524.8	3839	4333	4330.8
1368 x Exp1 24	2542.5	3779.3	2402.7	8442	4736.4	5704	2954.9	5610	3110.6	3874	6031	4458.6
CML165 x 87036	2992.4	4104.6	1487.3	5037	4392.4	5991	3896.1	5357	3830.2	5787	1885	4087.3
CML 358 x 87036	3036.4	3884.6	1230.1	7054	3660.6	4821	2743.2	5614	3494.5	7122	4572	4291.5
KU1414 x 87036	2408.6	5916.8	2593.3	5678	4587.9	5797	2829.2	5010	2546.4	4775	3502	4154.9
Entrada 29 x Exp1 24	2988.6	3666.9	1535.5	4077	4091.8	5742	3085.1	5846	4904.5	5981	9114	4602.0
CML494 x 9071	3363.3	4073.2	1365.1	6787	3928	4973	3076.3	6334	2930.6	4856	6113	4330.7

Genotypes	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	Mean across
CML 444 x Exp1 24	1001.1	4292.9	1213.7	3951	6355.8	6218	3324.2	5195	4480.8	5528	6007	4310.3
88069 x Exp1 24	3473	3795	1716	6861	4228.8	6387	3902.1	5263	2246	3577	7532	4427.2
Cam inb gp1 17 x Exp1 24	3470.2	3822.1	2328.9	5324	3605.2	5984	3019.9	4258	2739.3	6737	5034	4204.3
CLYN246 x Exp1 24	3087.7	4895.8	1491.3	5477	3359.5	6774	2629.2	6782	2106.4	4615	4255	4132.9
1368 x 9071	4105.5	4631.5	1716.2	6634	4263.8	4821	2323	4951	3321.2	4419	3720	4085.4
Ku1409 x 87036	3210.4	3427.2	1025.3	7119	2670.5	5075	4112.5	7122	3239.9	4109	3840	4088.5
88069 x 87036	2986.1	3739.8	4685.8	6029	1862.5	6448	3614.5	5833	2039	3779	4295	4117.8
ATP S8 30 Y-3 x 87036	2836.2	4329	1564	6347	3470.3	4941	3040.8	6651	2078.8	5245	6810	4280.3
CML 254 x Exp1 24	2807	3415.7	1320.5	7871	3362.6	4583	3075.2	6546	2758.9	4569	2497	3903.1
CLYN246 x 9071	3957.2	4324.3	1757.6	6241	2753.7	5208	3307.6	6545	2002.1	4168	7479	4314.2
CLWN201 x 9071	4017.8	4295.5	1074.5	6810	4454.1	6308	2215.2	4168	1737.7	5171	3091	3947.3
CML343 x Exp1 24	2554	3590.5	633.8	3567	2955.4	4610	5254	6507	4814.9	5754	3259	3960.3
CLQRCWQ26 x 9071	3046	4279.8	1344.6	5545	4120.3	5768	2643.6	5217	3359.9	4870	4735	4079.1
87036 x Exp1 24	2887	3800.8	622.6	2765	3241.2	6826	3350	6045	4231.6	6410	2710	3908.9
ATP S9 30 Y-1 x Exp1 24	4059.6	4223.9	2084.8	3287	4701.5	5616	2810.5	5343	3915.8	4069	5153	4106.3
ATP S6-20-Y-1 x 9071	3775.4	4727.2	2297.9	5191	3866.7	4402	2672.6	5211	3093	4858	5917	4168.5
J16-1 x 9071	2624.9	4372.4	914	6936	3352	3897	2755.4	5172	4389	5617	1746	3814.9
CML 358 x Exp1 24	3120.3	4518.3	1570.3	5464	4507.5	6138	2510.9	4427	3260.1	4356	4121	3998.4
Entrada 3 x 87036	3271.4	4022.9	1472.8	3010	4953	6699	2826.4	4791	2338	6311	2858	3876.9
CML494 x 87036	2229.2	3444.4	830.4	6429	4622.9	5474	1914.7	7609	2277.2	4532	3021	3860.0
J18-1 x 87036	848	2985.7	1137.5	5768	4699.6	6220	3518.4	6377	2773.8	4603	5767	4049.3
CML 444 x 87036	1203.8	2329	2257.7	3243	4542.3	5444	3430.6	6945	3490.8	5890	6492	4095.5
Cam inb gp1 17 x 9071	4023.2	4822.8	1169.4	4854	1658	3302	2752.8	4595	4991.8	6600	6197	4070.2
ATP S5 31 Y-2 x 9071	3047.6	4272.7	1483.2	5742	3578.6	5111	3076.3	5216	3148.9	4081	3100	3811.1
V-481-73 x Exp1 24	4440.7	5456.2	2807.7	5626	2847.3	3244	2539.2	3709	3644	4350	5626	4013.0
Cla 17 x Exp1 24	4136.8	4833.7	1141.6	5368	2407.2	4637	2439.4	5301	3457.5	4937	3303	3819.0
5057 x Exp1 24	2420.1	4166.1	1137	5846	3922.4	5762	2500.3	5181	2671.9	4866	4416	3894.7
ATP S8 30 Y-3 x Exp1 24	2171.4	4581.4	1185.6	5563	3082.3	4826	4722.4	5860	2870.6	3581	5622	3992.5
KU1414 x Exp1 24	2282.5	3915.8	1131.4	4933	2711.7	6958	2466.1	4947	4164.2	4867	3486	3808.4
TZ-STR-133 x Exp1 24	3964.4	4662.7	1299.9	4016	2032.2	4596	3237.8	3117	4651.8	6783	4136	3861.1
ATP S5 31 Y-2 x Exp1 24	3199.6	3870.7	1958.1	6812	3419.8	3881	2810	5930	1788.4	4585	6187	4022.3
ATP S6 20 Y-2 x 9071	2348	4503.4	1545.6	4540	3977.5	5418	2869.8	6618	1908	4511	4708	3897.6
Exp1 24 x 9071	1791	3474.9	983.7	4559	2850	5635	2280.5	7950	3778	4692	5155	3912.4
Cla 17 x 87036	2306.3	3637.3	1122.6	8960	2645.2	3791	3620	5744	2383.8	3677	3835	3792.6

Genotypes	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	**E11**	**Mean across**
ATP S8 30 Y-3 x 9071	2969.4	4535.2	1213.6	5866	3266.5	4224	2177.6	4687	3675.1	5246	2708	3696.2
CML 254 x 87036	2286.6	2745.8	1612.5	4134	2805.5	4625	3572.7	5956	4229.5	5861	2331	3661.9
88094 x 87036	2853.4	3266.7	897	4120	3868.8	5422	2659.4	5598	3693.4	5433	4119	3809.3
TZ-STR-133 x 9071	2490.1	2962.3	1780.9	5622	4074.4	4783	3630.9	5274	2407.4	4783	5403	3916.0
CML451 x 9071	3505.1	4344.8	1591.7	5821	2173.5	3470	4768.3	5683	2532.3	3591	5821	3920.8
CML 254 x 9071	2124.9	3528.4	1040.1	4676	4461.7	5024	2487.4	6249	2548.4	5084	4343	3774.1
TZMI 102 x 87036	2230.4	2878.6	1121.1	6198	2933.8	5126	2421.3	5492	3041.6	5661	5385	3849.9
TZMI 102 x Exp1 24	2958.9	3694.6	1377.9	3313	3771.4	4508	4042.8	6902	2688.1	3507	3423	3655.3
Ku1409 x 9071	3351.3	5784.4	1230.4	4379	3675.6	4410	1263.8	4107	3513.4	5043	2569	3583.6
Entrada 3 x 9071	3469.4	4430.4	1938.4	4507	2660.2	5372	2245.8	5209	2699.8	4159	4532	3741.0
5012 x 87036	2899.3	3279.7	779.9	4412	4504.7	5051	2934.7	5418	2054.8	5355	4750	3759.0
Ku1409 x Exp1 24	2788.2	3052.1	1668.5	7390	3175.8	3750	3004.5	4607	3333	3704	3801	3660.1
87036 x 9071	2175.2	2510.9	698.5	6253	1902.5	3273	2374.5	4011	3985.7	5968	2067	3211.2
88069 x Cam inb gp1 17	782.3	1279.8	1798.6	4049	1804.1	2754	2783.2	4600	1951.6	4424	5032	2823.4
Means	**3065.6**	**4132.4**	**1660.7**	**5881.6**	**3718.9**	**5413.0**	**3129.9**	**5832.4**	**3208.4**	**4992.7**	**4737.6**	**4158.13**